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PREFACE

Natural science is an exciting and very useful subject. This textbook will show you all its beauty and will help you become true explorers. The main aim of this book is to answer the fundamental question: “What is science and what is its importance in our life?”

Starting from the fi rst pages, you will realise that this textbook is completely different from any other usual textbook full of theory and formulas. Every chapter contains useful information, curious facts, tasks for individual and group work. You will also learn how to conduct research and experiments yourselves, search for information, make your own discoveries.

Another valuable feature of this textbook is the language. Every sentence has been carefully chosen so that it is not diffi cult for you to understand science in English language. This textbook will not only help you improve your English, but it will also make you a part of a big international science community.

Please pay attention to the structure of this textbook. Remember: a textbook is no longer the only source of information in the modern world. With the help of carefully selected tasks, you are going to learn such important skills as critical thinking, problem solving, information analysis, creativity, imagination, teamwork, digital literacy etc.

Dear students, teachers and parents, as this is the fi rst edition of the 10 grade Physics textbook, we would appreciate any feedback from you so that together we can make the future editions much better, more accurate and much more effective for your learning. If you have any questions, suggestions or ideas regarding the contents of this book, please feel free to contact us:

via email: *admin@astanakitap.kz*

via telegram app: *@astanakitap*

Best regards,,

team of authors, “Астана-кітап"

HOW TO USE THIS BOOK

Driving questions motivating students' interest

Topic subjects

Main texts

Activities to do during the lesson by students themselves

7.1 IDEAL GAS EQUATION

You will

- apply ideal gas equation for problem solving.

Why blue tube is attached to the tool?

Activity

Add 5-10 mL of water to the Erlenmeyer flask. Put on the balloon to the flask. Place the balloon/flask on the hot plate and heat up the water. Write down your observations. (Do not forget safety instructions, wear goggles)

The ideal gas law is the equation of state for an ideal gas, establishing the relationship between the four parameters of a gas sample. These four parameters are pressure, volume, temperature and number of moles of the gas sample. All gases behave more or less ideally at low pressures, so, when three of these four parameters are given for any gas sample, the unknown fourth parameter can be found.

Ideal gas law is an empirical physics law. It is derived from experiment and observation, rather than theory. Experiment shows that the ratio of the products

$$\frac{(Pressure)\times(Volume)}{(Number\ of\ moles)\times(Absolute\ Temperature)}$$

equals the same constant for any gas sample.

$$\frac{pV}{\nu T}=const$$

The constant in the equation is expressed as R

$$R=\frac{pV}{\nu T}=8.31\ \frac{J}{mole\cdot K}$$

In the more famous form is,

$$pV=\nu RT$$

The constant, R, can have two different units, as shown in the Table 1.

P	V	T	R
Pa	m³	K	8.31 J/moleK
atm	L	K	0.082 atm · L/K

Table 1

In terms of mass and molar mass of the gas sample the equation becomes

$$pV=\frac{m}{M}RT$$

To establish a relationship between the number of molecules of a gas and its pressure, use

$$pV=\frac{N}{N_A}RT \qquad pV=N\frac{R}{N_A}T$$

N is the number of molecules of the gas, N_A is Avogadro's number.

Since both R and N_A are constants, their ratio must be physical constant. It is called the 'Boltzmann' constant' and is represented as k.

$$k=\frac{R}{N_A}=1.38\cdot10^{-23}\ \frac{J}{K}$$

Thus, the ideal gas law becomes

$$pV=NkT \qquad p=\frac{N}{V}kT \qquad p=nkT$$

where n - molecular concentration.

Molecular concentration is the number of molecules in unit volume. Now the ideal gas law can be expressed in terms of molecular concentration.

Written in this form, the ideal gas law indicates that the pressure of a gas depends on two factors:

- Absolute temperature
- Molecular concentration

Research time

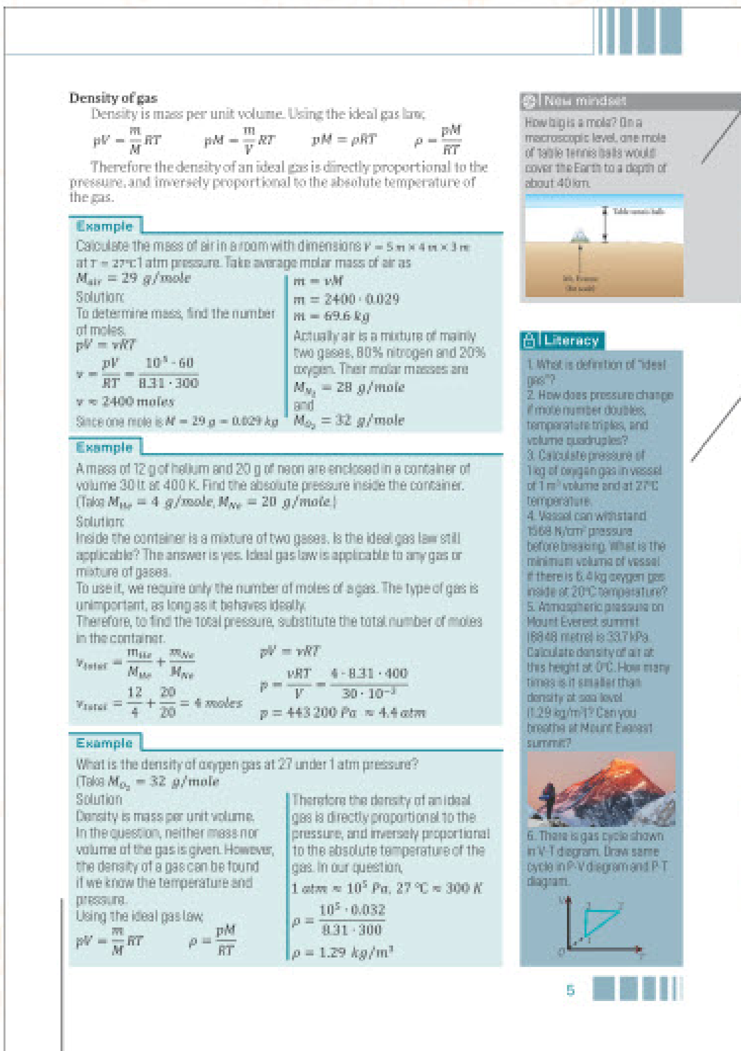
What is the pressure in human kidney ? Bigger or smaller than atmospheric pressure? Explain your answer.

4

HOW TO USE THIS BOOK

Interesting facts

Questions to consolidate topic



Density of gas

Density is mass per unit volume. Using the ideal gas law;

$pV = \frac{m}{M}RT \qquad pM = \frac{m}{V}RT \qquad pM = \rho RT \qquad \rho = \frac{pM}{RT}$

Therefore the density of an ideal gas is directly proportional to the pressure, and inversely proportional to the absolute temperature of the gas.

Example

Calculate the mass of air in a room with dimensions $V = 5\,m \times 4\,m \times 3\,m$ at $T = 27°C$ 1 atm pressure. Take average molar mass of air as $M_{air} = 29\ g/mole$

Solution:

To determine mass, find the number of moles.

$pV = \nu RT$

$\nu = \frac{pV}{RT} = \frac{10^5 \cdot 60}{8.31 \cdot 300}$

$\nu \approx 2400\ moles$

Since one mole is $M = 29\ g = 0.029\ kg$

$m = \nu M$

$m = 2400 \cdot 0.029$

$m = 69.6\ kg$

Actually air is a mixture of mainly two gases, 80% nitrogen and 20% oxygen. Their molar masses are $M_{N_2} = 28\ g/mole$ and $M_{O_2} = 32\ g/mole$

Example

A mass of 12 g of helium and 20 g of neon are enclosed in a container of volume 30 lt at 400 K. Find the absolute pressure inside the container. (Take $M_{He} = 4\ g/mole$, $M_{Ne} = 20\ g/mole$.)

Solution:

Inside the container is a mixture of two gases. Is the ideal gas law still applicable? The answer is yes. Ideal gas law is applicable to any gas or mixture of gases.

To use it, we require only the number of moles of a gas. The type of gas is unimportant, as long as it behaves ideally.

Therefore, to find the total pressure, substitute the total number of moles in the container.

$\nu_{total} = \frac{m_{He}}{M_{He}} + \frac{m_{Ne}}{M_{Ne}}$

$\nu_{total} = \frac{12}{4} + \frac{20}{20} = 4\ moles$

$pV = \nu RT$

$p = \frac{\nu RT}{V} = \frac{4 \cdot 8.31 \cdot 400}{30 \cdot 10^{-3}}$

$p = 443\,200\ Pa \approx 4.4\ atm$

Example

What is the density of oxygen gas at 27 under 1 atm pressure? (Take $M_{O_2} = 32\ g/mole$

Solution

Density is mass per unit volume. In the question, neither mass nor volume of the gas is given. However, the density of a gas can be found if we know the temperature and pressure.

Using the ideal gas law,

$pV = \frac{m}{M}RT \qquad \rho = \frac{pM}{RT}$

Therefore the density of an ideal gas is directly proportional to the pressure, and inversely proportional to the absolute temperature of the gas. In our question,

$1\ atm \approx 10^5\ Pa,\ 27\ °C \approx 300\ K$

$\rho = \frac{10^5 \cdot 0.032}{8.31 \cdot 300}$

$\rho = 1.29\ kg/m^3$

New mindset

How big is a mole? On a macroscopic level, one mole of table tennis balls would cover the Earth to a depth of about 40 km.

Literacy

1. What is definition of "ideal gas"?
2. How does pressure change if mole number doubles, temperature triples, and volume quadruples?
3. Calculate pressure of 1 kg of oxygen gas in vessel of 1 m³ volume and at 27°C temperature.
4. Vessel can withstand 1568 N/cm² pressure before breaking. What is the minimum volume of vessel if there is 6.4 kg oxygen gas inside at 20°C temperature?
5. Atmospheric pressure on Mount Everest summit (8848 metre) is 33.7 kPa. Calculate density of air at this height at 0°C. How many times is it smaller than density at sea level (1.29 kg/m³)? Can you breathe at Mount Everest summit?
6. There is gas cycle shown in V-T diagram. Draw same cycle in P-V diagram and P-T diagram.

5

Examples of problem solving with solutions


air astana

CHAPTER 1: MOTION

1.1 Physics in modern world

You will

- tell opinion about role of physics in modern world and provide supporting evidence

Question

Why do we study laws of Nature?

Physics is the natural science that studies matter, motion, space, time, energy and force. Physics is closely related to other sciences such as mathematics, chemistry, biology, medicine, computer science, archaeology, etc. For example, calculus was invented by famous physicist Isaac Newton. Also first web browser was developed in the physical centre CERN (Conseil Européen pour la Recherche Nucléaire).

Aim of physics is to describe everything around us, from the movement of tiny particles to the motion of people, cars, spaceships, stars and galaxies. Everything around you can be described by laws of physics. You do not need to be a scientist to use physics. Knowledge of physics is useful in everyday situations as well as in non-scientific professions.

Physics is the foundation of many important disciplines. Since chemistry deals with the interactions of atoms and molecules (Figure 1), it is related to atomic and molecular physics. Most branches of engineering are applied physics. Physics is main part of structural stability in architecture (Figure 2), and it is also involved in the acoustics, heating and lighting of buildings. Parts of geology also are based on physics, such as earthquake analysis, and heat transfer in the Earth. Some disciplines, such as biophysics and geophysics, are hybrids of physics and other disciplines.

Figure 1

Figure 2

Physics is involved in medical diagnostics, such as X-rays, magnetic resonance imaging (MRI), and ultrasonic blood flow measurements. Medical therapy directly involves physics. For example, cancer radiotherapy uses ionizing radiation. Physics can also explain sensory phenomena, such as how musical instruments make sound (Figure 3), how the eye detects color (Figure 4), and how lasers can transmit information.

Figure 3

Figure 4

Physics has retained the most basic aspects of science, so it is used by all of the sciences, and the knowledge of physics makes other sciences easier to understand.

Example

What are the pillars of modern world? How are they related to physics and branches of physics?
Solution:
Three main pillars of modern world are PRODUCTION, TRANSPORTATION and COMMUNICATION.
PRODUCTION is process of producing material entities like goods and non-material entities like information, knowledge, and culture.
TRANSPORTATION is movement of material entities like humans, goods and energy.
COMMUNICATION is movement of non-materials entities like ideas, information, knowledge, and culture.
Physics transformed PRODUCTION.
Before industrial revolution production was limited to:
1) Human energy (work with hands and handheld tools)
2) Animal energy (use of animals for agriculture, etc.)

3) Water and wind energy (watermills, windmills, etc.)

After industrial revolution production expanded to include:
1) Chemical energy (energy of coal, gas, petroleum, etc. used in factories)
2) Electrical energy (all electric tools and electronics)
3) Nuclear energy (nuclear power plants, etc.)

All these are related to the topics of Thermodynamics, Energy, Electromagnetism, Nuclear Physics.
Physics transformed TRANSPORTATION.
Before industrial revolution transportation was limited to:
1) Human transport (walk on feet)
2) Animal transport (horses, camels, etc.)
3) Water transport (ships used sea currents, sea winds and rivers)

After industrial revolution transportation expanded to include:
1) Land transportation (trains, cars, etc.)
2) Air transportation (planes, helicopters, spaceships, etc.)
3) Water transportation (submarines, ships, etc.)

All these are related to topics of Kinematics, Dynamics, Aerodynamics, Hydrodynamics, Thermodynamics, Electromagnetism, Jet Propulsion.
Physics transformed COMMUNICATION.
Before industrial revolution communication was limited to:
1) Oral communication (talk with people)
2) Handwriting communication (letters, books, etc.)

After industrial revolution and information revolution communication expanded to include:
1) Print media (newspapers, books, journals, etc. printed on printing press)
2) Chemical media (film stock used for photography and cinematography)
3) Magnetic media (magnetic audiotapes, magnetic videotapes)
4) Electronic digital media (digital books, newspapers, journals, digital photo, audio and video, Internet, etc.)
All these are related to topics of Dynamics, Thermodynamics, Electromagnetism, Quantum Physics, Geometric Optics, Relativity.

Activity

Imagine how transportation will look like after 100 years from now and illustrate (draw) it.

Career

One of the jobs of future is going to be robotics engineering.

Is it true?

Atoms are 99.9999999999999 percent empty space. Actually this empty space is filled with energy not matter.

Research time

Choose one thing in your room that has connection to physics. Express by drawing the development of that thing step by step.

Literacy

1. State the meaning of word “physics”.
2. Classify main branches of physics in order of increasing importance. Provide reasoning for your classification.
3. Predict future development of physics. Sketch tree diagram that shows roots, stem (trunk), branches, leaves and fruits of physics.
4. Select five areas of your daily life. Construct table that compares them with life of a person who lived 1000 years ago.

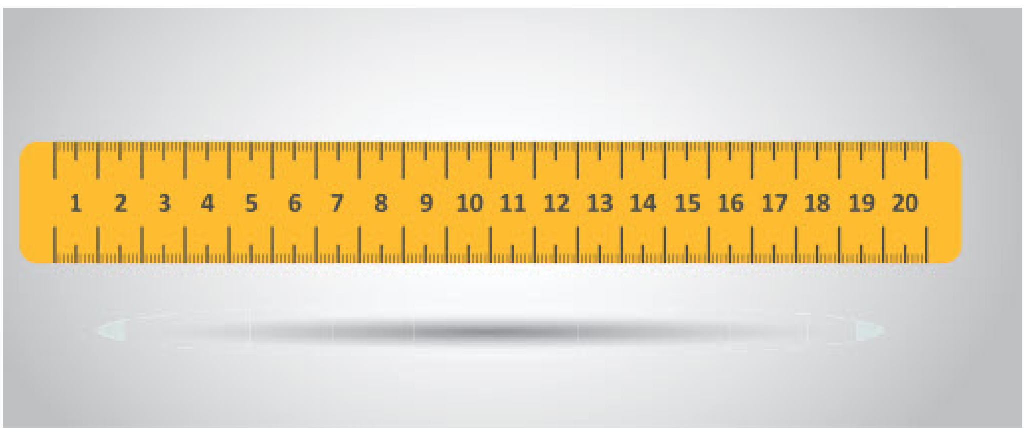
5. Write small critique essay that evaluates influence of physics on history of humanity.
6. Design the plan of development of physics science for next 100 years, so that it will be maximally useful for humanity.

1.2 MEASUREMENT ERROR. ANALYSIS OF RESULTS OF MEASUREMENT

You will

- tell difference between random error and systematic error.
- determine dependent, independent and controlled variables.

QUESTION



Can you measure thickness of hair with ordinary ruler? Explain your answer.

a) Accuracy and precision

What is measurement? Measurement is a comparison between an unknown quantity and a standard. Careful measurements are very important in physics. Experimental work is never perfect, but it is necessary to obtain accurate results. In describing the imperfection, one must consider both an accuracy and precision.

Accuracy – a description of how close a measurement is to the correct value of the measured quantity.

Precision – the degree to which repeated measurements under unchanged conditions show the same results, Figure 5.

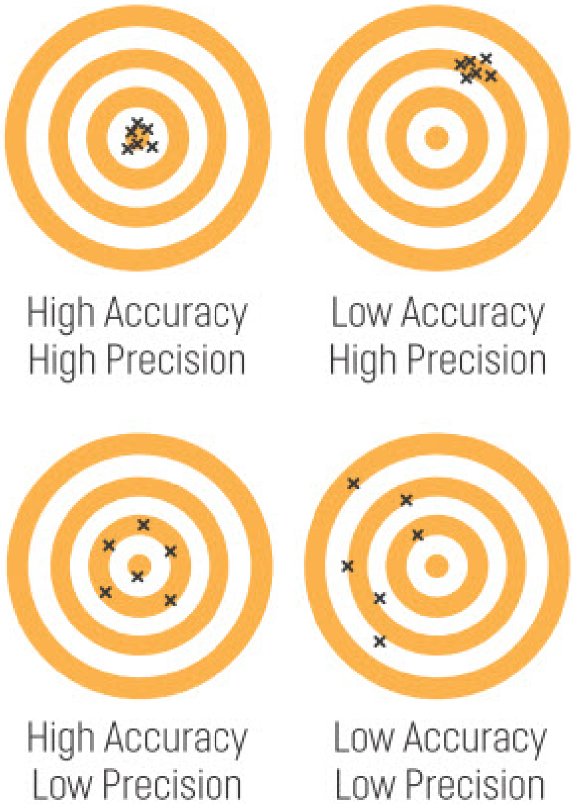


Figure 5

b) Types of errors

Error is the difference between a measured value of a quantity and its true value.

There are two types of error that contribute to our uncertainty about a reading – systematic and random.

Systematic error is a type of error that deviates by a fixed amount from the true value of measurement, Figure 6a.

Random error is an error in measurement caused by factors which vary from one measurement to another, Figure 6b.

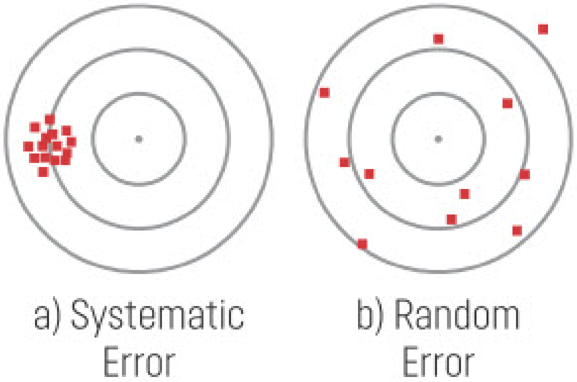


Figure 6

Random error	Systematic error
Unpredictable, can be greater or less than the actual result	Always affects the measurement in one direction
Caused by limitations of the equipment or environmental conditions	Caused by incorrectly calibrated instrument or experimenter error, Figure 7a and Figure 7b
Can be reduced by using repeated measurements	Can be reduced by good experimental design

c) Variables

When you perform an experiment, it is important to change only one factor at a time. Variable is any factor that might aff ect the behavior of an experimental setup. The independent variable is the factor that is changed or manipulated during the experiment. The dependent variable is the factor that depends on the independent variable. All other variables must be kept the same throughout the investigation. The variables that are not changed are called controlled variables.

d) Absolute and relative errors

The values of uncertainties that we have been looking at are called absolute error. These values have the same units as the quantity and should be written to the same number of decimal places. Dividing the uncertainty by the value itself gives us the relative error.

$$\langle x \rangle = \frac{x_1 + x_2 + x_3 + \cdots + x_N}{N}$$

$$\Delta x = \sqrt{\frac{(\langle x \rangle - x_1)^2 + \cdots + (\langle x \rangle - x_N)^2}{N(N-1)}}$$

$$\delta = \frac{\Delta x}{\langle x \rangle} \cdot 100\%$$

Δx– absolute error ⟨x⟩– average value
δ – relative error N – number of measurements

Example

Pen was measured 6 times. Results of measurement are in table. Calculate absolute and relative error of measurement. Fill the table.

Trial No.	1	2	3	4	5	6
x_N (mm)	152	150	155	148	150	151
<x>						
(<x>-x_N)						
(<x>-x_N)^2						
Δx (mm)						
δ (%)						

Formulas:

$$\langle x \rangle = \frac{x_1 + x_2 + x_3 + \cdots + x_N}{N}$$

$$\delta = \frac{\Delta x}{\langle x \rangle} \cdot 100\%$$

$$\Delta x = \sqrt{\frac{(\langle x \rangle - x_1)^2 + \cdots + (\langle x \rangle - x_N)^2}{N(N-1)}}$$

Calculations:

$$\langle x\rangle = \frac{152 + 150 + 155 + 148 + 150 + 151}{6} = 151\ mm$$

$$\Delta x = \sqrt{\frac{(151-152)^2+(151-150)^2+(151-155)^2+(151-148)^2+(151-150)^2+(151-151)^2}{6\cdot(6-1)}}$$

$$\Delta x = 0.97\ mm$$

$$\delta = \frac{0.97}{151}\cdot 100\% = 0.64\%$$

Trial No.	1	2	3	4	5	6
x_N (mm)	152	150	155	148	150	151
$\langle x\rangle$	151	151	151	151	151	151
$(\langle x\rangle - x_N)$	-1	1	-4	3	1	0
$(\langle x\rangle - x_N)^2$	1	1	16	9	1	0
Δx (mm)	0.97	0.97	0.97	0.97	0.97	0.97
δ (%)	0.64	0.64	0.64	0.64	0.64	0.64

Is it true?

If there is inclination of 1 % in the base of construction, it can cause collapse.

New mindset

$1.01^{365} = 37.78$
$1^{365} = 1$
$0.99^{365} = 0.0255$
Look at these expressions. How can you relate them to one year of your life?

Activity

Measure the length of one of your fingers from four different sides. Find the average length with absolute error.

Research time

Measure your height after you wake up, before you go to bed and when you are lying. Find your average height and calculate the error.

Literacy

1. Write definition of “error of measurement”.
2. Discuss reasons for appearance of random error and systematic error.
3. Absolute error of 5 metre measuring tape is 0.2 cm. What is its relative error?
4. A person’s pulse rate is 80 ± 2 beats/min. What is the relative error?
5. Bathroom scale reads mass as 75 kg with a 3% uncertainty. What is the uncertainty of mass (in kilograms)?
6. Design step by step procedure of measuring length by using ruler that minimizes error of measurement.

1.3 Equations of uniformly accelerated motion

You will

- derive formula of displacement in accelerated motion from velocity-time graph.

Question

How fast does average car reach 100 km/h?

Uniform accelerated motion is a type of motion in which the velocity of an object changes by an equal amount in every equal time period, Figure 8. There are five physical quantities that describe uniformly accelerated motion: displacement, time, initial velocity, final velocity, acceleration (**$s, t, \upsilon_0 \upsilon, a$**).

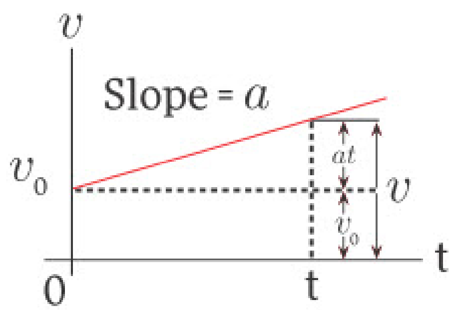


Figure 8.
Velocity-time graph

We can derive equations that describe relationship between these quantities from velocity-time graph, Figure 8.

Acceleration is change of velocity per unit time. So we can write

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t} \qquad a = \frac{v - v_0}{t - 0} \qquad v = v_0 + at$$

Because the velocity is increasing or decreasing uniformly, we can express the average velocity as the arithmetic average of the initial velocity and the final velocity :

$$v_{av} = \frac{v + v_0}{2}$$

We can now use this result along with the defining equation for average velocity to obtain an expression for the displacement of an object as a function of time.

$$s = v_{av}t = \frac{v + v_0}{2}t$$

$$s = \frac{1}{2}(v + v_0)t$$

We can obtain another useful expression for displacement by substituting the equation for into equation for .

$$s = \frac{1}{2}(v_0 + at + v_0)t$$

$$s = v_0 t + \frac{1}{2}at^2$$

Finally, we can obtain an expression that doesn’t contain time by substituting time into equation for .

$$t = \frac{v - v_0}{a} \qquad s = \left(\frac{v + v_0}{2}\right)\left(\frac{v - v_0}{a}\right)$$

$$s = \left(\frac{v^2 - {v_0}^2}{2a}\right) \qquad v^2 = v_0^2 + 2as$$

So, now we have four equations that describe accelerated motion.We should apply each equation separately for x-axis and y-axis. These equations can be used to solve any problem in one-dimensional motion with constant acceleration. There is usually more than one way to solve a given problem, depending on which equations are selected and what quantities are given.

These equations can be used to solve any problem in one-dimensional motion with constant acceleration. There is usually more than one way to solve a given problem, depending on which equations are selected and what quantities are given.

Example

Here is the velocity-time graph of a car. Calculate acceleration and displacement of the car.

Given:

$v_0 = 15 \text{ m/s}$

$v = 27 \text{ m/s}$

$t = 4 \text{ s}$

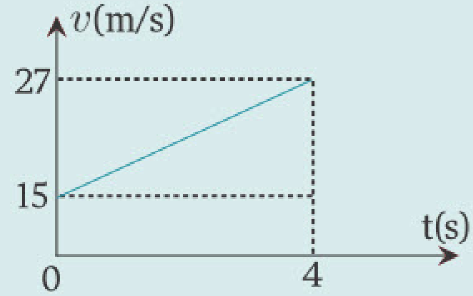
$a = ?$

$s = ?$

Formulas:

$$v = v_0 + at$$

$$s = \frac{1}{2}(v + v_0)t$$



Calculations:

$$a = \frac{v - v_0}{t} \qquad a = \frac{27 - 15}{4} \qquad s = \frac{1}{2}(27 + 15) \cdot 4$$

$$a = 3\, m/s^2 \qquad s = 84\, m$$

Activity

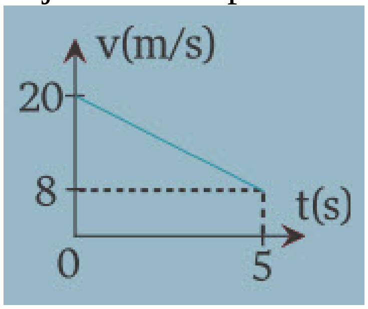
Draw a 10 cm ×10 cm box. Divide it into 4 boxes. Into the first write the word “Acceleration”. Into the second write your own definition. Into the third draw a picture that explains the word. Into the fourth write a translation in your native language.

Word: Acceleration	Your own definition:
Picture:	Translation:

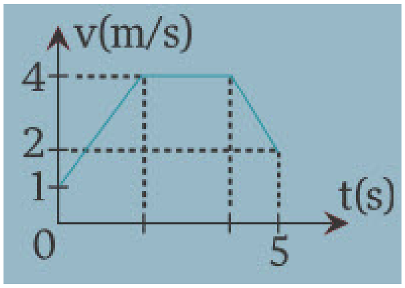
Literacy

1. State definition of “acceleration”.
2. Explain “acceleration” in your own words. Give examples of the lowest acceleration and the highest acceleration.

3. The velocity-time graph for an object is given on the figure. Plot its acceleration-time graph. In which direction is the object moving? When object will stop?



4. The velocity-time graph of an object is given on the figure. How many different accelerations does the object experience in 5 s? Compare these accelerations. Plot its acceleration-time graph.



5. Argue if there should be limit on maximum acceleration of cars. Support your point of view with factual evidence.

6. Human body can endure acceleration of 4g (40 m/s^2). Design plane that travels from Astana to Almaty (about 1000 km) with 40 m/s^2 acceleration. How long will it travel?

Career

Acceleration is very essential on the start line for Formula 1 racers.

Important note

These equations are applied if the acceleration is uniform.

$$v = v_0 + at$$

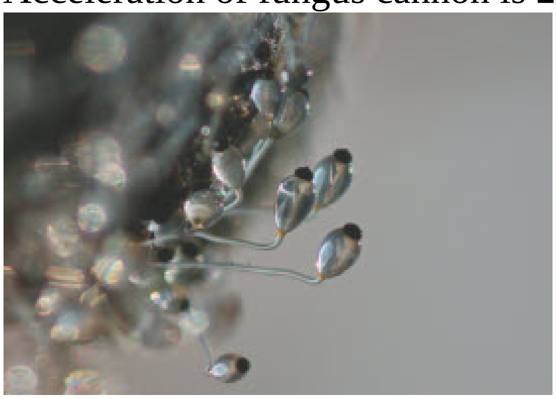
$$s = v_0 t + \frac{1}{2}at^2$$

$$v^2 = {v_0}^2 + 2as$$

$$s = \frac{1}{2}(v + v_0)t$$

Is it true?

Acceleration of fungus cannon is 200000 m/s^2.



Interesting question

What is the maximum acceleration that human body can endure?

Research time

Download a mobile application that can measure acceleration (accelerometer). Measure the maximum acceleration when you start to run, jump etc.

Physics in life

Acceleration is stronger for curvilinear paths rather than for highways. Why?

Important note

Vectors will sometimes be written as boldface letters such as **A**.

1.4 Graphs of accelerated motion

You will

- apply equations of motion for solving analytical and graphical problems.

Question

Why do people use graphs?

Uniform accelerated motion is a type of motion in which the velocity of an object changes by an equal amount in every equal time period, Figure 9.

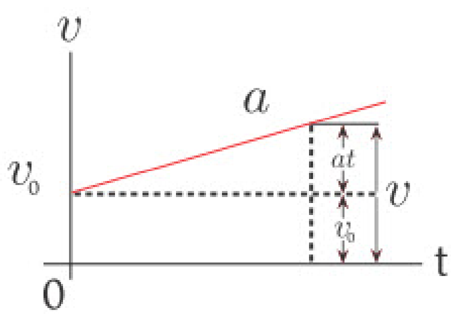


Figure 9.
Velocity-time graph

We can find displacement and acceleration from velocity-time graph. Area under the velocity-time graph is equal to displacement. Slope of the velocity-time graph is equal to acceleration.

Equations given below are used to study and analyze accelerated motion.

$$v = v_0 + at; \qquad s = v_0 t + \frac{1}{2}at^2;$$

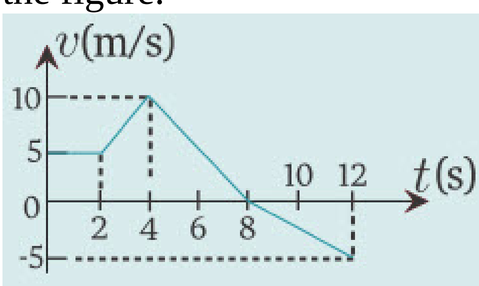
$$v^2 = {v_0}^2 + 2as; \qquad s = \frac{1}{2}(v + v_0)t;$$

$$s = x - x_0;$$

Where **s** is displacement, t is time, $\boldsymbol{v_0}$ is initial velocity, $\boldsymbol{v}$ is final velocity, **a** is acceleration,x_0 is initial position, x is final position.

Example

The velocity-time graph of a car at a position x_0 = 5 m at t_0 = 0 is shown in the figure.



a) Find its total displacement in 12 sec.
b) Determine time at which car changes direction of motion.
c) Find its position at the 12th second.
d) Plot the position-time graph.
e) Plot the acceleration-time graph.

Formulas:

$$s = \frac{1}{2}(v + v_0)t \qquad s = x - x_0 \qquad v = v_0 + at$$

Calculations:

a) To find the total displacement of the car, the total area under the velocity-time graph should be calculated.
The area between t = 0 and t = 2 s is

$$s_1 = 5 \cdot 2 = 10\ m$$

The area between t = 2 s and t = 4 s is

$$s_2 = \frac{1}{2}(10 + 5) \cdot 2 = 15\ m$$

The area between t = 4 s and t = 8 s is

$$S_3 = \frac{1}{2}(10 \cdot 4) = 20\ m$$

The area between t = 8 s and t=12 s is

$$S_4 = \frac{1}{2}(-5 \cdot 4) = -10\ m$$

The total displacement is equal to the algebraic sum of these areas.

$$s = s_1 + s_2 + s_3 + s_4$$
$$s = 10 + 15 + 20 - 10 = 35 \text{ m}$$

b) Sign of velocity changes when car changes direction. Initially car moves in positive direction. At t = 8 sec velocity is zero and after t = 8 sec, car moves in negative direction. That means car changes direction at t = 8 sec.
c) Final position of car can be found by these formulae

$$x = x_0 + s; \qquad x = 5 + 35 \text{ m};$$

d) To be able to draw the position-time graph of the car, the positions at the instants t=2 s, t=4 s, t=8 s and t=12 s must be known. The positions can be calculated using the s values which were obtained in part a.

t (sec)	0	2	4	8	12
$x=x_0+s$	5	5+10	5+10+15	5+10+15+20	5+10+15+20-10
$x=x_0+s$	5	15	30	50	40

e) The slope of the velocity-time graph gives the acceleration.

$$a = \frac{v - v_0}{t}$$

The acceleration between t = 0 and t = 2 s

is $$a_1 = \frac{5-5}{2} = 0$$

The acceleration between t = 2 and t = 4 s

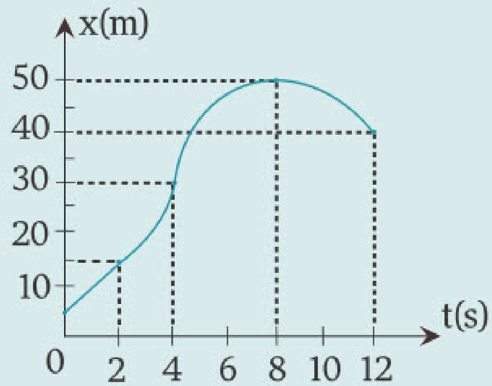
is $$a_2 = \frac{10-5}{2} = 2.5\ m/s^2$$

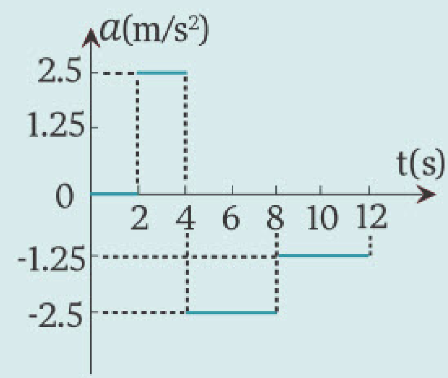
The acceleration between t = 4 and t = 8 s

is $$a_3 = \frac{0-10}{4} = -2.5\ m/s^2$$

The acceleration between t = 8 and t = 12 s

is $$a_4 = \frac{-5-0}{4} = -1.25\ m/s^2$$





Activity

Open in browser 'Moving Man Phet'. Start the simulation and click on the chart tab. Give initial position, velocity and acceleration. Try to predict the values on the graph. Click on start button. Observe the change in the graph. Analyze the motion and write down your conclusion.

Career

Drivers use accelerated motion principles while driving in the city.

Research time

Download mobile application that measures position, time, velocity and acceleration. Use it to draw velocity-time graph of a bus trip. Or use GPS and stopwatch. Use velocity-time graph to calculate accleration and displacement.

Literacy

1. Car accelerates from rest to 100 km/h in 6 sec. Calculate acceleration of car.
2. Explain relationship between displacement and acceleration. Draw displacement-acceleration graph.
3. A rock rolling down a slope from rest covers a distance of 4 m in the first second. What distance will it cover in 3 s?
4. A motorcyclist and a cyclist simultaneously begin to move from rest. The acceleration of the motorcyclist is three times greater than the acceleration of the cyclist. By how many times will the velocity of the motorcyclist be greater?
a) After the same interval of time as the cyclist.
b) After moving the same distance.
5. Research the car that has maximum acceleration. Is it dangerous for humans?
6. Proxima Centauri is the closest star to the Sun (4.25 light-years). 1 light year is about 9.5×10^{15} metres. Design spaceship that travels with constant acceleration of 1g (10 m/s^2) and calculate time of travel to Proxima

Centauri. How many years is it? What is maximum speed during trip? Is it greater than speed of light (3×10^8 m/s)?

1.5 Invariant and relative physical quantities. Galilean relativity

You will

- tell difference between invariant and relative physical quantities.
- apply equations of Galilean relativity for problem solving.

Question

You are in a train that moves with a velocity of 80 km/h. What is your velocity relative to other passengers?

a) Relative Velocity in One Dimension

According to the principle of Galilean relativity the laws of mechanics must be the same in all inertial frames of reference. Inertial frames of reference are those reference frames in which Newton's laws are valid. In these frames objects move in straight lines at constant speed unless acted on by a non-zero net force, thus the name "inertial frame" because objects observed from these frames obey Newton's 1st law, the law of inertia.

To describe a physical event, it's necessary to choose a frame of reference. For instance, standing on the surface of earth we feel that we are not in motion, however the earth is moving, so are we.

Imagine you are driving the car in Figure 10 at a constant velocity along a straight line. On passing traffic lights, we think of them as being stationary and ourselves in motion, Figure 10a. However, if you imagine yourself as a stationary observer in the car it is also possible to think of the car as being at rest and the traffic lights moving at the same speed but in the opposite direction, Figure 10b.

Next, think about a bus moving at the same velocity as the car, shown in Figure 10c. The bus appears to be stationary with respect to the car. So, motion is relative and it depends on the frame of reference.

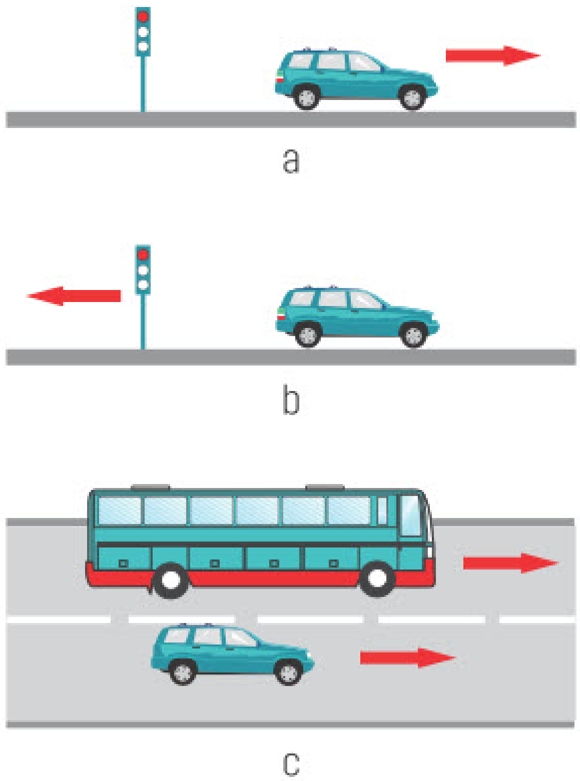


Figure 10

Let's study a numerical example: A car is moving at 30 m/s westwards and a bus passes it at 40 m/s westwards, Figure 11.

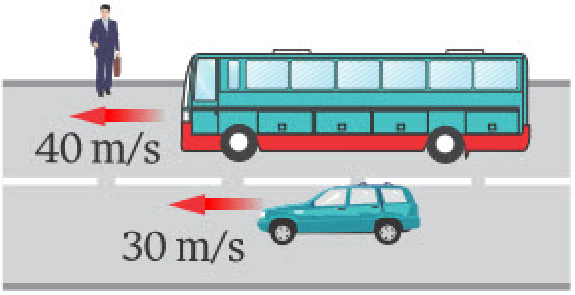


Figure 11

A stationary observer standing on the side of the road would measure the velocity of the bus to be 40 m/s westwards. However, with respect to the car the bus appears to be moving westwards at 10 m/s.

$$\vec{v}_{relative} = \vec{v}_{bus} - \vec{v}_{car}$$

$$v_{relative} = 40 - 30 = 10\ m/s$$

In general, in order to calculate relative velocity we use vectoral subtraction, as follows:

$$\vec{v}_{relative} = \vec{v}_{object} - \vec{v}_{observer}$$

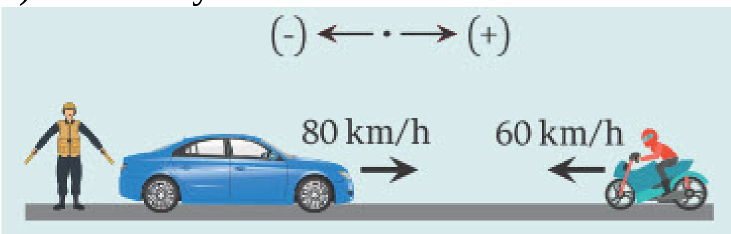
b) Relative Velocity in Two Dimensions

Another method must be used for analysing relative motion of objects moving perpendicular to each other, as shown in Figure 12. Knowing that velocity is a vector quantity, vector addition and subtraction is used to solve such problems in two-dimensions.

Figure 12

Example

The velocity vectors of a car and a motorcycle relative to the Earth are shown in the figure. Find the velocities of the car, the motorcycle and policeman relative to
a) A policeman, who is at rest next to the street
b) An observer in the car
c) A motorcyclist.



Given: $v_p = 0$
$v_c = 80 \text{ km/h}$
$v_m = -60 \text{ km/h}$

Formula: $\vec{v}_{relative} = \vec{v}_{object} - \vec{v}_{observer}$

a) Car: $v_{relative} = 80 - 0 = 80 \text{ km/h}$
Motorcycle: $v_{relative} = -60 - 0 = -60 \text{ km/h}$
Policeman: $v_{relative} = 0 - 0 = 0$

b) Car: $v_{relative} = 80 - 80 = 0$
Motorcycle: $v_{relative} = -60 - 80 = -140 \text{ km/h}$
Policeman: $v_{relative} = 0 - 80 = -80 \text{ km/h}$

c) Car: $v_{relative} = 80 - (-60) = 140 \text{ km/h}$
Motorcycle: $v_{relative} = -60 - (-60) = 0$
Policeman: $v_{relative} = 0 - (-60) = 60 \text{ km/h}$

Example

A small boat crosses a wide river with a steady speed of 5 m/s due north relative to the water, as shown in the figure. The river also has a steady speed of 2 m/s due west relative to the Earth.
a) What is the velocity of the boat relative
to an observer at rest on the ground?

b) How long does it take for the boat to cross the river, which is 800 m wide?
c) At which point does the boat intercept the other side of the river?
Calculations:
a) Denoting the velocity of the boat relative to the river as and the velocity of the river relative to the Earth as .
The following equation can be written;

$$\vec{v}_{BE} = \vec{v}_{BR} + \vec{v}_{RE}$$

Using the Pythagorean Theorem,

$$v^2{}_{BE} = v^2{}_{BR} + v^2{}_{RE}; \quad v^2{}_{BE} = 5^2 + 2^2;$$
$$v_{BE} = \sqrt{29} = 5.4 \text{ m/s};$$

b) If it takes 1 s to travel 5 m to the North, then it takes 160 s to travel 800 m which is the width of the river

$$s_y = v_y t; \qquad t = \frac{s_y}{v_y}; \qquad t = \frac{800}{5} = 160 \text{ s};$$

c) It takes 1 s to undergo a displacement of 2 m to the West, thus in 160 s the boat covers 320 m in the westward direction until it reaches the other side of the river.

$$s_x = v_x t; \qquad s_x = 2 \cdot 160 = 320 \text{ m};$$

Activity

While you are sitting at your desk, what is your relative speed to:
a) the ground?
b) the centre of Earth?

Physics in life

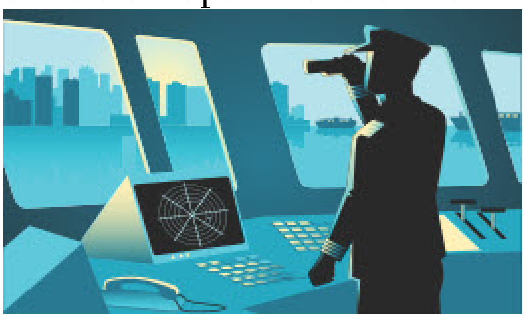
The velocity of the passenger relative to the observer is not zero, whereas relative to the train it is zero.

Is it true?

Saharan desert ants count their steps and perform an advanced mathematical operation called “path integration.”

Career

Sailors or captains use Galilean relativity to prevent crashes with other boats.



Literacy

1. Write definition of “relative velocity”.
2. Give three examples of zero relative velocity from your daily life.
3. A river flows at a velocity of 3 m/s. A fish has a velocity of 4 m/s in still water. What is the velocity of the fish relative to the Earth and the river.
a) If it swims in the same direction as the river?
b) If it swims in the opposite direction to the river?
c) If it swims perpendicularly to the river flow?
4. Two trains are moving towards each other at velocities of 36 km/h and 54 km/h. A passenger in the first train observes that the second train passes his train in a time interval of 6 seconds. What is the length of the second train?

1.6 Curvilinear motion

You will

- determine radius of curvature of trajectory, tangential acceleration, centripetal acceleration, total acceleration during curvilinear motion.

Question

Does hammer have acceleration when an athlete throws it? How does magnitude and direction of velocity change?

a) Total acceleration

We know that acceleration is a change in velocity. In curvilinear motion, the direction of the velocity changes constantly, so there is always an associated acceleration, even when magnitude of the velocity is constant. Total acceleration of curvilinear motion is equal to vector addition of centripetal acceleration and tangential acceleration.

The directions of the velocity of an object at two different points are shown, and the change of velocity Δv is seen to point directly toward the centre of curvature if $\Delta r \to 0$, Figure 13.

$$\Delta\vec{v} = \vec{v}_2 - \vec{v}_1$$

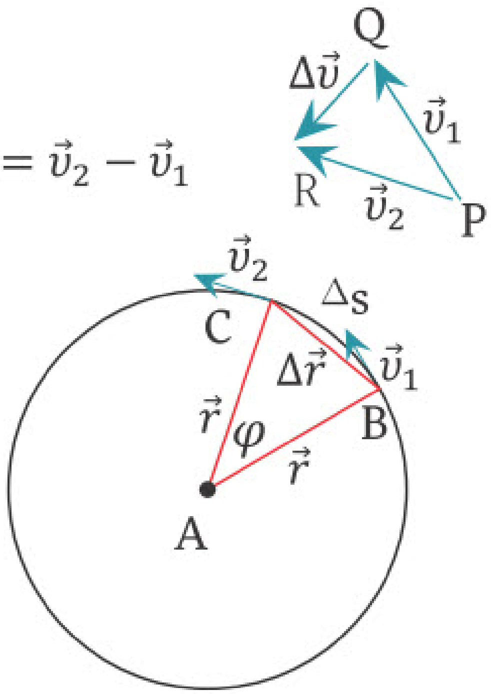


Figure 13

Formula of centripetal acceleration is

$$a_c = \frac{v^2}{R}$$

If motion is non-uniform, object has both tangential (linear) and centripetal acceleration, Figure 14.

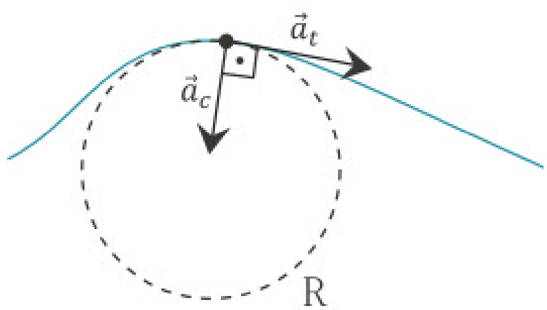


Figure 14

Formula of tangential acceleration is

$$a_t = \frac{\Delta v}{\Delta t}$$

Total acceleration is equal to vector addition of these two accelerations.

$$\vec{a} = \vec{a}_t + \vec{a}_c$$

Magnitude of total accleration can be calculated by Pythagorean theorem.

$$a = \sqrt{{a_t}^2 + {a_c}^2}$$

b) Kinematics of rotational motion

Linear quantities, like position, displacement, velocity, and acceleration, have angular equivalents for rotational motion. Changing the angular position of the body is called angular displacement. Angular velocity of an object is the change of angular displacement with respect to time. Angular acceleration is the change of the angular velocity during the unit time.

Linear motion		Rotational motion			Formula
displacement	$\vec{s}$	angular displacement	φ	rad	$\varphi = \frac{\ell}{R}$
velocity	$\vec{v}$	angular velocity	$\vec{\omega}$	rad/s	$\omega = \frac{v}{R}$
acceleration	$\vec{a}$	angular acceleration	$\vec{\varepsilon}$	rad/s^2	$\varepsilon = \frac{a_t}{R}$

The procedure used to derive the kinematic equations for linear motion with constant acceleration can be used to derive similar equations for rotational motion under constant angular acceleration. Every term in equation of linear motion has a corresponding term equation of rotational motion.

Linear motion	Rotational motion
$v = v_0 + at$	$\omega = \omega_0 + \varepsilon t$
$s = v_0 t + \frac{1}{2}at^2$	$\varphi = \omega_0 t + \frac{1}{2}\varepsilon t^2$
$v^2 = v_0^2 + 2as$	$\omega^2 = \omega_0^2 + 2\varepsilon\varphi$

Example

Runner runs circular track at constant speed of 8.66 m/s. He experiences centripetal acceleration of 2.5 m/s^2. What is radius of circular track? How many seconds does runner need to run one lap?

Given:

$v = 8.66\ \mathrm{m/s}$
$a_c = 2.5\ \mathrm{m/s^2}$
$R = ?$

Formulas:

$$a_c = \frac{v^2}{R} \qquad s = 2\pi R \qquad s = vt$$

Calculations:

$$R = \frac{v^2}{a_c} \qquad R = \frac{8.66^2}{2.5} = 30\ m \qquad s = 2 \cdot 3.14 \cdot 30 = 188.4\ m$$

$$t = \frac{s}{v} \qquad t = \frac{188.4}{8.66} = 21.76\ s$$

Activity

Measure how fast you draw a circle with a stopwatch or timer. Find angular and tangential speed of your pen/pencil's tip.

Literacy

1. What type of acceleration changes direction of motion only? What type of acceleration changes only magnitude of velocity but does not change direction of motion?
2. What is the difference between centripetal and tangential acceleration?
3. An centrifuge accelerates from rest to 1000 rpm in 3 min. What is the tangential acceleration, centripetal acceleration and total acceleration of a point 10 cm from the axis of rotation?
4. Space stations can produce artificial gravity by rotation. Space station has diameter of 100 metre and period of rotation of 16 sec. Compare artificial gravity of space station and natural gravity of the Earth.
5. What is the total acceleration of car that uniformly accelerates from rest to 100 km/h in 6 sec on a circular track that has 20 metre radius? Is it safe acceleration for human being?

Physics in life

There are speed limits before turns on highways. Why?

Career

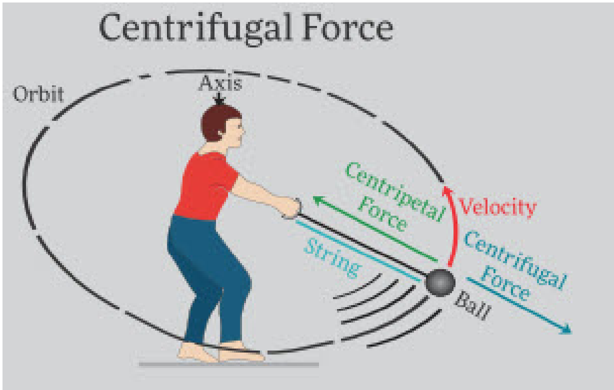
Endurance of astronauts (cosmonauts) is tested by centrifuge.

Important note

Angles are measured in radians. Angles expressed in terms of degrees must be converted to radians. Also, check your calculator for being in degree or radian mode when solving problems involving rotation.

Is it true?

Centrifugal force is a pseudo force and it is not real like centripetal force.


Centrifugal Force
Orbit
Axis
Centripetal
Force
Velocity
String
Centrifugal
Force
Ball

1.7 CIRCULAR MOTION

You will

- determine radius of curvature of trajectory, tangential acceleration, centripetal acceleration, total acceleration during curvilinear motion.

Question

What parameter does gauge on the left show? What is RPM?

A toy car moves in a circular path with constant linear speed, Figure 15a. This type of motion is called circular motion.

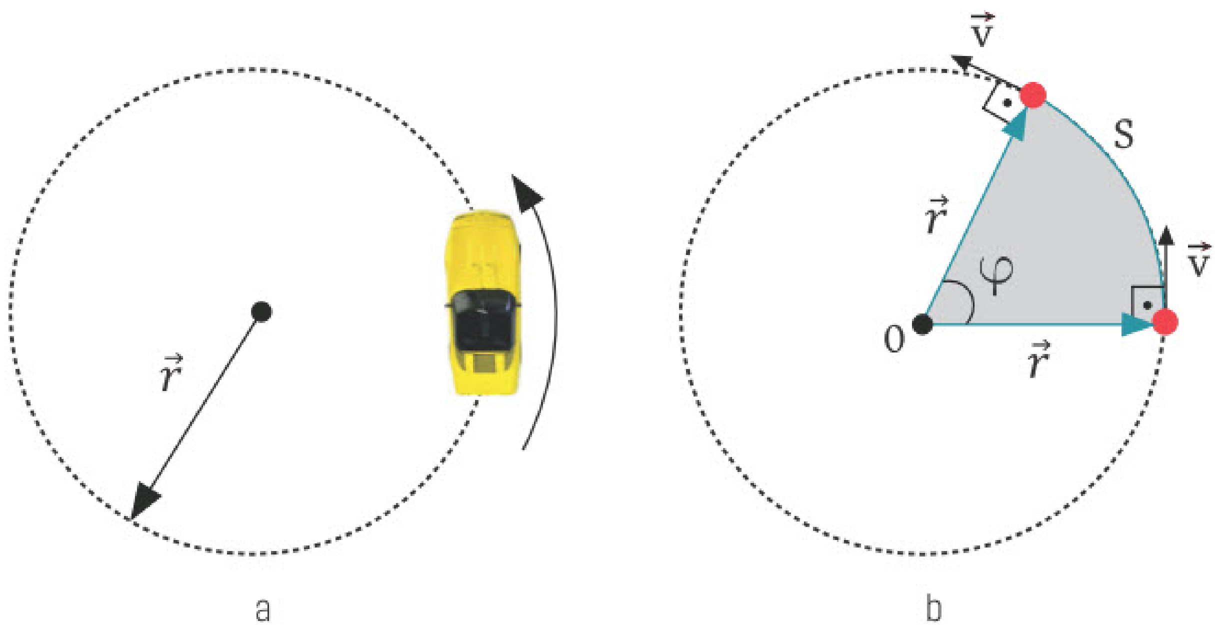


Figure 15

Imagine that the toy car sweeps the angle φ in a time interval t, Figure 15b. This angle depends on the radius (r) and arc length (s). This relation is in the formula:

$$\varphi = \frac{s}{r}$$

φ-angle [rad]
s– length of arc [m]
r– radius [m]

The unit of angle in this formula is radians. One complete revolution is 360° or 2π radian. That's why we can write

$$360^\circ = 2\pi \text{ radian}; \qquad 1 \text{ radian} = \frac{360^\circ}{2\pi} \approx 57.3^\circ;$$

Since the linear speed is constant, we can write the relationship between t, υ ,s and (length of the arc) as

$$s = vt$$

When toy car makes one complete revolution, it travels distance

$$s = 2\pi r$$

We can write the new formula as

$$2\pi r = vT$$

r– radius [m]
υ– linear speed (tangential speed) [m/s]
T– period [s]

We call as “tangential speed” because it makes 90° with the radius, Figure 16.

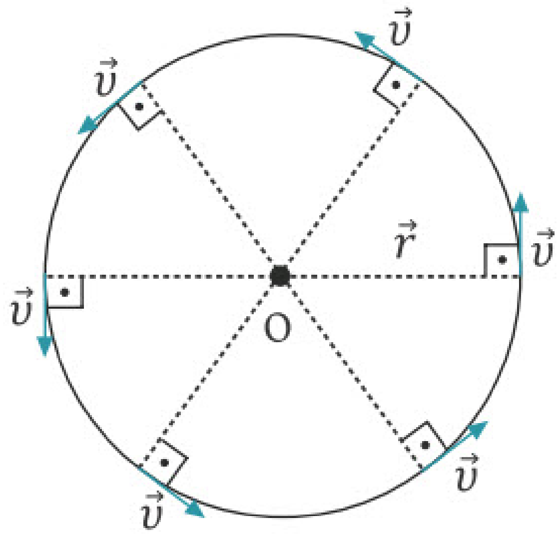


Figure 16

The time T is called period of rotation. Unit of the period is second. Period means “a time required to make one revolution”.

There is a concept of frequency which means “number of revolutions in 1 second”. For example, car’s wheel has a period of 0.12 seconds. This means that in 1 second it makes 1/0.12 ≈ 8.33 revolutions. The relationship of period and frequency is in the formula

$$f = \frac{1}{T}$$

f - frequency [1/s] or [Hz] - Hertz
T- period [s]

Example

The drum of a washing machine starts from rest and reaches 800 rpm (revolutions per minute) in 10 sec. What is the centripetal, tangential, and total acceleration of the point at the edge of drum after 10 sec? Diameter of the drum is 60 cm.

Given:

$f = 800\ rpm = \frac{800}{60} = 13.33\ Hz$

$t = 10\ s$

$d = 60\ cm = 0.6\ m$

$v_0 = 0$

$a_c = ?$

$a_t = ?$

$a = ?$

Formulas:

$$R = \frac{d}{2} \qquad v = 2\pi R f$$

$$a_c = \frac{v^2}{R} \qquad a_t = \frac{\Delta v}{\Delta t}$$

$$a_t = \frac{v - v_0}{t} \qquad a = \sqrt{{a_c}^2 + {a_t}^2}$$

Calculations:

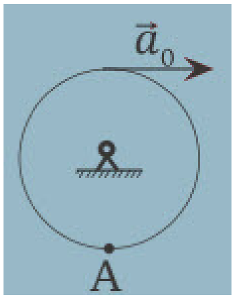
$$R = \frac{0.6}{2} = 0.3\ m \qquad v = 2 \cdot 3.14 \cdot 0.3 \cdot 13.33 = 25.12\ m/s$$

$$a_c = \frac{25.12^2}{0.3} = 2103.38\ m/s^2 \qquad a_t = \frac{25.12 - 0}{10} = 2.512\ m/s^2$$

$$a = \sqrt{2103.38^2 + 2.512^2} = 2103.38\ m/s^2$$

Literacy

1. What is the trajectory of an object if centripetal acceleration is zero and tangential acceleration is non-zero?
2. What is the trajectory of an object if tangential acceleration is zero and centripetal acceleration is non-zero?
3. Car moves on a circular track that has radius of 40 metre. Equation of motion of car is given as $s=A+Bt+Ct^2$, where A=5m, B=12 m/s, C=-0.5 m/s^2. Calculate velocity, tangential acceleration, centripetal acceleration and total acceleration of car at the moment t=4 sec.
4. Particle in circular collider starts moving from rest with constant tangential acceleration. Calculate angle between velocity and total acceleration after first rotation.
5. Sheave that has radius of 0.5 metre starts to be rotated by rope pulled with $a_0=0.1\ m/s^2$ acceleration. Calculate centripetal, tangential and total acceleration of point A at the edge of sheave at the moment t=2 sec.



6. Aid box is dropped from horizontally flying plane. Altitude of plane is 3000 metre, speed is 900 km/h. Calculate radius of curvature of trajectory of aid box after 10 sec. Neglect air resistance and assume $g=10$ m/s^2.

Physics in life

Sparks from grinder fly off due to tangential velocity.

Is it true?

To pass death loop there must be high enough velocity.

Activity

What is the tangential speed of the points on the Equator and on the Poles of the Earth?

Research time

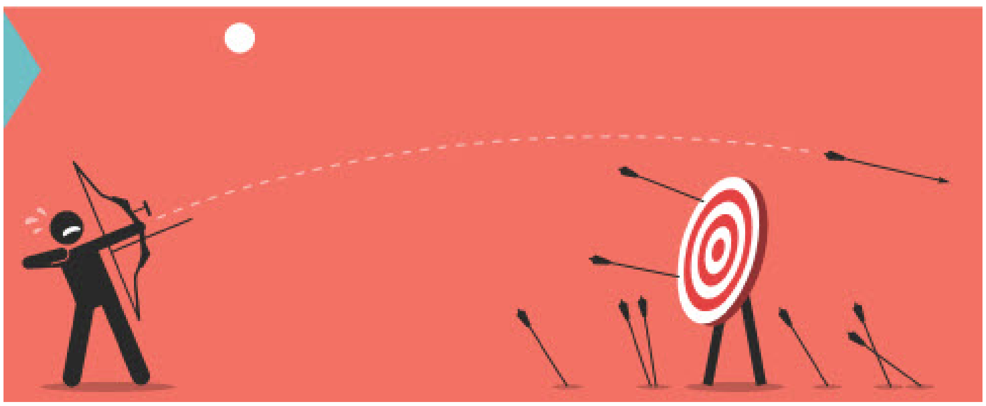
Good HDD (Hard Disk Drive) makes 7200 RPM (Revolutions Per Minute).
a) Find its frequency and angular speed.
b) HDD's diameter is 3.5 inches (7.62 cm). What is the tangential velocity of the points at the edge of the disk?
c) Nowadays SSD (Solid State Disk) is used instead of HDD. Why?

1.8 Projectile motion

You will

- determine kinematic parameters of an object performing projectile motion.

Question



Why do archers take the aim higher when they are shooting at a long distance?

Projectile motion - is a form of motion in which an object is thrown near the Earth's surface, and it moves along a curved path under the action of gravity only, Figure 17.

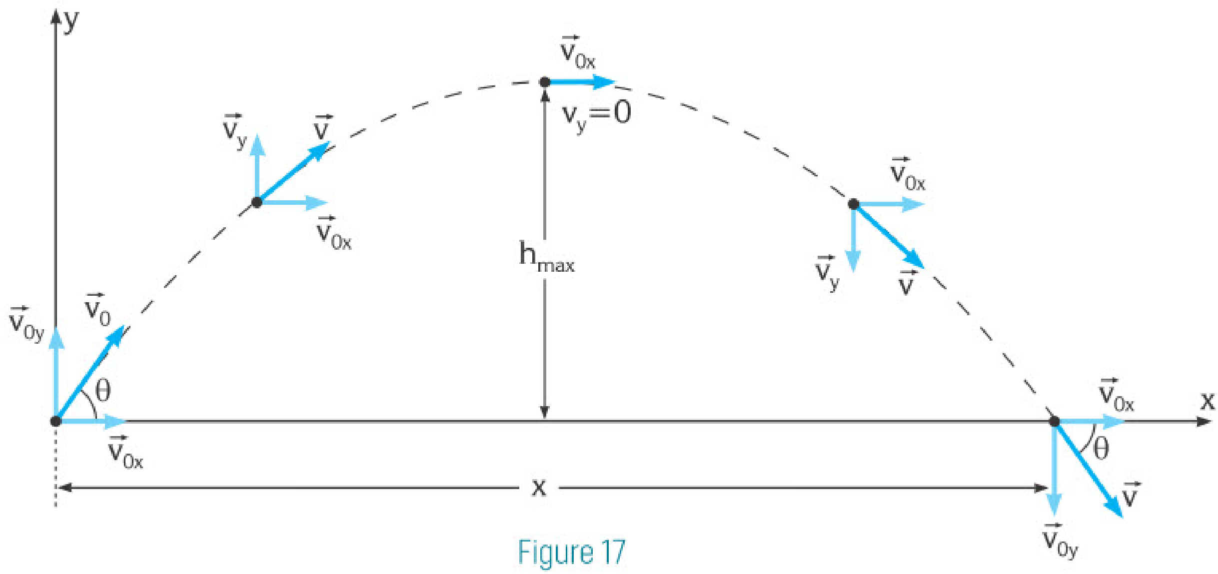


Figure 17

The most important fact about projectile motion is that the horizontal and vertical motions are completely independent of each other. This feature allows us to break up a problem into two separate problems, one for the horizontal motion (with zero acceleration) and one for the vertical motion (with constant downward acceleration).

$a_x = 0$ $\qquad\qquad$ $a_y = -g$

$\upsilon_{0x} = \upsilon_0 \cos\alpha$ $\qquad\qquad$ $\upsilon_{0y} = \upsilon_0 \sin\alpha$

Because there is no acceleration in the horizontal direction, the horizontal component of velocity does not change from its initial value υ_{0x}.

$$\vec{\upsilon} = \vec{\upsilon}_0 + \vec{a}t \qquad \upsilon_x = \upsilon_{0x} - 0 \cdot t \qquad \upsilon_x = \upsilon_{0x}$$

The vertical motion is the analogue of free fall. The vertical velocity component initially directed upward, and its magnitude uniformly decreases to zero which marks the maximum height of the path. The vertical velocity component then reverses direction, and its magnitude increases with time.

$$\vec{\upsilon} = \vec{\upsilon}_0 + \vec{a}t \qquad \upsilon_y = \upsilon_{0y} - gt$$

Total time of flight is twice more than time to the maximum height of the path.

$$0 = \upsilon_0 \sin\alpha - g\frac{t}{2} \qquad t = \frac{2\upsilon_0 \sin\alpha}{g}$$

The horizontal range is the horizontal distance the object travelled when it returns to its initial height. We can derive formula of range by substituting time into horizontal distance formula.

$$\vec{s} = \vec{v}_0 t + \frac{1}{2}\vec{a}t^2 \qquad x = v_{0x}t + \frac{1}{2}\cdot 0 \cdot t^2 \qquad x = v_0 \cos\alpha\, t$$

$$x = v_0 \cos\alpha \cdot \frac{2v_0 \sin\alpha}{g} \qquad x = \frac{v_0^2 \sin 2\alpha}{g}$$

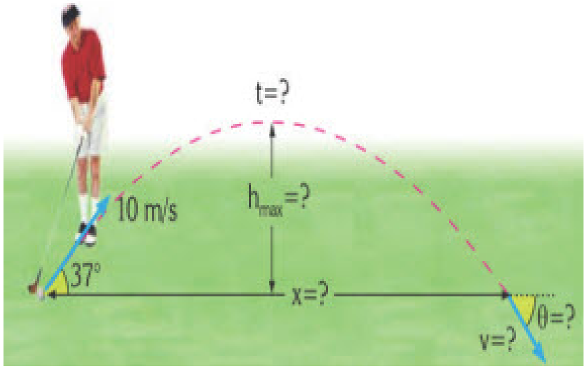
At the point of maximum height the component of vertical velocity is equal to zero.

$$v^2 = v_0^2 + 2as \qquad v_y^2 = v_{0y}^2 - 2gy$$

$$0 = (v_0 \sin\alpha)^2 - 2gh_{max} \qquad h_{max} = \frac{(v_0 \sin\alpha)^2}{2g}$$

Example

A golf ball is struck at a velocity of 10 m/s and an angle of 37° with the horizontal, as shown in the figure.



a) Calculate the time for the ball to reach its maximum height?

b) How high will the ball rise, h_{max}?

c) What is the range of the ball?

Given: $\alpha = 37°$, $\sin 37° \approx 0.6$, $\cos 37° \approx 0.8$, $\sin 74° \approx 0.96$, $g \approx 10\ m/s^2$

Formulas:

$$t = \frac{v_0 \sin\alpha}{g}$$

$$h_{max} = \frac{(v_0 \sin\alpha)^2}{2g}$$

$$x = \frac{v_0^2 \sin 2\alpha}{g}$$

Calculations:

$$t = \frac{10 \cdot 0.6}{10} = 0.6\ s$$

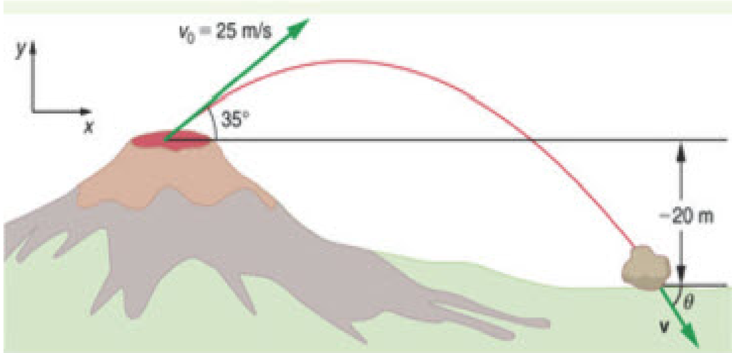
$$h_{max} = \frac{(10 \cdot 0.6)^2}{2 \cdot 10} = 1.8\ m$$

$$x = \frac{10^2 \cdot 0.96}{10} = 9.6\ m$$

Literacy

1. What type of motion is horizontal component of projectile motion?
2. What type of motion is vertical component of projectile motion?
3. Kangaroo can jump 13 metre in horizontal direction. What is the velocity of kangaroo if it jumps at an angle of 30°?

4. Rock is ejected from volcano. Calculate time of fl ight and velocity of rock immediately before it hits the ground.



5. What should angle of throw be so that maximum height of the ball is twice less than range of the ball?
6. Water flows from garden hose at an angle of 30° with velocity of 15 m/s. Cross-sectional area of hose is 1 cm^2. Calculate mass of water in the air.

Physics in life

Archer fish use projectile motion to catch its prey.

Research time

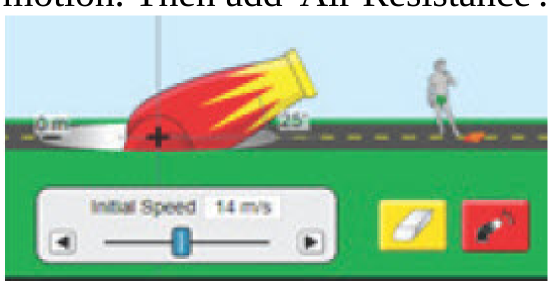
Make a launcher with rubber bands. Measure the maximum range it can reach and record the angle. Calculate the initial velocity to reach maximum range.

Important note

The path of projectile motion is parabolic.

Activity

Open in browser 'Projectile Motion Phet'. Fire the cannonball and observe its motion. Then add 'Air Resistance'. How does trajectory change and why?

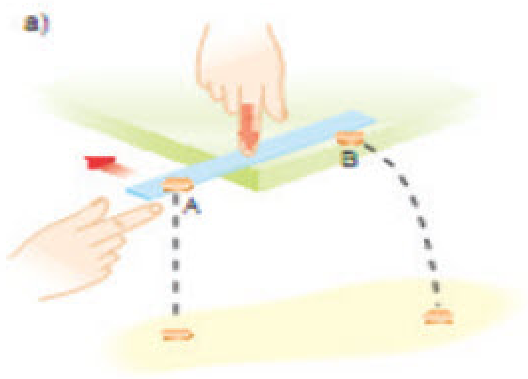


Career

Professional sportsmen use projectile motion in basketball, football, volleyball, tennis, golf and etc.

Is it true?

If you throw two coins as shown in the fi gure, they will fall at the same time.



LAB WORK #1

Title:

Acceleration of body on an inclined plane

Objectives:

- write result of experiment with measurement error.

Equipment:

Safety glasses, gloves, inclined plane, meterstick, small ball, stopwatch.

Theory:

$$\vec{a} = \frac{\Delta\vec{v}}{\Delta t} = \frac{\vec{v} - \vec{v}_0}{t - t_0}$$

If an object undergoes a uniform change in velocity with time it is said to have a constant acceleration. The following equations of kinematics are used to define uniformly accelerated motion:

$$v = v_0 + at$$

$$\Delta x = v_0 t + \frac{1}{2}at^2$$

$$\Delta y = \frac{1}{2}(v_0 + v) \cdot t$$

$$v^2 = v_0^2 + 2a\Delta x$$

Where

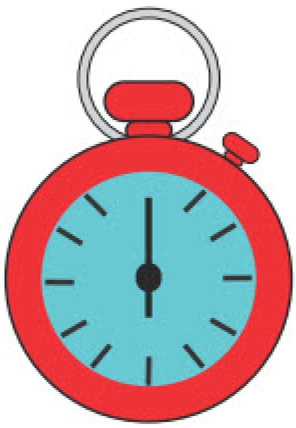
a is the constant acceleration
υ_o is the initial velocity
υ is the final velocity
Δx is the displacement
t is the time

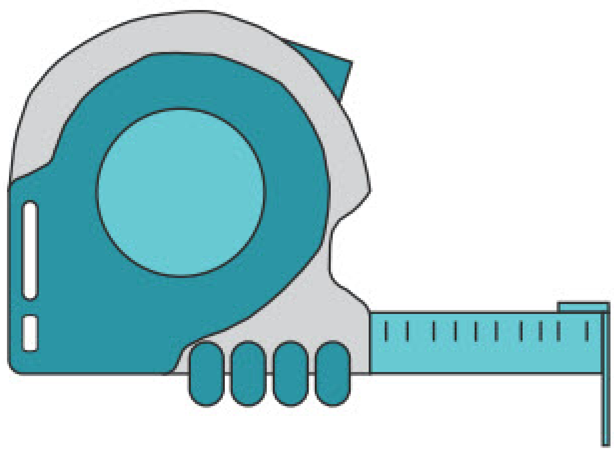
Procedure:

1. Release the ball from the top of the inclined plane.
2. Measure displacement and time of the ball.
3. Calculate final velocity and acceleration by using displacement and time.
4. Put ball on different points of inclined plane and repeat 5 more times.
5. Plot a graph of displacement-square of time.
6. Use graph to calculate acceleration.
7. Calculate the error of the acceleration.

Conclusion:

1. What is the relationship between the displacement and square of time?





LAB WORK #2

Title:

Relationship between range and angle in projectile motion

Objectives:

- analyse trajectory of an object performing projectile motion

Equipment:

Safety glasses, gloves, compass, ballistic pistol, measuring tape, ball.

Theory:

Range of projectile motion can be calculated by this formula.

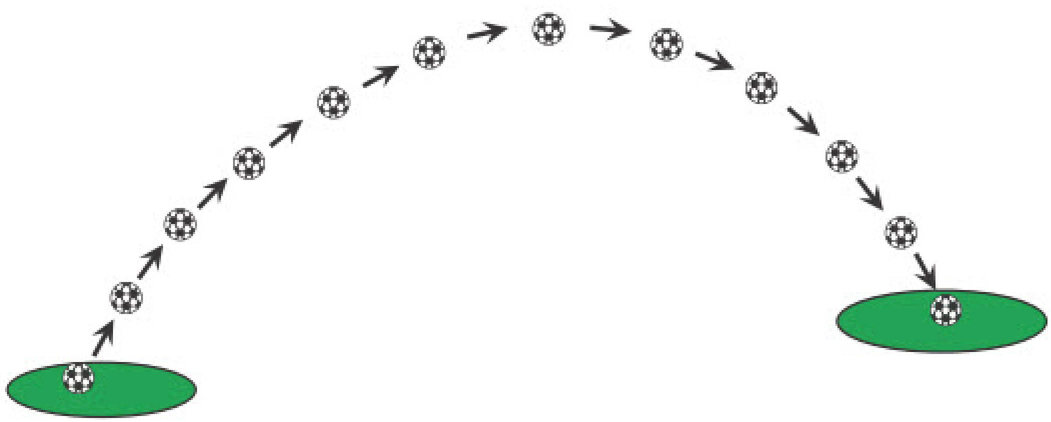
$$x = \frac{{v_0}^2 \sin 2\alpha}{g}$$

Procedure:

1. Shoot ballistic pistol at different angles given in table.
2. Measure range for each case and record it in the table.
3. Plot range versus angle graph.
4. Determine angle for maximum range.
5. Use formula and calculator to fill the table.

6. Calculate average value of initial velocity, absolute error and relative error of initial velocity.

α (°)	10	20	30	40	45	50	60	70	80
x (m)									
$\sin 2\alpha$									
v_0 $\left(\frac{m}{s}\right)$									



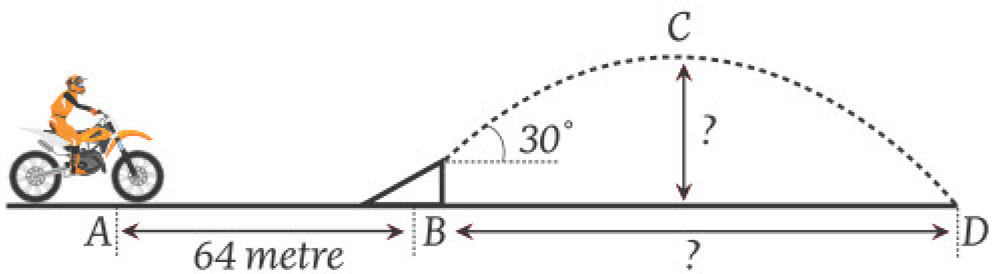
Conclusion:

1. How did air resistance affect the results?

2. What will change if the ball will be heavier or lighter?

CHECK YOURSELF

Stuntman performs stunt shown on the figure. He starts motorbike from rest and accelerates with 8 m/s^2 acceleration. Then he uses inclined plane to launch into air. Use figure to answer questions 1-25. Neglect air resistance and assume stuntman and motorbike to be point objects. $g=10\ m/s^2$.



1. How long does stuntman travel between points A and B?
A) 1 sec
B) 2 sec
C) 3 sec
D) 4 sec
E) 5 sec

2. How long does stuntman travel between points B and C?
A) 0.6 sec
B) 1.6 sec
C) 2.6 sec
D) 3.6 sec
E) 4.6 sec

3. How long does stuntman travel between points C and D?
A) 0.6 sec
B) 1.6 sec
C) 2.6 sec
D) 3.6 sec
E) 4.6 sec

4. How long does stuntman travel in the air?
A) 0.2 sec
B) 1.2 sec
C) 2.2 sec
D) 3.2 sec
E) 4.2 sec

5. What is the velocity of the motorbike at point A?
A) 8 m/s
B) 32 m/s
C) 27.71 m/s
D) 0
E) 16 m/s

6. What is the velocity of the motorbike at point B?
A) 8 m/s
B) 32 m/s
C) 27.71 m/s
D) 0
E) 16 m/s

7. What is the velocity of the motorbike at point C?
A) 8 m/s
B) 32 m/s
C) 27.71 m/s
D) 0
E) 16 m/s

8. What is the velocity of the motorbike at point D?
A) 8 m/s
B) 32 m/s
C) 27.71 m/s
D) 0
E) 16 m/s

9. What is the maximum height that stuntman reaches?
A) 12.8 m
B) 14.8 m

C) 16.8 m
D) 18.8 m
E) 10.8 m

10. What is horizontal distance between points B and D?
A) 98.68 m
B) 58.68 m
C) 68.68 m
D) 78.68 m
E) 88.68 m

11. At which point velocity of motorbike is 27.71 m/s?
A) A
B) B
C) C
D) D
E) There is no right answer

12. At which point velocity of motorbike is 25 m/s?
A) A
B) B
C) C
D) D
E) There is no right answer
13. What is the height of motorbike when its velocity is 30 m/s?
A) 5.2 m
B) 6.2 m
C) 7.2 m
D) 8.2 m
E) 9.2 m

14. What is the velocity of motorbike when its height is 10 metre?
A) 8.71 m/s
B) 18.71 m/s
C) 28.71 m/s
D) 38.71 m/s

E) 48.71 m/s

15. What is the height of motorbike when its velocity is 27.71 m/s?
A) 2.8 m
B) 12.8 m
C) 22.8 m
D) 32.8 m
E) 42.8 m

16. What is the velocity of motorbike when height of motorbike is 15 metre?
A) 8.71 m/s
B) 18.71 m/s
C) 28.71 m/s
D) 38.71 m/s
E) There is no right answer

17. What is the direction of the velocity of motorbike after 5.6 sec from the start of motion?
A) 0°
B) 10°
C) 20°
D) 30°
E) 40°

18. What is the direction of the velocity of motorbike after 4.001 sec from the start of motion?
A) 0
B) 10°
C) 20°
D) 30°
E) 40°

19. What is the direction of the velocity of motorbike after 5 sec from the start of motion?
A) 2.22°
B) 12.22°
C) 22.22°
D) 8.22°
E) 18.22°

20. What is the direction of the velocity of motorbike after 7 sec from the start of motion?
A) 12.8°
B) 22.8°
C) 6.8°
D) 16.8°
E) 26.8°

21. How many times during the motion velocity of motorbike is equal to 30 m/s?
A) 1
B) 2
C) 3
D) 4
E) 0

22. How many times during the motion velocity of motorbike is equal to 15 m/s?
A) 1
B) 2
C) 3
D) 4
E) 0

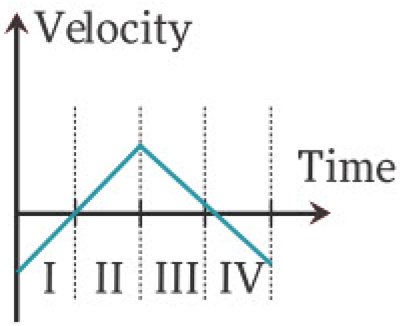
23. What should be velocity of motorbike in point B so that motorbike lands 100 metre away from point B?
A) 34 m/s
B) 36 m/s
C) 38 m/s
D) 40 m/s
E) 32 m/s

24. What should be acceleration of motorbike between points A and B so that motorbike lands 100 metre away from point B?
A) 8 m/s^2
B) 9 m/s^2
C) 10 m/s^2
D) 11 m/s^2
E) 12 m/s^2

25. Plot time-acceleration graph for time interval between A and D and acceleration between A and B. What should be the acceleration between A and B so that time of travel between A and D is minimum?
A) 8 m/s^2
B) 9 m/s^2
C) 10 m/s^2
D) 11 m/s^2
E) 12 m/s^2

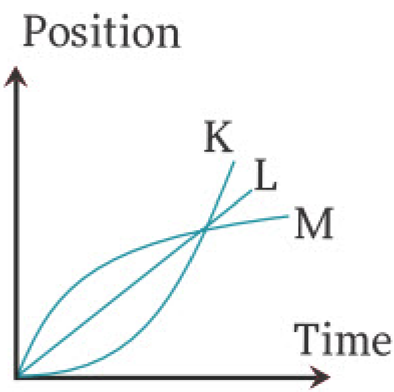
Motion with Constant Acceleration

1. The velocity-time graph of a moving object is given in the figure. In which intervals acceleration is negative?



A) I
B) II
C) III
D) IV

2. The position-time graphs of the objects K, L and M moving along a straight line are shown in the figure.



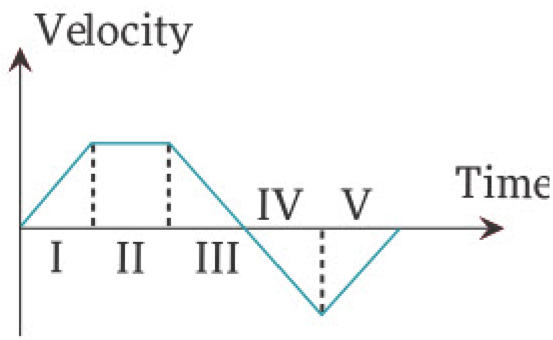
Which of the following statements may be correct?
I. The velocity of object L is constant.
II. The accelerations of objects K and M are constant.
III. Object L accelerates uniformly.
A) I only
B) II only
C) III only
D) I and II
E) II and III

3. An object moving with a constant velocity of 2 m/s along a straight path starts to decelerate at 0.2 m/s2. How many seconds later does the object

stop after starting to decelerate?

A) 5
B) 10
C) 15
D) 20
E) 25

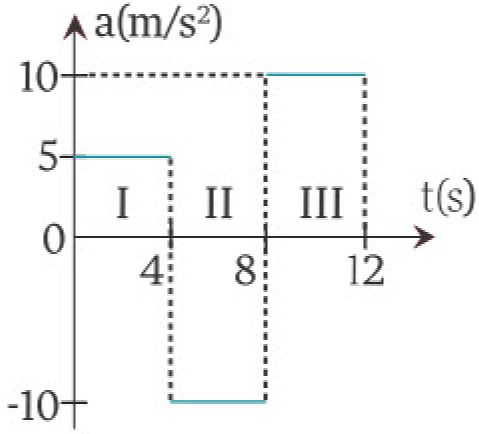
4.The velocity-time graph of a moving object is shown in the figure.



Which of the following statements concerning the acceleration of the object is correct?

A) Within interval I, the acceleration increases in the '+' direction.
B) Within interval II, the acceleration is constant in the '+' direction.
C) Within interval III, the acceleration decreases in the '–' direction.
D) Within interval IV, the acceleration is constant in the '–' direction.
E) Within interval V, the acceleration increases in the '+' direction.

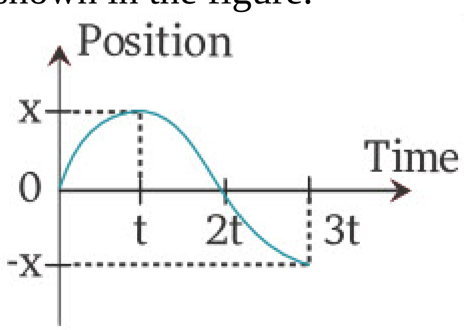
5. The acceleration-time graph of an object initially moving with a velocity of 5 m/s is shown in the figure.



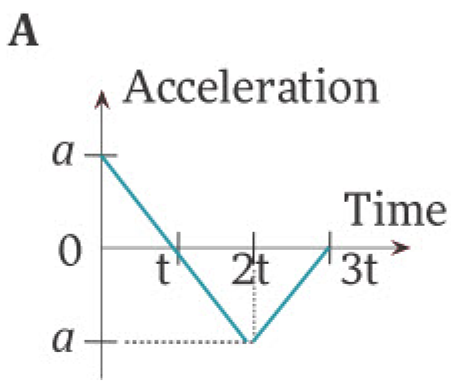
In which time interval(s) does the object change the direction of its motion?
A) I only
B) II only
C) III only
D) I and II
E) II and III

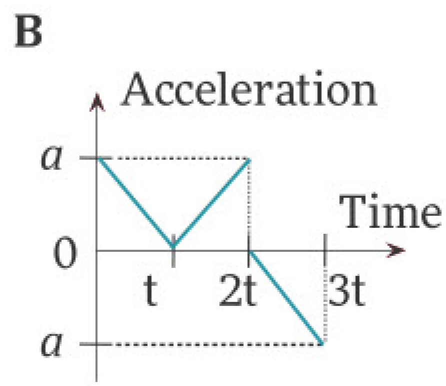
6. An object moving with constant acceleration along a straight line covers 64 m within 4 s, starting its motion from rest. If the object keeps on accelerating at the same rate, what is its velocity in the 10th second, in m/s?
A) 20
B) 30
C) 40
D) 80
E) 100

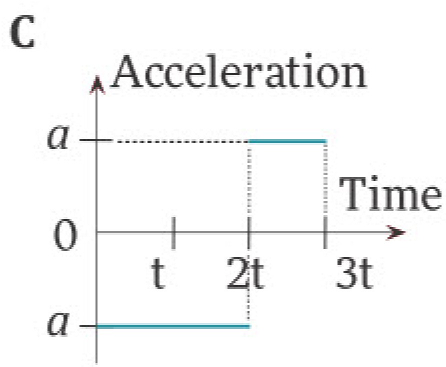
7. The position-time graph of an object moving along a straight line is shown in the figure.

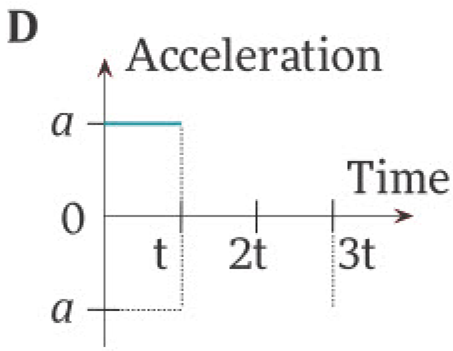


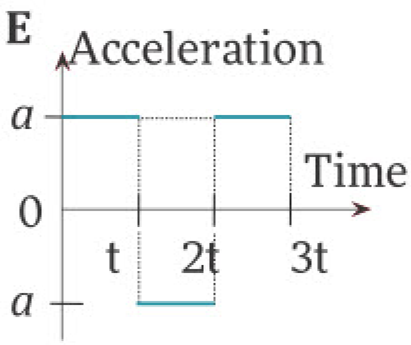
Which of the following is the acceleration-time graph of the object?



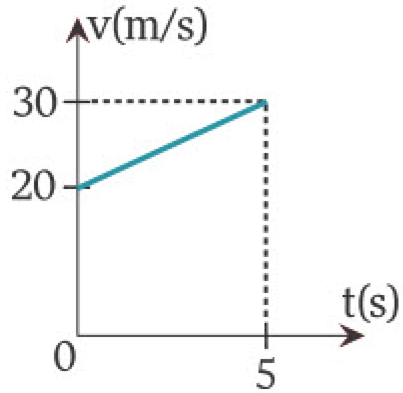








8. The velocity-time graph of an object is as shown in the figure.



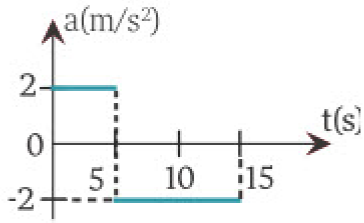
What is the magnitude of the displacement of the object within the interval 0-5 s, in metres?

A) 25
B) 50
C) 75
D) 100
E) 125

9. When an object, moving with an initial velocity of 100 m/s, is decelerating at a constant rate, it covers a distance of 700 m within 10 s. What is the deceleration of the object, in m/s^2?

A) 2
B) 4
C) 6
D) 8
E) 10

10. The acceleration-time graph of an object, starting its motion from rest, is shown in the figure.

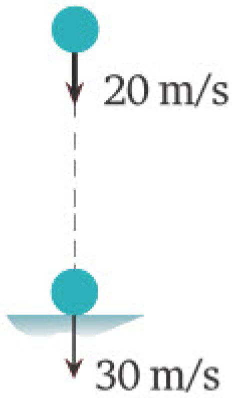


What is the magnitude of the displacement of the object between t=5 s and t=10 s, in metres?

A) 25
B) 50
C) 75
D) 150
E) 175

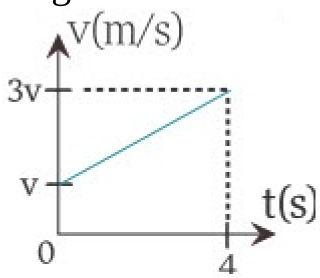
Freely Falling Objects

1. An object thrown vertically downward from a height with an initial speed of 20 m/s strikes the ground with a speed of 30 m/s.



What was the height of the object from the ground, in metres? (Take g=10 m/s^2)
A) 10
B) 15
C) 20
D) 25
E) 30

2. The velocity-time graph of an object thrown vertically downwards from a height is as shown in the figure. υ is equal to 20 m/s.



What was the height of the object from the ground, in metres? (Take g=10 m/s^2)
A) 160

B) 180
C) 200
D) 225
E) 250

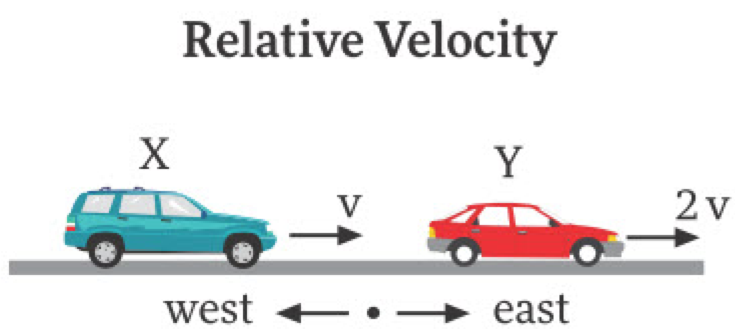
3. Which of the following concerning the acceleration of an object thrown vertically upwards is correct?
A) It decreases during the motion of the object and becomes zero at its maximum height.
B) It increases during the motion of the object.
C) It decreases as the object ascends and increases as the object descends.
D) It is constant during the motion of the object.
E) It decreases during the motion of the object.

4. An object thrown vertically upwards falls back to its initial position after 8 s. What was the initial velocity of the object, in m/s?
(Take g=10 m/s2)
A) 30
B) 40
C) 50
D) 60
E) 70

5. An object is thrown vertically upwards with an initial speed of 50 m/s. What will the direction of the velocity and acceleration be after 4 s?
(Take g=10 m/s2)

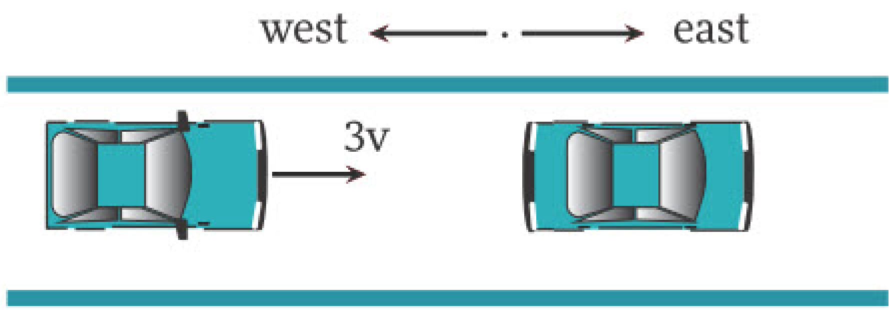
Velocity	Acceleration
A) up	up
B) up	down
C) down	up
D) down	down
E) up	zero

Relative Velocity



1. The cars X and Y, shown in the figure, travel at speeds of v and 2v, respectively, towards the east.
What is the direction and magnitude of the velocity of car Y relative to an observer in car X ?
A) East, 2v
B) East, v
C) West, v
D) West, 2v
E) East, 3v

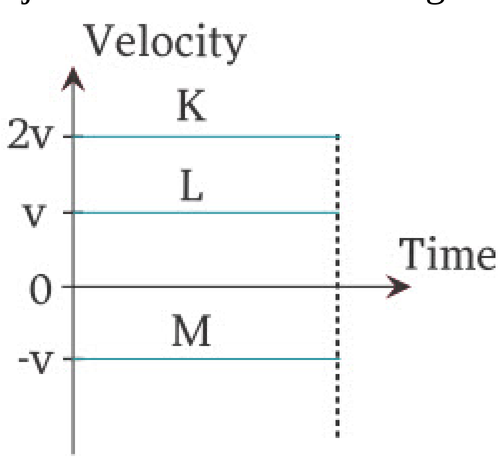
2. The cars X and Y travel along the same path and the velocity of car X relative to the ground is 3v.
If the velocity of car Y relative to car X is 2v towards the west, what is the velocity of car Y relative to the ground?



A) West, v
B) East, v
C) West, 2v
D) East, 2v
E) West, 3v

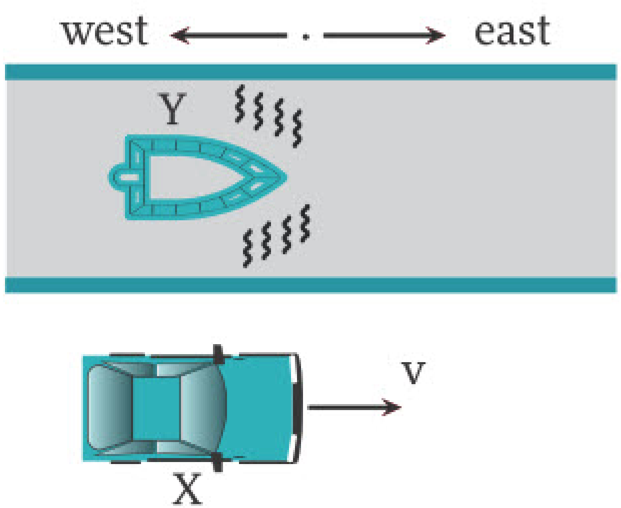
3. Which of the following statements concerning cars X and Y moving along parallel roads may be correct?
I. An observer travelling in car X sees car Y at rest.
II. An observer travelling in car X sees car Y moving away from car X.
III. An observer travelling in car X sees car Y approaching car X.
A) I only
B) II only
C) III only
D) I and II
E) I, II and III

4. The velocity-time graphs of the objects K, L and M, which were initially adjacent are shown in the figure.



Which of the following statements is/are correct?
I. The velocity of object L relative to object M is equal to the velocity of object K relative to the ground.
II. The velocity of object L relative to object K is equal to the velocity of object M relative to the ground.
III. The distance between objects K and L doesn't change in time.
A) I only
B) II only
C) III only
D) I and II
E) I and III

5. An observer in car X, travelling at velocity v relative to the ground towards the east, observes motorboat Y on the river at rest. Which of the following statements may be correct?

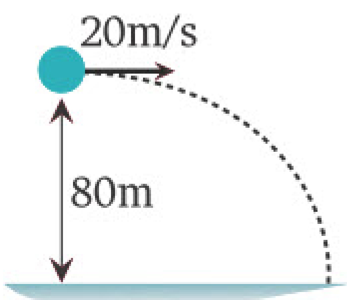


I. The velocity of boat Y relative to the ground is of magnitude v towards the east.
II. The flow velocity of the river relative to the ground is of magnitude v towards the east.
III. The flow velocity of the river relative to the ground is of magnitude v towards the west.
A) I only
B) II only
C) III only
D) I and II
E) I, II and III

Horizontal Projectile Motion

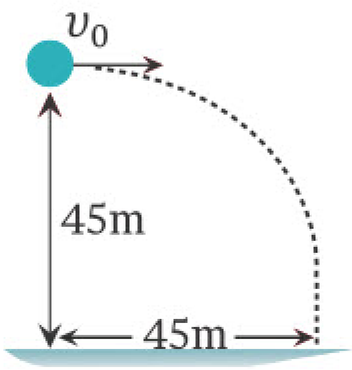
1. Which of the following statements concerning an object thrown horizontally is/are correct?
I. Its initial velocity vector is parallel to the ground.
II. Its speed is minimum when it is thrown and maximum when it strikes the ground.
III. The acceleration of the object is constant and equal to gravitational acceleration.
A) II only
B) III only
C) I and III
D) II and III
E) I, II and III

2. An object is thrown horizontally from a height of 80 m with an initial velocity of 20 m/s, as shown in the figure.



How many metres does the object travel in the horizontal direction? (Take $g=10\ m/s^2$)
A) 50
B) 60
C) 70
D) 80
E) 90

3. An object is thrown horizontally from a height of 45 m with an initial velocity of υ_0, as shown in the figure.

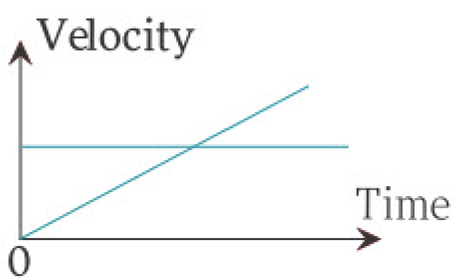


What is υ_0, in m/s, if the object travels 45 m in the horizontal direction?

(Take g=10 m/s^2)
A) 10
B) 15
C) 20
D) 25
E) 30

4. An object is thrown horizontally at a certain height with an initial velocity of 20 m/s. What is the magnitude of the horizontal and vertical components of velocity of the object, vx and vy after 3 s, in m/s? (Take g=10 m/s^2)
A) vx: 20 m/s vy: 20 m/s
B) vx: 20 m/s vy: 30 m/s
C) vx: 30 m/s vy: 20 m/s
D) vx: 30 m/s vy: 30 m/s
E) vx: 20 m/s vy: 25 m/

5. The horizontal and vertical components of velocity of an object are plotted in the figure.



Which of the following may the motion of the object be?

A) Free fall
B) Vertically downward motion
C) Vertically upward motion
D) Horizontal projectile motion
E) Uniform linear motion

6. The objects K and L are at the same height. When object K is thrown horizontally, object L falls freely from rest.
What will the motion of object K be with respect to object L?
A) Uniform linear motion.
B) Horizontal projectile motion.
C) Free fall.
D) Vertically downward motion with an initial velocity.
E) Motion with constant acceleration along the horizontal axis.

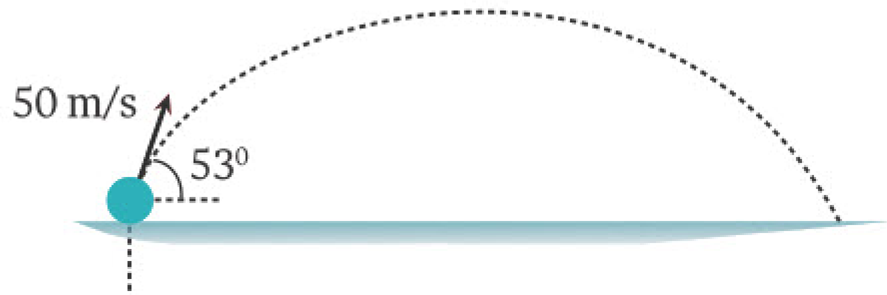
Projectile motion

1. Which of the following is/are correct concerning an object thrown at an angle to the horizontal?
I. It moves with constant speed in the horizontal.
II. Its speed is maximum when it is thrown and minimum at the maximum height.
III. It strikes the ground with a speed greater than its initial speed.
A) II only
B) III only
C) I and II
D) II and III
E) I, II and III

2. An object is thrown from the ground with an initial velocity of 50 m/s at an angle of 37° to the horizontal. What is the time of flight of the object, in seconds? (Take sin 37°=0.6; g=10 m/s^2)
A) 4
B) 6
C) 8
D) 10

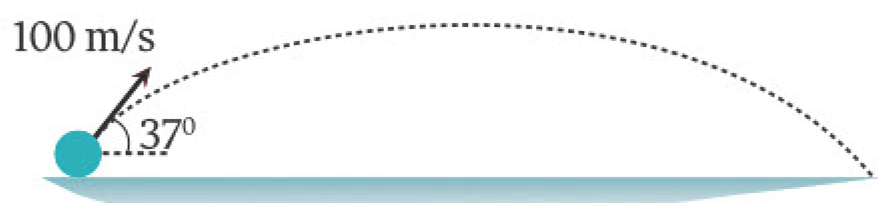
E) 12

3.



An object is thrown from the ground with an initial velocity of 50 m/s making an angle of 53º to the horizontal, as shown in the figure.
What is the range of the object, in metres?
(Take sin 53º=0.8; cos 53º=0.6; g=10 m/s2)
A) 80
B) 120
C) 180
D) 240
E) 400

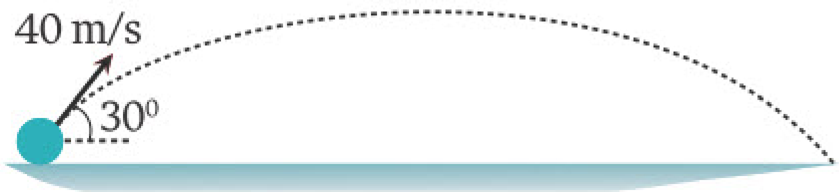
4.



An object is thrown from the ground with an initial velocity of 100 m/s at an angle of 37º to the horizontal, as shown in the figure. If the horizontal and vertical distances of the object are x and h, respectively, what is the ratio x/h within the first 4 seconds? (Take sin 37º = 0.6; cos 37º = 0.8; g = 10 m/s^2)
A) 1/2
B) 2/3
C) 1

D) 3/2
E) 2

5.



What is the maximum height of an object thrown from the ground with an initial velocity of 40 m/s at an angle of 30º to the horizontal, in metres? (Take sin 30º = 0.5; g = 10 m/s2)

A) 20
B) 25
C) 30
D) 35
E) 40

6. An object is thrown from the ground with an initial velocity of 100 m/s at an angle of 37º to the horizontal. If its speed at maximum height is v_1, and its speed when it strikes the ground is v_2, what is the ratio v_1 / v_2 ? (Take cos 37º = 0.8; g =10 m/s^2)
A)1/2
B)2/3
C)4/5
D)5/4
E)3/2

Equations of Motion with Constant Acceleration

1. A car starts from rest and accelerates at 1.5 m/s^2. Find its velocity and displacement 10 s later.

2. A train travelling at 54 km/h starts to decelerate at 0.3 m/s^2.
a) How long will it take to stop?
b) What is the stopping distance?

3. The maximum acceleration of a train is given as 0.2 m/s^2.
a) Find the velocity and displacement of the train in 12 s if it starts to speed-up from rest.
b) How long will it take for this train to reach a velocity of 54 km/h if it continues to accelerate at the same rate?

4. The velocity of an object at t=0 is measured as v=25 m/s. Find its speed and displacement at t=10 s
a) if it accelerates uniformly at 1.5 m/s^2.
b) if it decelerates uniformly at 1.5 m/s^2.

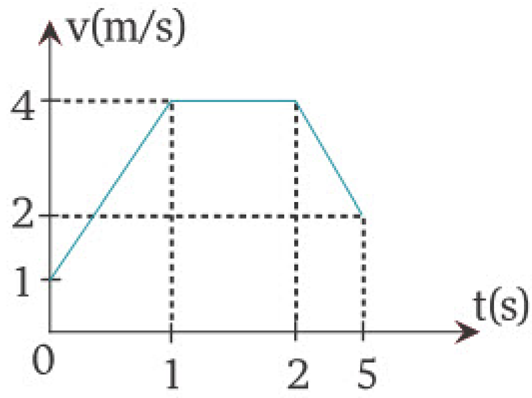
5. A rock rolling down a slope from rest covers a distance of 4 m in the first second. What distance will it cover in 3 s?

6. A car starts from rest and accelerates to 30 m/s in 6 s. What is the displacement of the car during the fourth second? (between t=3 s and t=4 s).

7. When the driver of a car which moves with a velocity of 90 km/h brakes, he can stop in 50 m. Calculate
a) The deceleration of the car
b) The time elapsed before he stops.

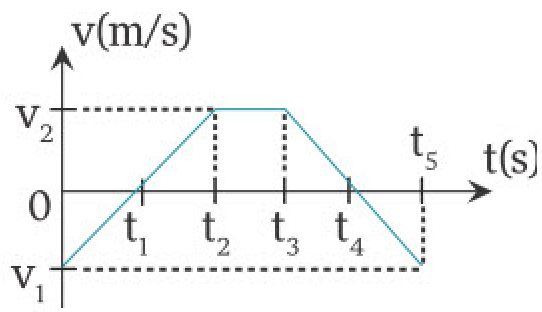
8. In case of an emergency, an automobile moving at a velocity of 75 km/h, stops in 6 seconds. Find the braking distance.

9. The velocity-time graph of an object is given on the right

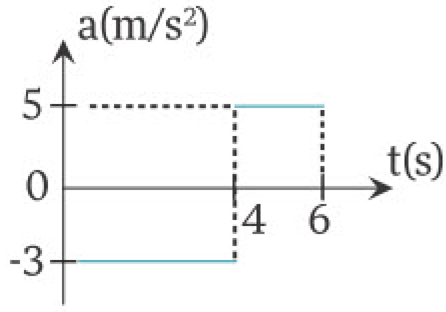


a) How many different accelerations does the object experience in 5 s?
b) Plot its a-t graph.

10. Between which time values in the figure is the object moving in the positive direction?

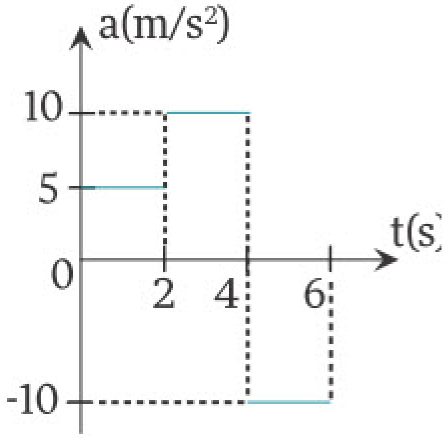


11. The acceleration-time graph for a particle moving along the x-axis is given in the figure.



What is its velocity at t=6 s if its initial velocity is 9 m/s in the positive direction?

12. The figure on the right-hand shows the acceleration - time graph for an object moving on a straight line.

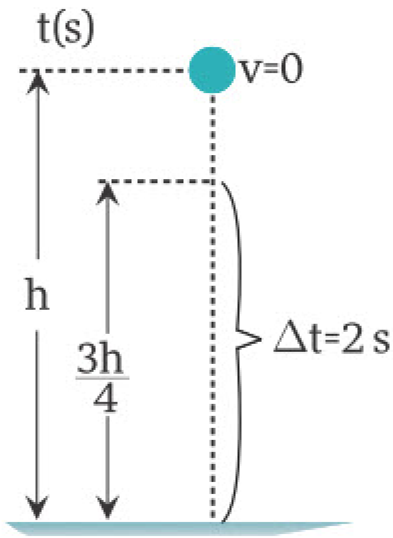


Draw the velocity - time graph
a) Taking v0=0,
b) Taking v0=8 m/s
c) Taking v0=–30 m/s.

Freely Falling Objects

1. An object is thrown vertically downwards from a height, at an initial velocity of 50 m/s. If it strikes the ground at 70 m/s, calculate the initial height of the object from the ground .
2. A stone is thrown upwards at 20 m/s from a bridge 60 m above sea level. Calculate
a) Its total time of the flight.
b) Its velocity just before it strikes the sea.
c) How many metres is the stone above sea level at t=3 s

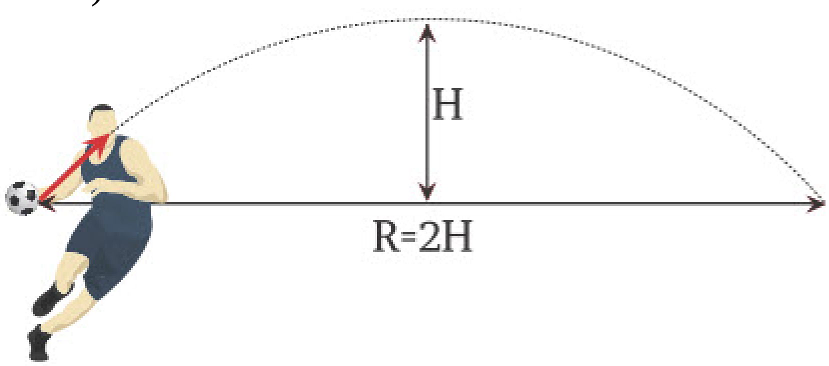
3. If an object which is left to fall freely from a height of h, travels the distance 3h/4 in the last 2 s before striking the ground, from what height was it dropped?



4. Two objects are released from the same height within a time interval of 1 s. How many seconds after the second object is released will the distance between the two objects be 20 m?

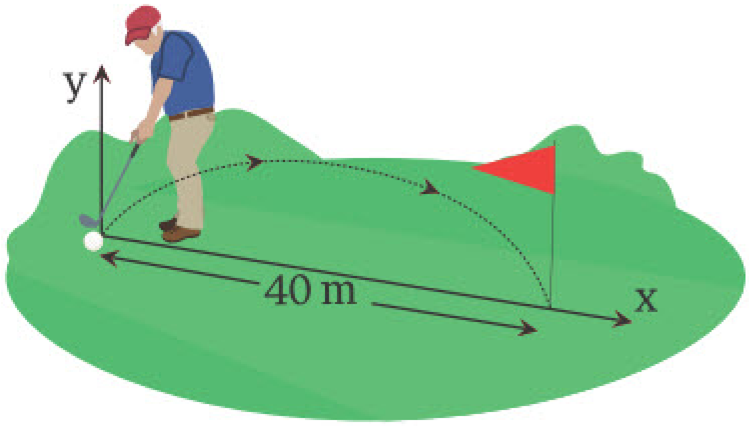
Projectile motion

1. A ball is thrown at an initial velocity of v making an angle with the horizontal. At its maximum height H, the magnitude of its velocity is 15 m/s. The horizontal range R of the ball is twice the maximum height (that is R=2H).



a) For how long is the ball in flight?
b) What is the magnitude and direction of the ball's initial velocity v?

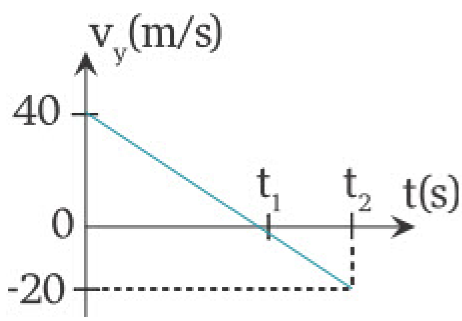
2. All objects in projectile motion achieve a maximum horizontal range when they are projected at 45° to the horizontal (if air resistance is ignored). A golf player strikes a golf ball so that it has a range of 40 m, as shown in the figure.



Find the ball's maximum height.

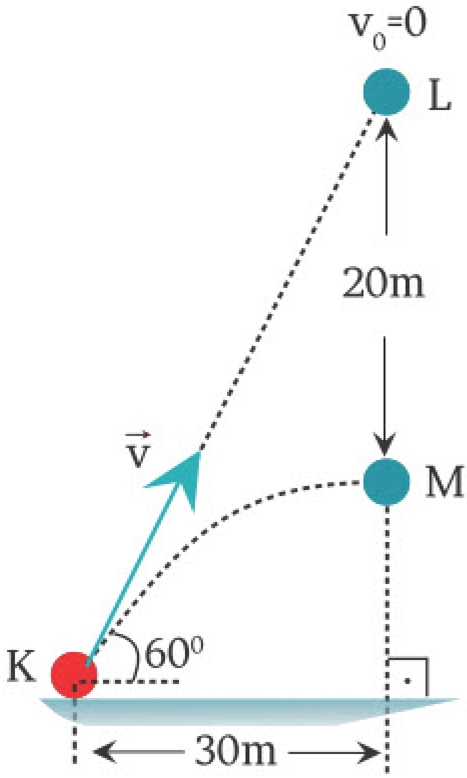
3. Askhat throws a ball at 8 m/s to Altynbek who is 5 m away. Altynbek catches the ball at the same height as Askhat threw it. At what angle did he throw the ball? (Hint: $\sin 2\alpha = 2 \sin\alpha \cos\alpha$)

4. A stone is thrown at an angle of 53° to the horizontal towards a hill. The graph shows how its vertical component of velocity changes in time.



a) Find the time the object is in the air.
b) What is the horizontal distance travelled by the stone?
c) How many metres above the point where it was thrown does the stone land?
5. At the moment a red ball is thrown from point K with a velocity of v, a green ball is released from point L, as shown in the figure. The balls collide at point M. What is the initial velocity v of the red ball?(Note that the red

ball always strikes the green ball regardless of its initial velocity, provided that both are thrown and released at the same time. Can you explain why?).



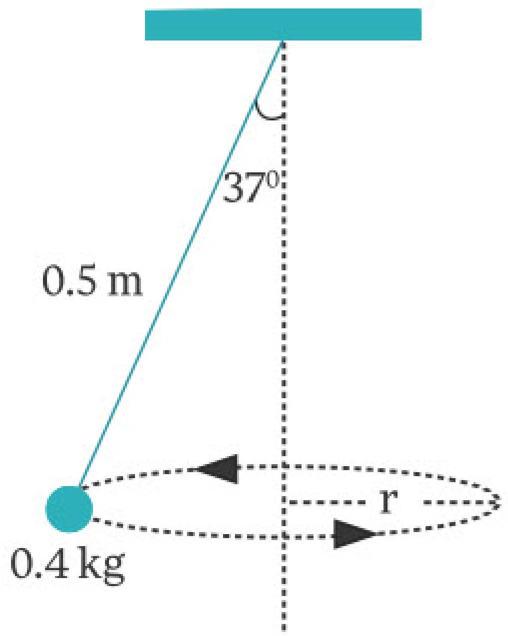
Circular motion

1. If the frequency of the rotor of a helicopter is 1200 cycles/min,

a) calculate the period of its rotor in seconds
b) if the rotor arm is 2.5 m long, find the tangential speed of a point at the far end of the arm. (Take π to be 3.14)

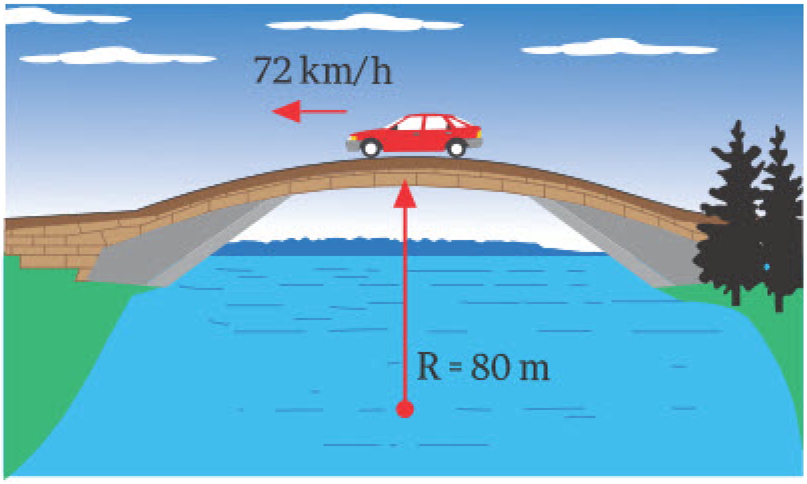
2. The period of the Moon orbiting the Earth is 27.3 days. If the Moon is 384 000 km away from the Earth, calculate its tangential speed. (Take π to be 3.14)

3. A 0.4 kg object attached to the end of a 0.5 m long string is rotated in a horizontal plane at a constant speed as the string makes an angle of 37° with the vertical.



a) Calculate the angular speed of the object.
b) Calculate the centripetal acceleration of the object.
c) Find the tension in the string. (Take g=10 N/kg)

4. A car having a mass of 960 kg, including the mass of the driver, is passing over a curved bridge of radius of curvature 80 m. The car has a constant speed of 72 km/h. What is the apparent weight of the car when it passes the highest point of the bridge, as shown in the figure? Does the driver at this moment feel that he is heavier or lighter?


72 km/h
R = 80 m

CHAPTER 2: FORCE

2.1. Force. Newton's laws of motion.

2.2. Normal Force. Friction force. Addition of forces.

2.3. Law of universal gravitation

2.4. Moment of Inertia of Rigid Body

2.5. Rotational Motion

Labwork 3

Check yourself

2.1 Force. Newton's laws of motion.

You will

- make possible problem-solving algorithms for motion of an object under effect of several forces.

Question

Barbell weighs about 2000 Newton. What is direction and magnitude of the force of an athlete?

a) What is force?

Force is a push or a pull. It can change speed or direction of motion. Force can also change a body’s shape or size.

Force is a vector quantity (it has both magnitude and direction). So, if two or more forces act on a body, we find the net force (or resultant force) by adding them as vectors.

Forces can act by contact or at a distance. Pulling a box, kicking a ball are examples of contact forces (physical contact between two objects). Type of force that does not involve physical contact between two objects is called field force. Examples of this kind of force:

- gravitational force (interaction between the object and Earth’s gravitational field)

- attraction or repulsion between electric charges (charged objects create electromagnetic field)

Diagrams that show force vectors as arrows are called free-body diagrams. A force vector points in the direction of the force, and its length is proportional to the magnitude of the force, Figure 18a , where **N** is reaction force, **T** is tension in the rope and **W** is weight of the object.

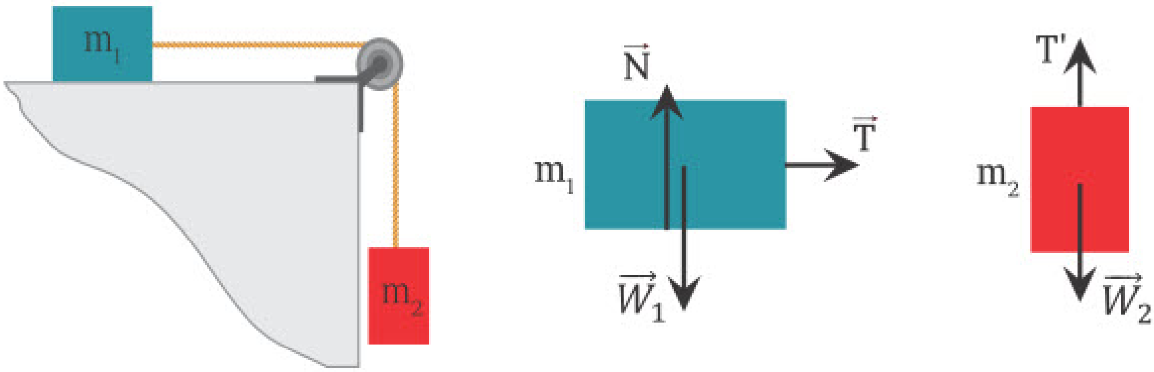


Figure 18a

b) Newton's Laws

Newton’s first law

A body stays at rest or moves with constant velocity, unless an external force makes it behave differently.

This law introduces the concept of inertia, the property of a body which enables it to resist changes in its velocity. Inertia is the natural tendency of an object to remain in its current state of motion. The mass of a body can be defined as a measure of its inertia, a measure of how difficult it is to change its velocity. It is difficult to make a heavy body at rest start moving, but it is equally difficult to stop a heavy body.

Newton’s second law

The acceleration of an object is directly proportional to the net force acting on the object and inversely proportional to the object’s mass.

In equation form, we can state Newton’s second law as

$$\vec{F}_{net} = m\vec{a}$$

F_{net} : vector sum of all forces acting on a body [Newton]

m : mass [kg]

a: acceleration [m/s^2]

Newton’s third law

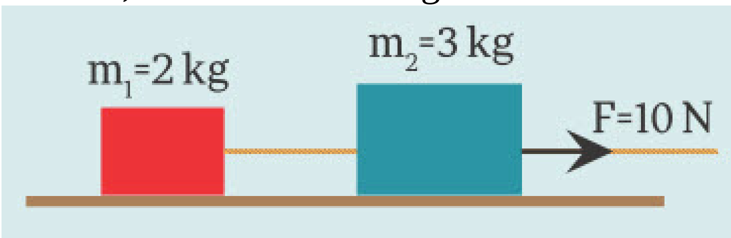
If a body A exerts a force on body B, then body B exerts an equal but opposite force on body A.

Forces never occur singly but always in pairs as a result of the action between two bodies. For example, when you step forward from rest your foot pushes backward on the Earth, and the Earth exerts an equal and opposite force forward on you, Figure 18b.

Figure 18b

Example

Masses m_1=2 kg and m_2=3 kg attached to each other with a string, are moving on a smooth horizontal surface under the effect of a horizontal force of 10 N, as shown in the figure.



a) Determine the acceleration of the system.
b) Determine the value of the tension in the string.

Given:

$m_1 = 2\ kg$

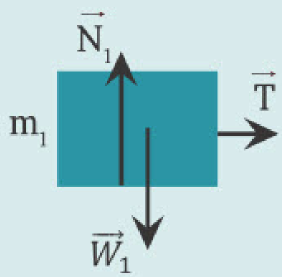
$m_2 = 3\ kg$

$F = 10\ N$

$g = 10\ m/s^2$

Formulas: $\vec{F}_{net} = m\vec{a}$

Calculations:



For vertical direction: $F_{net} = ma$

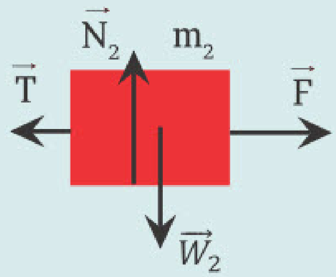
$N_1 - W_1 = ma_y$ ($a_y = 0$ because object does not move in vertical direction)

$N_1 = W_1 = m_1 g = 20$ N

For horizontal direction:

$F_{net} = ma$

$T = m_1 a$



For vertical direction: $F_{net} = ma$

$N_2 - W_2 = ma_y$ ($a_y = 0$ because object does not move in vertical direction)

$N_2 = W_2 = m_2 g = 30$ N

For horizontal direction:

$F_{net} = ma$ $\qquad F - T = m_2 a$

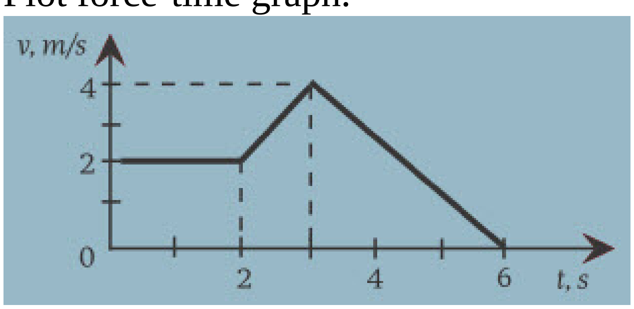
$F = m_2 a + T$ $\qquad F = m_2 a + m_1 a$

$a = \dfrac{F}{m_1 + m_2}$ $\qquad a = \dfrac{10}{2+3}$

$a = 2\ m/s^2$ $\qquad T = 2 \cdot 2 = 4\ N$

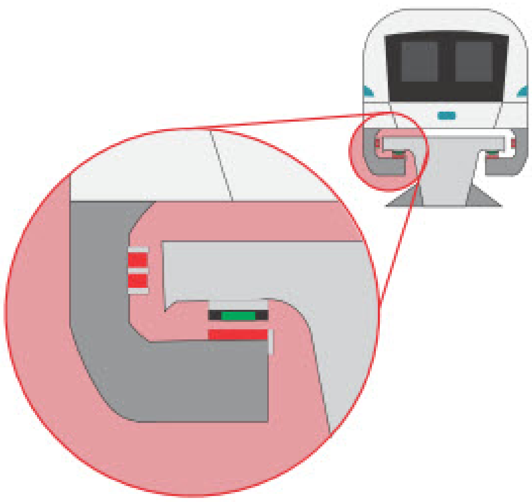
Literacy

1. What is the definition of “inertia”?
2. What is the main idea of Newton’s second law?
3. There is velocity-time graph of an object. Mass of the object is 0.5 kg. Plot force-time graph.



4. A 600 gram object starts to move with 8 m/s^2 acceleration under the effect of two forces of 2 N and 3 N. Calculate angle between these forces.
5. Load of 1 kg is lifted upward with a rope that can withstand 20 N before breaking down. Calculate maximum distance that you can lift this load in 1 sec time.

Activity



Draw free-body diagram for maglev train.

Research time

Imagine that you are carrying a bag of 10 kg. Draw free body diagram for bag and body.

Physics in life

Your weight changes when elevator moves upwards and downwards with acceleration.

Important note

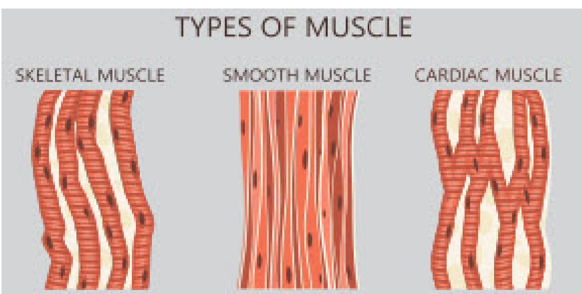
If more than one force is acting on an object, you must find the net force before applying Newton’s second law. The acceleration will be in the direction of the net force.

New mindset

How does Newton's third law work in relationship between people?

Is it true?

If all muscles of human body contract, they can produce force of 250000 Newtons.



2.2 Normal Force. Friction force. Addition of forces

You will

- make possible problem-solving algorithms for motion of an object under effect of several forces.

Question

A car stops better on ice when the wheels keep rolling rather than when they are locked. Why?

Normal force

When two objects are in contact, they exert a force on each other. The normal force is the perpendicular contact force exerted by a surface on another object. The normal force is always perpendicular to the plane of contact between two objects, but is it always equal to the weight of an object?

If object is pulled up a little bit, the normal force exerted by the table on the box is less than the box's weight. Similarly, if you pushed down on the box on the table, the normal force would be more than the box's weight, Figure 19.

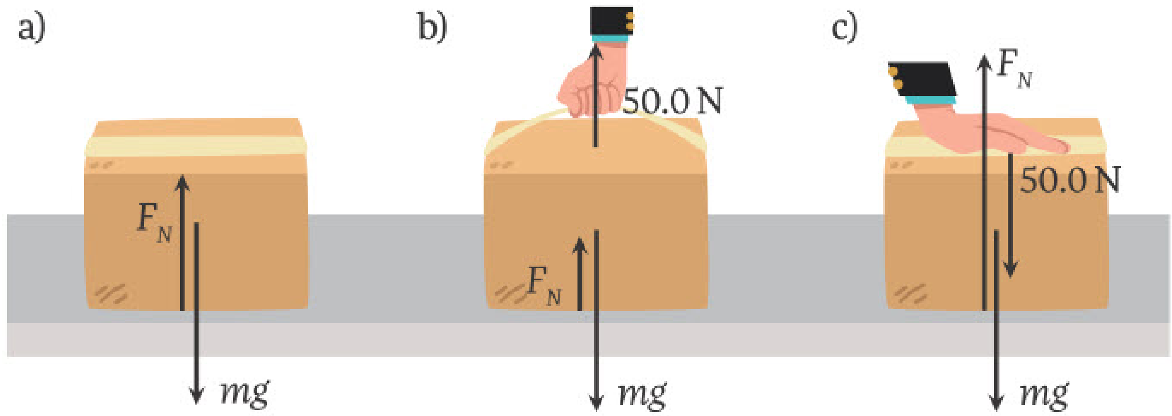


Figure 19

The normal force is always perpendicular to the contact surface but is not always opposite to the direction of gravity force. In the case when object stands on the inclined plane the normal force is perpendicular to the plane, but it is not directly opposite to the gravitational force. The magnitude of the normal force on inclined plane can be calculated as
N = mgcosα, Figure 20.

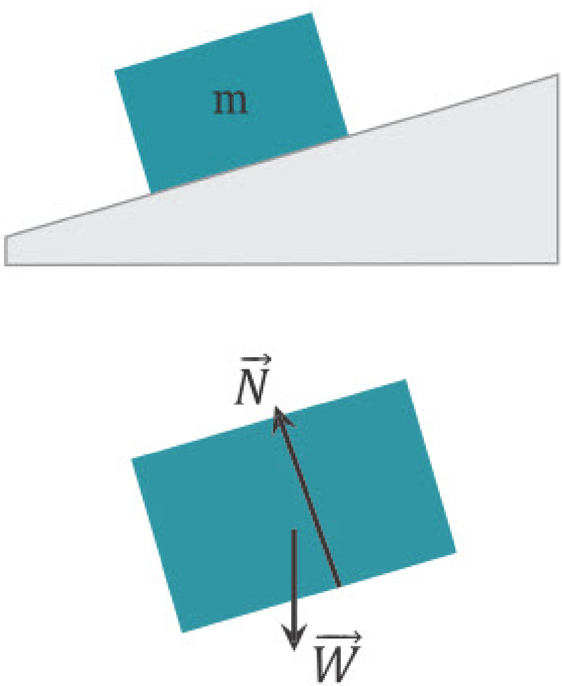


Figure 20

Friction

Friction is a result of the interaction between the atoms of the two surfaces in contact, Figure 21.

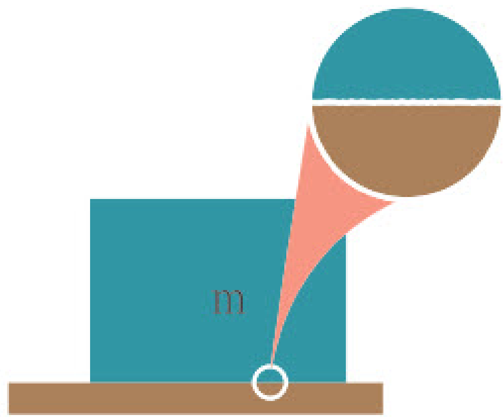
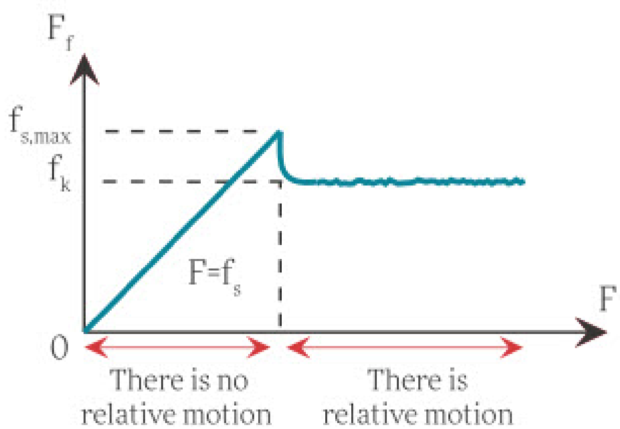


Figure 21

There are two types of frictional force. A static friction exists when you start to move an object from rest. A kinetic friction exists when object is moving. The static frictional force that you must apply to start an object moving is larger than the kinetic frictional force.

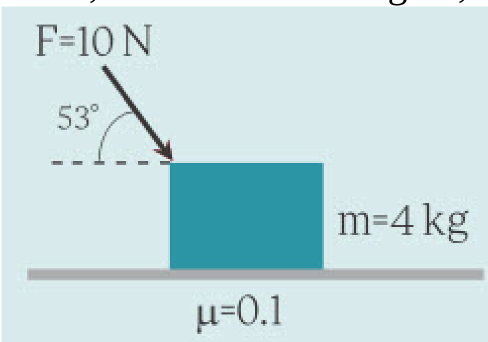


The magnitude of friction force (f) depends on normal force and coefficient of kinetic friction. The coefficient of friction (symbolized by the Greek letter μ), is a scalar value which describes the ratio of the force of friction and the normal force. The coefficient of friction depends on the materials used and ranges from zero to one.

$$f = \mu N$$

Example

A 4 kg block is stationary on a surface. The coefficient of kinetic friction between the block and the surface is 0.1. If a force of 10 N is applied to the block, as shown in the figure,



find

a) the friction force acting on the block,

b) the acceleration gained by the block.

Given:

$m = 4\ kg$

$\mu = 0.1$

$F = 10\ N$

$g = 10\ m/s^2$

$\alpha = 53°$ $(sin\ 53° = 0.8;\ cos\ 53° = 0.6)$

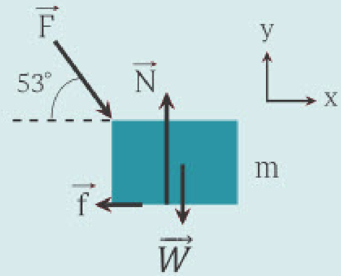
Formulas:

$\vec{F}_{net} = m\vec{a}$

$W = mg$

$f = \mu N$

Calculations:
First we need to divide 10 N force into horizontal and vertical components.



$F_y = F \sin 53°$

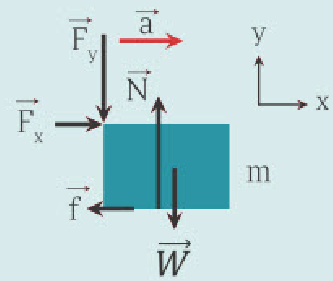
$F_x = F \cos 53°$

For vertical direction:

$F_{net} = ma$

$N - W - F_y = ma_y$ ($a_y = 0$ because object does not move in vertical direction)

$N = W + F_y = mg + F_y$



$N = 4 \cdot 10 + 8 = 48\ N$

For horizontal direction:

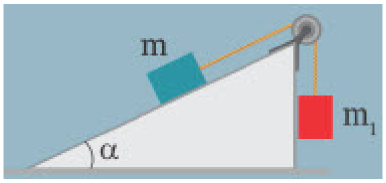
$f = \mu N \qquad f = 0.1 \cdot 48 = 4.8\ N$

$F_{net} = ma \qquad F_x - f = ma \qquad a = \dfrac{F_x - f}{m}$

$a = \dfrac{6 - 4.8}{4} \qquad a = 0.3\ m/s^2$

Literacy

1. Why there is friction force?
2. Why there is elastic force of the spring?
3. An 80 kg person descends on a parachute at 5 m/s. What is the speed of descent of a 40 kg person on the same parachute? Assume that force of resistance of air is proportional to the square of velocity.
4. There are two objects, m=5 kg and m_1=8 kg on an inclined plane that has an angle α=30°. Coefficient of friction between object and inclined plane is 0.2. Calculate tension of the rope, acceleration of objects and force acting on pulley. Masses of pulley and rope are negligibly small.

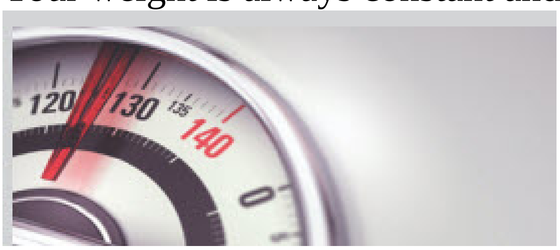


Activity

Make an inclined plane from books and notebooks. Find the coefficient of friction between book and notebook.

Is it true?

Your weight is always constant and does not change on other planets.



Research time

Open "Phet Forces and Motion". Find the friction force acting on an object sliding down from inclined plane.

Physics in life

Suspension bridges such as the Semey Bridge have flexible connectors that sag under its own weight, giving a characteristic curve when the weight is evenly distributed along the length.

2.3 Law of universal gravitation

You will

- explain physical meaning of inertial mass and gravitational mass.
- explain gravitational field and distance graph of point object, explain gravitational potential and distance graph of point object.
- apply Newton's law of universal gravitation in problem solving.

Question

Do lighter objects fall faster than heavier objects? Why?

Newton's law of universal gravitation

If two particles with masses m_1 and m_2 are separated by a distance r, a gravitational force F acts along a line joining them with magnitude given by:

$$F = G\frac{m_1 m_2}{r^2}$$

where G = 6.673×10^{-11} Nm^2/kg^2 is constant of universal gravitation. The gravitational force is always attractive.

From Newton's third law, we know that the force F_{12} exerted by m_1 on m_2, is equal in magnitude but opposite in direction to the force F_{21} exerted by m_2 on m_1, Figure 22.

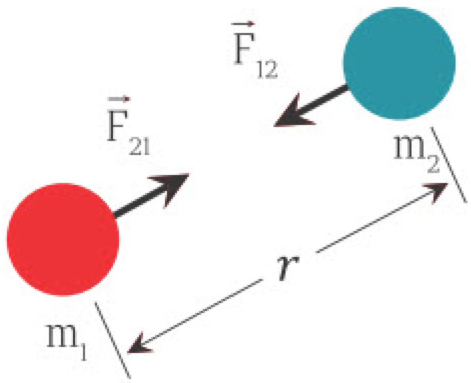


Figure 22

Inertial mass and gravitational mass

Mass is equal to the ratio of the net force exerted on an object to its acceleration. This kind of mass, related to the inertia of an object, is called inertial mass and is represented by the following equation:

$$m_{inertial} = \frac{F_{net}}{a}$$

The inertial mass of an object is a measure of the object's resistance to force.

Newton's law of universal gravitation, $F = Gm_1m_2 /r^2$, involves different kind of mass. This mass determines the magnitude of the gravitational force between two objects and it is called gravitational mass. If you measure the gravitational force exerted on an object by another object of mass m, at a distance r, then you can define the gravitational mass in the following way:

$$m_{grav} = \frac{F_{grav}r^2}{mG}$$

Inertial mass and gravitational mass are equal in magnitude. This principle is called the principle of equivalence.

Gravitational field

The strength of a gravitational field, g, is the force per unit mass on a small test mass placed in that field. g is also known as the “gravitational acceleration” because any object will accelerate towards the centre of a planet with this gravitational acceleration. On the surface of Earth g ≈ 9.81 m/s^2, on the Moon g ≈ 1.6 m/s^2. Gravitational field strength is measured in N/kg and it is calculated by this formula

$$g = \frac{F}{m} = G\frac{M}{r^2}$$

The graph on the Figure 23 shows how g varies with distance from the centre of a large spherical object (planet or star). As you can see, g is inversely proportional to the square of distance, r, from the centre of the planet. However, this is only from the surface of that object (radius of the planet). Inside the planet the gravitational field strength is linearly proportional to distance from the centre of planet.

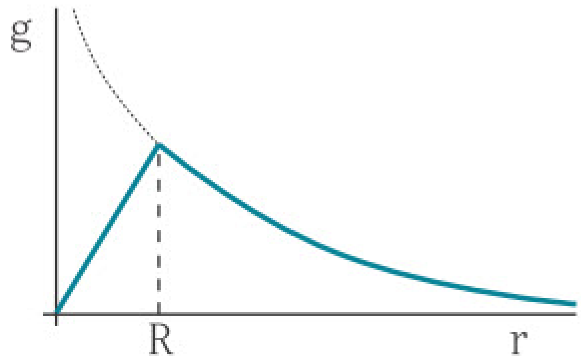


Figure 23

Gravitational potential

The gravitational potential, V, is energy required per unit mass to remove that mass from the gravity field. The formula for the gravitational potential is:

$$\varphi = -G\frac{M}{r}$$

The gravitational potential at an infinite distance from a mass is zero. The negative nature of V shows that gravity is an attractive force and that the system binds masses together and that you need energy to escape the system. The gravitational potential near the Earth is described in the Figure 24.

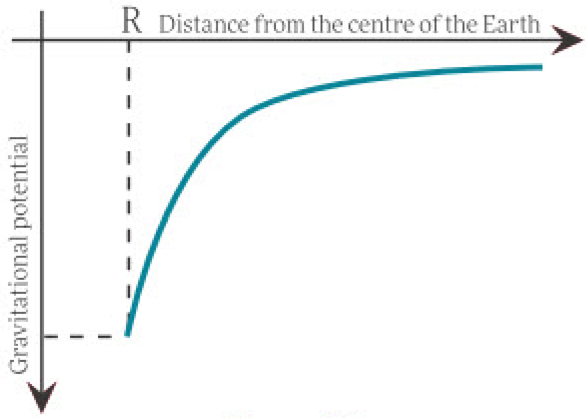
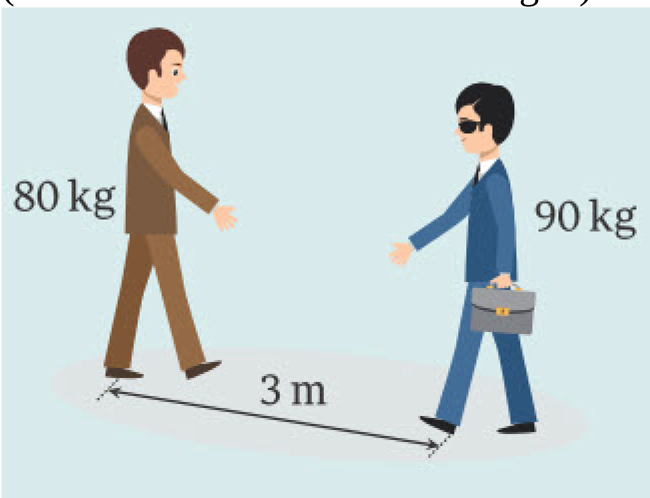


Figure 24

Example

What is the gravitational force acting on two men, one weighing 80 kg and the other weighing 90 kg, who are standing 3 metres away from each other?

(Take $G = 6.673 \times 10^{-11}\ Nm^2/kg^2$)



Given:

m_1=80 kg

m_2=90 kg

$G = 6.673 \times 10^{-11}\ Nm^2/kg^2$

r=3 m

Formulas: $F = G\dfrac{m_1 m_2}{r^2}$

Calculations:

$$F = 6.67 \cdot 10^{-11} \cdot \frac{80 \cdot 90}{3^2}$$

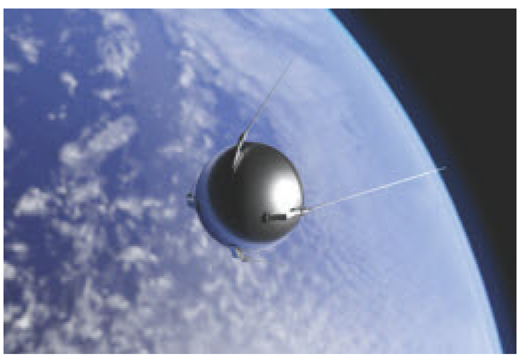
$$F = 5.34 \cdot 10^{-8}\ N$$

$$F = 0.000000054\ N$$

Discussion:

As you can see gravitational force is very small between small masses. So in our daily lives we can neglect gravitational force between objects.

Literacy



1. How does gravitational force change when distance between objects increases twofold?
2. Why do Earth and Sun pull each other?
3. At what height from the surface of the Earth does body fall freely 1 metre in the first second?
4. How would length of year change if mass of the Earth quadruples? How would length of year change if mass of the Sun quadruples?
5. Period of Sputnik-1 launched from Baikonur in 1957 was 96.2 minute. Calculate the height of Sputnik-1 from the surface of the Earth. Assume orbit to be circular.
6. At what depth from the surface of the Earth gravitational field strength will be 8 m/s2? Assume density of Earth to be uniform.

Activity

Imagine that we live in the world without gravity. How would the transportation look like? Draw it.

Is it true?

Distance between Earth and Moon is so small that it is enough for placing all planets in the Solar system between them.

Research time

Even though the gravitational force is same on both objects, why it is the smaller one that tend move to the bigger one?

New mindset

When bamboo is planted, it starts to grow only after 5 years. But on the fifth year it grows 27 metres tall in just 6 weeks. That means to make six week progress there should be five years preparation.

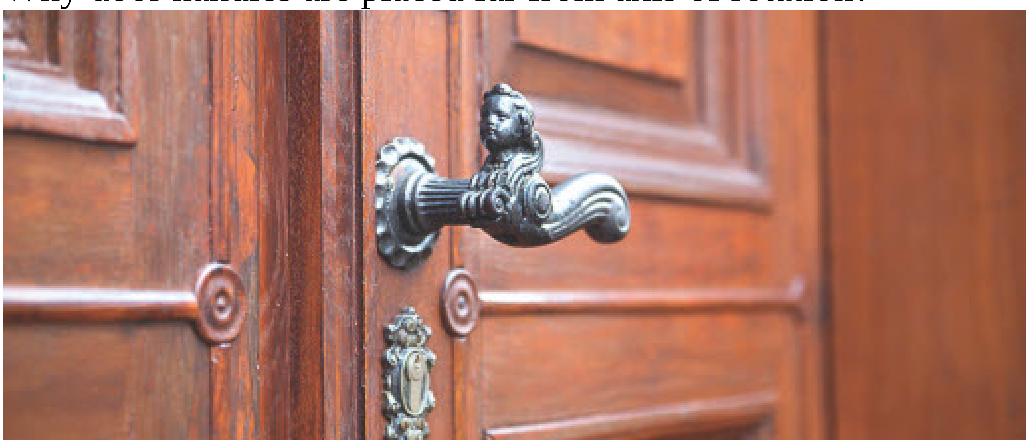
2.4 Moment of inertia of rigid body

You will

- use parallel axis theorem (Huygens–Steiner theorem) for calculation of moments of inertia of bodies.

Question

Why door handles are placed far from axis of rotation?



Moment of inertia is a property of any object which can be rotated. It is a scalar value which tells us how difficult it is to change the rotational velocity of the object around a given rotational axis.

Moment of inertia in rotational motion is similar to mass in linear motion. The rotational inertia depends on mass and on the distribution of that mass relative to the axis of rotation.

Moment of inertia is represented by the symbol I and has unit kg . m2. For a point object located at a distance r from the axis of rotation, the moment of inertia is given by the following equation.

$$I = mr^2$$

For most objects, whose mass is distributed continuously moment of inertia is less than mr^2. The moment of inertia also depends on the location of the rotational axis. Moments of inertia of different objects are shown on the Figure 25.

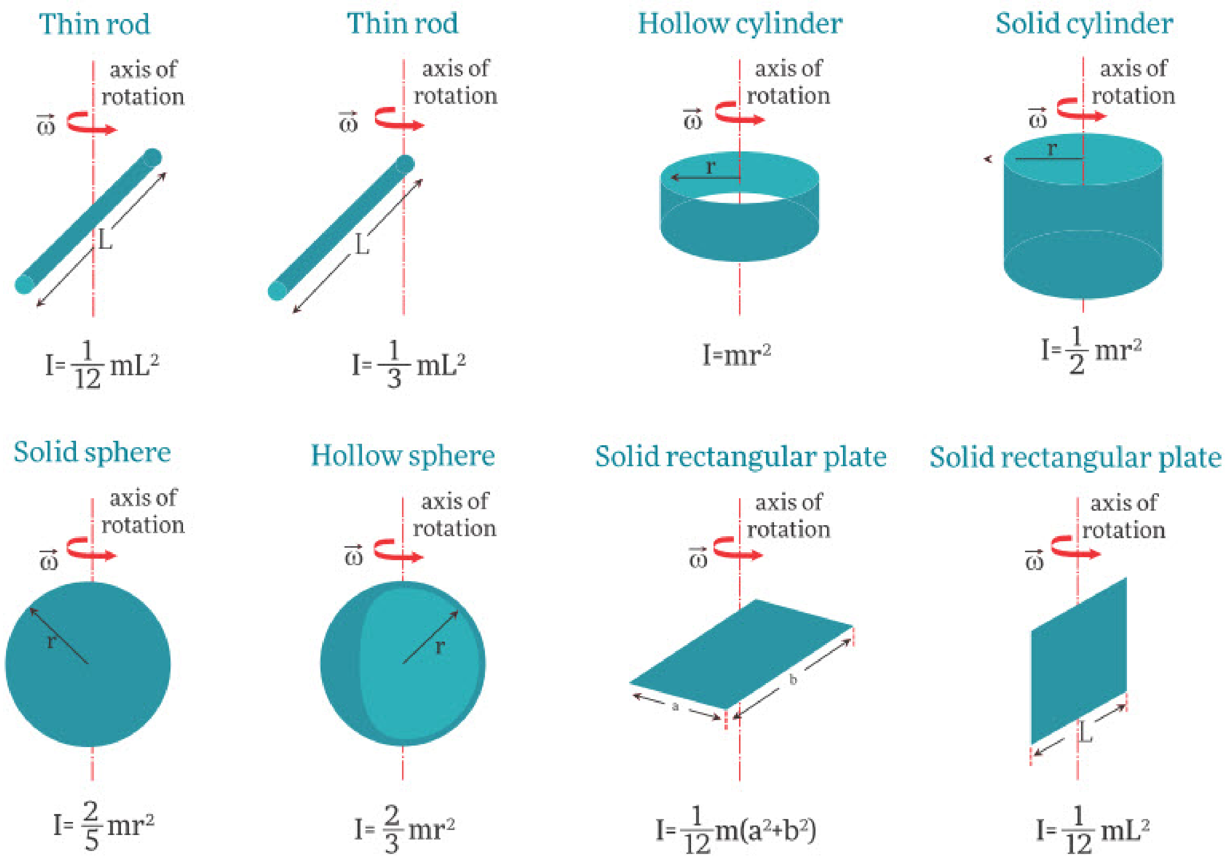


Figure 25

Suppose we want to find the rotational inertia of a body of mass m about any rotational axis. ICM is the rotational inertia of the body about axis that extends through the body's centre of mass. Let r be the perpendicular distance between the given axis and the axis through the centre of mass, which must be parallel, Figure 26.

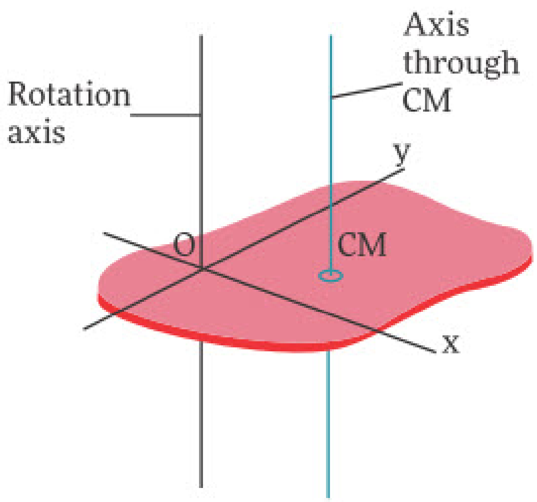


Figure 26

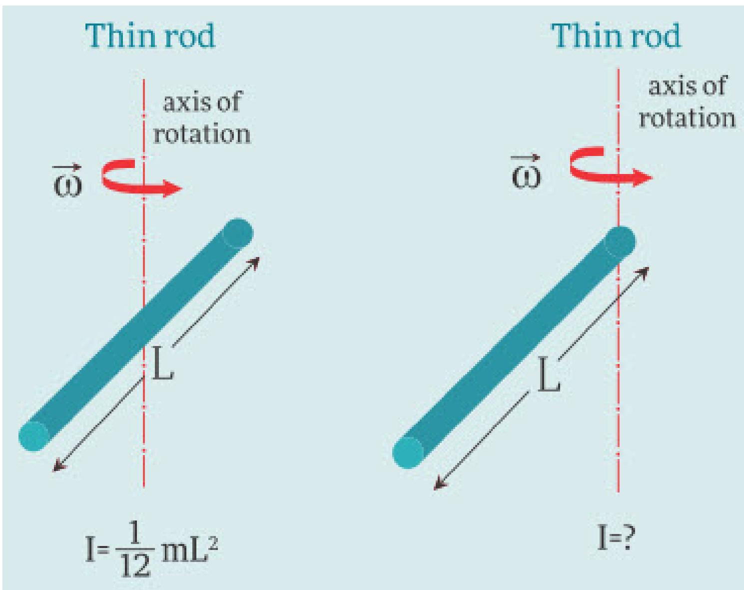
Then the rotational inertia I about the given axis is:

$$I = I_{CM} + mr^2$$

This equation is known as the parallel-axis theorem (or Huygens-Steiner theorem).

Example

Moment of inertia of rod about centre of rod is $I_{CM}=1/12\times ml^2$.



Determine moment of inertia of rod about end of rod. Mass of rod is 1 kg, length of rod is 50 cm.

Given:

$m = 1\ kg$

$l = 50\ cm = 0.5\ m$

$r = \frac{l}{2} = 0.25\ m$

Formulas:

$I_{CM} = \frac{1}{12} ml^2$

$I = I_{CM} + mr^2$

Calculations:

$I = \frac{1}{12} \cdot 1 \cdot 0.5^2 + 1 \cdot 0.25^2$

$I = 0.083\ kg \cdot m^2$

Discussion:

As you can see, moment of inertia increases. That means it becomes harder to rotate the rod.

Activity

Sit in the revolving chair and hold heavy objects in your outstretched hands (dumbbells). Start revolving and then put objects near your chest. What does happen? Why? Explain it by using moment of inertia.

Literacy

1. What is definition of “moment of inertia”?
2. Which object is harder to rotate, object that has large moment of inertia or object that has small moment of inertia?

3. Sphere has mass of 2 kg and radius of 20 cm. Calculate moment of inertia of sphere if distance between axis of rotation and centre of mass of sphere is 60 cm.
4. Calculate moment of inertia of physical pendulum that consists of rod (length of 50 cm and mass of 3 kg) and sphere (radius of 10 cm and mass of 8 kg) attached to each other. Axis of rotation is the end of the rod.
5. Moment of inertia of solid cylinder is 0.0225 kg . m^2. Radius of cylinder is 10 cm and its mass is 3 kg. Calculate distance between centre of cylinder and axis of rotation.
6. How would moment of inertia of iron disk (20 cm radius and 5 cm length) change if it is melted and shaped into solid sphere?

Activity

Find the moment of inertia of your bag.

Is it true?

You rotate faster on the chair if you bend your legs.

Important note

Moment of inertia is analogous to mass, but there are major differences. Mass is an inherent property of an object. The moment of inertia of an object depends on the shape of the object, its mass, and the choice of axis of rotation.

Research time

Why do ropewalkers use long rods? Explain your answer by using moment of inertia.

Physics in life

We use long wrenches to make rotation easy.

2.5 Rotational motion

You will

- apply equation of rotational motion for problem solving.
- draw an analogy between physical quantities of translational motion and rotational motion.

Question

Why do figure skaters open their arms and legs widely, and then pull them in?

Equation of rotational motion

Torque is a turning action on a body about a rotation axis due to force . Torque causes rotation of a rigid body. Torque is calculated by formula

$$\tau = Fr\sin\alpha$$

where is the angle between   and . Here we want to derive the Newton's 2nd law for rotational motion.

$$\vec{F} = m\,\vec{a}; \qquad Fr = mar;$$

Since,

$$a = \varepsilon r,$$

$$Fr = mr^2\varepsilon$$

For torque:

$$\tau = Fr\sin\alpha:$$

$$\tau = mr^2\varepsilon; \qquad \tau = I\varepsilon;$$

If more than one force is applied to the particle:

$$\tau_{net} = I\varepsilon$$

Angular momentum

The angular velocity of a rotating object changes only if torque is applied to it. This is a statement of Newton's 2nd law for rotational motion. This equation can be rewritten in the same way as Newton's second law of motion:

$$\tau = I\frac{\Delta\omega}{\Delta t}; \qquad \tau\Delta t = I\Delta\omega;$$

The left side of this equation, , is the angular impulse of the rotating object. The right side can be rewritten as . The product of a rotating object's moment of inertia and angular velocity is called angular momentum and it is represented by the symbol L.

$$L = I\omega$$

The angular impulse on the object is equal to the change in the object's angular momentum, which is called the angular impulse-angular momentum theorem.

$$\tau\Delta t = L - L_0$$

Conservation of angular momentum

Like linear momentum, angular momentum can be conserved. The law of conservation of angular momentum states that if no net external torque acts on an object, then its angular momentum does not change.

$$L = L_0$$
$$I_0\omega_0 = I\omega$$

A spinning ice-skater demonstrates conservation of angular momentum, Figure 27. When she pulls her arms in, she begins spinning faster. By pulling arms close to body, the ice-skater brings more mass closer to the axis of rotation. Therefore, decreasing the moment of inertia causes increasing of angular velocity.

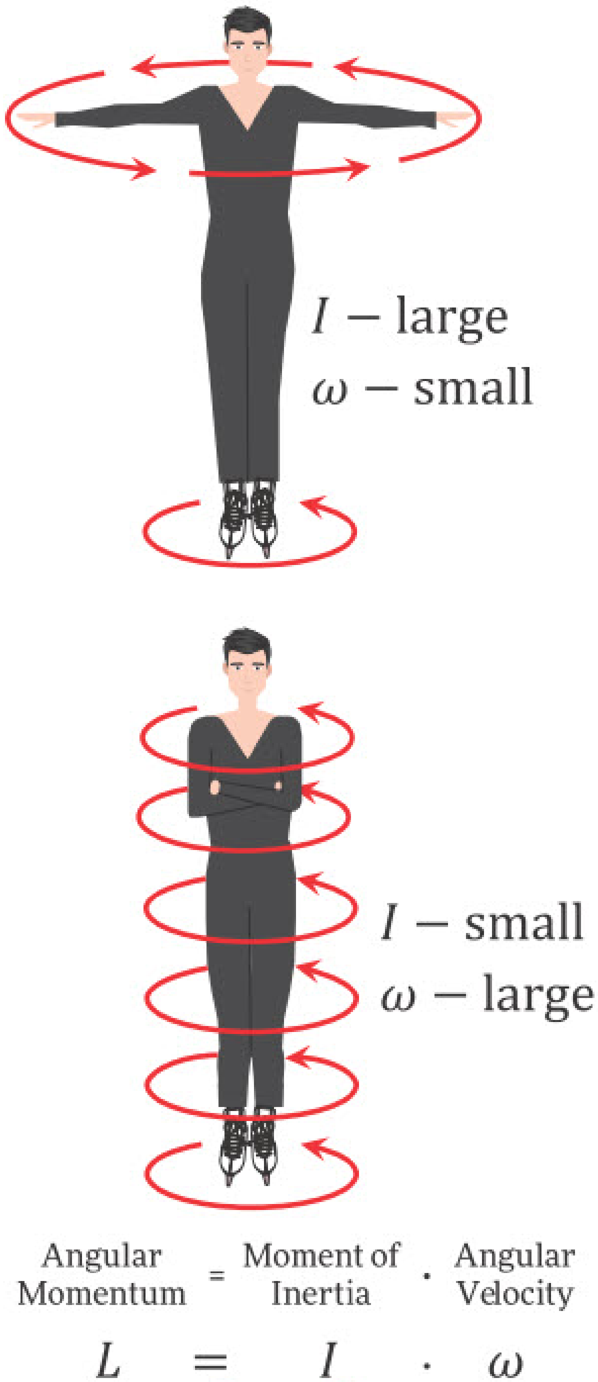


Figure 27

The analogy between quantities of linear and rotational motion is given in Table 1.

Linear motion		Rotational motion	
Velocity	$\vec{v} = \vec{s}/t$	Angular velocity	$\omega = \alpha/t$
Acceleration	$\vec{a} = \Delta\vec{v}/t$	Angular acceleration	$\vec{\varepsilon} = \Delta\vec{\omega}/t$
Mass	m	Rotational inertia	I
Newton's 2nd law	$\vec{F} = m\vec{a}$	Newton's 2nd law	$\vec{\tau} = I\vec{\varepsilon}$
Kinetic energy	$E_k = mv^2/2$	Kinetic energy	$E_k = I\omega^2/2$
Power	$P = \vec{F} \cdot \vec{v}$	Power	$P = \vec{\tau} \cdot \vec{\omega}$
Linear momentum	$\vec{p} = m\vec{v}$	Angular momentum	$\vec{L} = I\vec{\omega}$

Table 1

Example

Person pushes a merry-go-round with a force of 200 N. Radius of the 40 kg merry-go-round is 2 metres. Calculate the angular acceleration and frequency after 5 sec. The merry-go-round is a uniform disk. Neglect friction.

Given:

$F = 200\ N$
$m = 40\ kg$
$r = 2\ m$
$t = 5\ s$
$\omega_0 = 0$

Formulas:

$\tau_{net} = Fr \sin\alpha$
$\tau_{net} = r \cdot F$
$\tau_{net} = I\varepsilon$
$I = \frac{1}{2}mr^2$
$\omega = \omega_0 + \varepsilon t$
$\omega = 2\pi f$

Calculations:

$$\varepsilon = \frac{r \cdot F}{\frac{1}{2}mr^2} = \frac{2F}{mr}$$

$$\varepsilon = \frac{2 \cdot 200}{40 \cdot 2} = 5\ rad/s^2$$

$$f = \frac{\omega}{2\pi} = \frac{\varepsilon t}{2\pi} = \frac{\frac{2F}{mr}t}{2\pi} = \frac{Ft}{\pi mr}$$

$$f = \frac{Ft}{\pi mr} = \frac{200 \cdot 5}{3.14 \cdot 40 \cdot 2} = 3.98\ Hz$$

Discussion:
As you can see, frequency is large. Why? That is because we neglected friction.

Activity

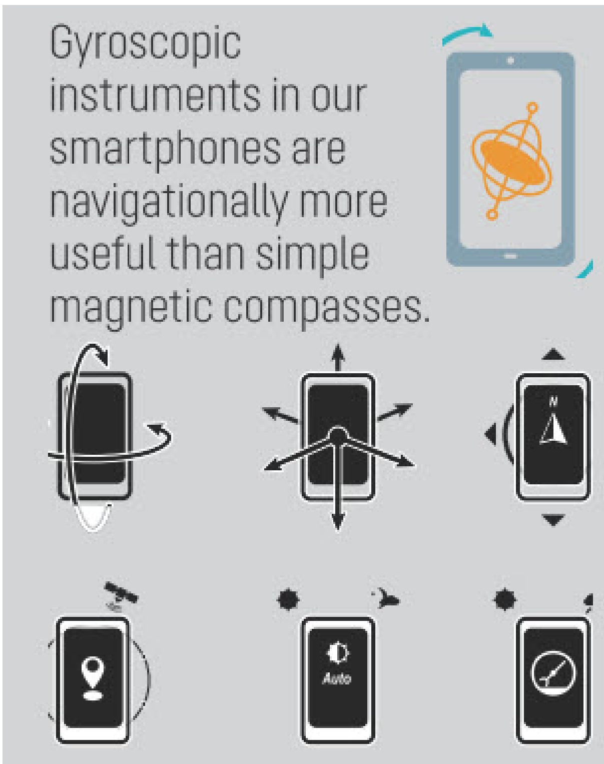
Draw a 10 cm × 10 cm box. Divide into 4 boxes. Into the first, write the word “Angular momentum”. Into the second, write your own definition. Into the third, draw a picture that resembles the word. Into the fourth, write a translation in your native language.

Word: Angular momentum	Your own definition:
Picture:	Translation:

Research time

Open "Physics Aviary Circular Acceleration". How much force must be applied by the engine to increase the speed of a 1 ton car from 5 m/s to 10 m/s? Does it depend on radius?

Is it true?



Physics in life

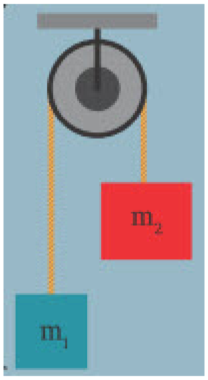
When you lean right on bicycle, you will also turn right. This is because of changing angular momentum.

Career

Sailors use gyroscopes to navigate in oceans.

Literacy

1. What is angular momentum?
2. Why does angular momentum conserve?
3. Disk that has moment of inertia of 63.6 kg . m^2 is rotating with angular speed of 31.4 rad/sec. Calculate torque that stops disk in 20 sec.
4. Force of 100 Newton is applied to the edge of a disk that has 0.5 metre radius and 50 kg mass. Calculate angular acceleration of disk and time after which disk will rotate at 100 rev/sec.
5. What is the acceleration of objects m_1=100 gram and m_2=110 gram if mass of the pulley is 400 grams? Assume pulley is solid cylinder.



6. A 2 kg disk is rolling on horizontal surface with speed of 4 m/s. Calculate kinetic energy of rotational motion, kinetic energy of translational motion, and total kinetic energy.

LAB WORK #3

Title:

Motion of rigid body on inclined plane

You will

-determine the moment of inertia of the body through an experiment.

Equipment:

Safety glasses, gloves, tripod, measuring tape, ball, inclined gutter (trough).

Theory:

The moment of inertia I of a body is a measure of how hard it is to get it rotating about some axis.

To determine the moment of inertia we use conservation of energy and equations of motion.

Energy of ball at points A and B is same.

$$E_A = E_B$$

$$mgh = \frac{mv^2}{2} + \frac{I\omega^2}{2}$$

$$\omega = \frac{v}{R}$$

$$I = mR^2\left(\frac{2gh}{v^2} - 1\right)$$

$$v = \frac{l}{t}$$

$$H = \frac{1}{2}gt^2$$

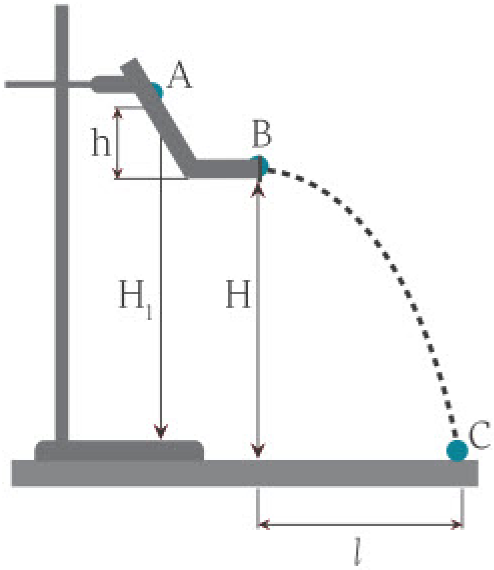
$$t = \sqrt{\frac{2H}{g}}$$

$$v = l \cdot \sqrt{\frac{2H}{g}}$$

$$v^2 = l^2 \cdot \frac{2H}{g}$$

$$I = mR^2 \left(\frac{4hH}{l^2} - 1\right)$$

№	$h(m)$	$H(m)$	$l(m)$	$R(m)$	$m(kg)$	$I(kg \cdot m^2)$
1						
2						
3						
4						
5						
6						



Procedure:

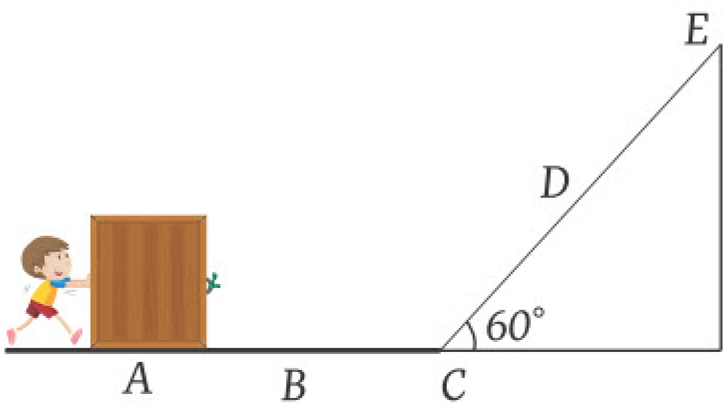
1. Put ball in point A and measure H1.
2. Release ball and mark point C.
3. Measure and H.
4. Measure R and m.
5. Calculate I.
6. Put ball at different height and repeat steps 1-5 five more times.
7. Calculate Iaverage and absolute and relative error.

Conclusion:

1. Compare experimental and theoretical values of moment of inertia. Are they same or different? Why?

CHECK YOURSELF

Boy starts to push 20 kg crate that is initially at rest with force of 100 Newton. Coefficient of friction on the horizontal surface and inclined plane is 0.3. Distance AC is 10 metre, distance CE is 8 metre. Use figure to answer questions 1-25.



1. What is normal contact force in interval AC?

A) 60 N

B) 100 N

C) 200 N

D) 333.33 N

E) 666.66 N

2. What is normal contact force in interval CE?

A) 60 N

B) 100 N

C) 200 N

D) 333.33 N

E) 666.66 N

3. What is friction force in interval AC?

A) 173.21 N

B) 200 N

C) 100 N

D) 60 N

E) 30 N

4. What is friction force in interval CE?

A) 173.21 N

B) 200 N

C) 100 N

D) 60 N

E) 30 N

5. What is absolute value of acceleration of crate between points A and C?

A) 1 m/s^2

B) 2 m/s^2

C) 3 m/s^2

D) 4 m/s^2

E) 5 m/s^2

6. What is absolute value of acceleration of crate between points C and E?

A) 6.16 m/s^2

B) 5.16 m/s^2

C) 4.16 m/s^2

D) 3.16 m/s^2

E) 2.16 m/s^2

7. What is velocity of crate at point A?

A) 0

B) 4.32 m/s

C) 5.32 m/s

D) 6.32 m/s

E) 7.32 m/s

8. What is velocity of crate when it passes point C first time?

A) 0

B) 4.32 m/s

C) 5.32 m/s

D) 6.32 m/s

E) 7.32 m/s

9. What is velocity of crate at point B that is located 4 metre away from point A?

A) 5 m/s

B) 4 m/s

C) 3 m/s

D) 2 m/s

E) 1 m/s

10. How long does crate travel from point A to point B?

A) 5 s

B) 4 s

C) 3 s

D) 2 s

E) 1 s

11. How long does crate travel from point B to point C?

A) 1.16 s

B) 2.16 s

C) 0.16 s

D) 1 s

E) 0.5 s

12. How long does crate travel from point C to point E?

A) 1 s

B) 2 s

C) 3 s

D) 4 s

E) There is no right answer

13. Point D is the farthest point on the inclined that crate can reach. What is distance CD?

A) 1.88 m

B) 2.88 m

C) 3.88 m

D) 4.88 m

E) 5.88 m

14. How long does crate travel from point C to point D?

A) 0.226 s

B) 1.226 s

C) 2.226 s

D) 3.226 s

E) 4.226 s

15. What is velocity of crate at point D?

A) 6.32 m/s

B) 4.32 m/s

C) 2.32 m/s

D) 0.32 m/s

E) 0

16. What is velocity of crate when it comes to point C second time?

A) 6.09 m/s

B) 4.09 m/s

C) 2.09 m/s

D) 0.09 m/s

E) 0

17. How far away from point C is the crate when its velocity becomes zero third time?

A) 0.046 m

B) 1.046 m

C) 2.046 m

D) 3.046 m

E) 4.046 m

18. What is absolute value of acceleration of crate after it passes point C second time?

A) 8 m/s^2

B) 6 m/s^2

C) 4 m/s^2

D) 2 m/s^2

E) 0

19. How many seconds do pass from the start of motion when velocity of crate becomes zero third time?

A) 2.79 s

B) 4.79 s

C) 6.79 s

D) 0.79 s

E) 0

20. What should be minimum force of the boy so that crate reaches point E?

A) 153.28 N

B) 143.28 N

C) 133.28 N

D) 123.28 N

E) 113.28 N

21. What should be force of the boy so that crate travels at constant speed on interval AC?

A) 20 N

B) 30 N

C) 40 N

D) 50 N

E) 60 N

22. What should be force of the boy so that crate travels at constant speed on interval CE?

A) 173.21 N

B) 203.21 N

C) 233.21 N

D) 143.21 N

E) 263.21 N

23. Boy pushes with such force that crate travels at constant speed on interval CE. How long does crate travel from point A to point E?

A) 0.34 s

B) 1.34 s

C) 2.34 s

D) 3.34 s

E) 4.34 s

24. Boy pushes with such force that crate travels at constant speed on interval CE. What is the acceleration of crate on interval AC?

A) 7.161 m/s^2

B) 5.161 m/s^2

C) 3.161 m/s^2

D) 1.161 m/s^2

E) 9.161 m/s^2

25. Boy pushes with such force that crate travels at constant speed on interval CE. What is the velocity of crate at point E?

A) 9.97 m/s

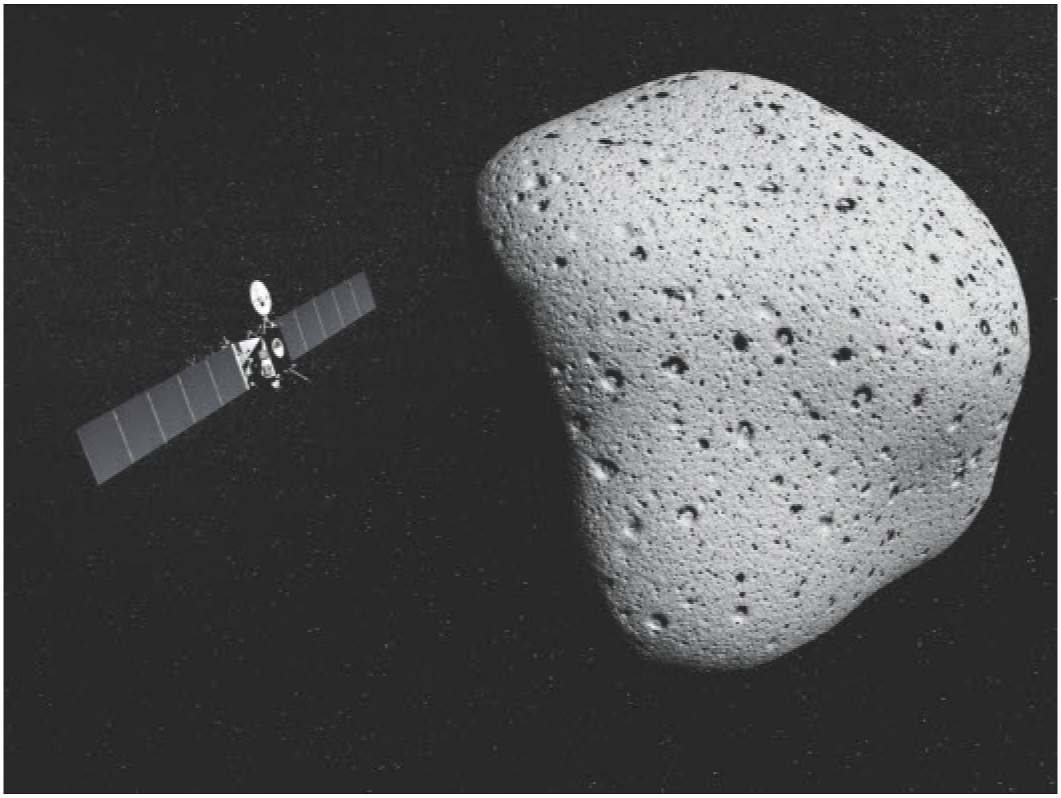
B) 10.97 m/s

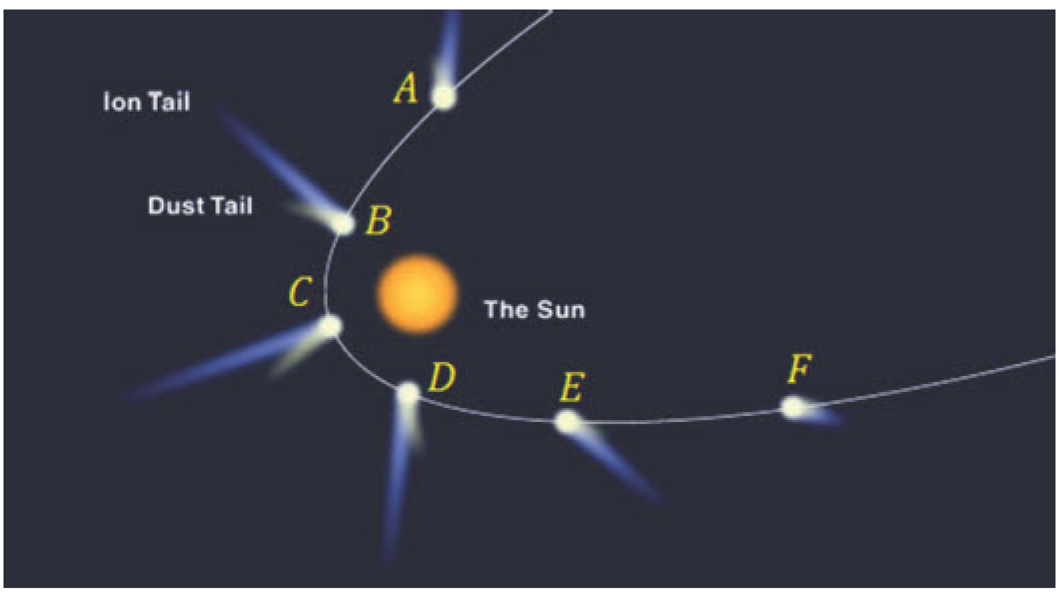
C) 11.97 m/s

D) 12.97 m/s

E) 13.97 m/s

Comet named as Churyumov-Gerasimenko was discovered in 1969 in Fesenkov Astrophysical Institute (aphi.kz) in Almaty. Between 2004 and 2016 Rosetta spacecraft (rosetta.esa.int) was used to study this comet and in 2014 lander module Philae landed on a comet. Maximum velocity of comet is 38 km/s, mass of comet is 10^{13} kg, volume of comet is 18.7 km^3. Perihelion is 186 million km, aphelion is 849.7 million km. Mass of Sun is 2×10^{30} kg. Assume comet to be sphere. Use this data and figures to answer questions 26-55.




Ion Tail
A
Dust Tail
B
C
The Sun
D
E
F

Point	Distance from Sun (metre)
A	4.21E+11
B	2.16E+11
C	1.86E+11
D	2.07E+11
E	4.08E+11
F	8.12E+11

26. At which point gravitational force between the comet and the Sun is the greatest?

A) F

B) A

C) C

D) D

E) Aphelion

27. At which point gravitational force between the comet and the Sun is the smallest?

A) F

B) A

C) C

D) D

E) Aphelion

28. What is the gravitational force between the comet and the Sun at the point A?

A) $4.54 \cdot 10^{9}$ N

B) $5.54 \cdot 10^{9}$ N

C) $6.54 \cdot 10^{9}$ N

D) $7.54 \cdot 10^{9}$ N

E) $8.54 \cdot 10^{9}$ N

29. What is the gravitational force between the comet and the Sun at the point B?

A) $0.87 \cdot 10^{10}$ N

B) $1.87 \cdot 10^{10}$ N

C) $2.87 \cdot 10^{10}$ N

D) $3.87 \cdot 10^{10}$ N

E) $4.87 \cdot 10^{10}$ N

30. What is the gravitational force between the comet and the Sun at the point C?

A) $4.86 \cdot 10^{10}$ N

B) $3.86 \cdot 10^{10}$ N

C) $2.86 \cdot 10^{10}$ N

D) $1.86 \cdot 10^{10}$ N

E) $0.86 \cdot 10^{10}$ N

31. What is the gravitational force between the comet and the Sun at the point D?

A) $1.12 \cdot 10^{10}$ N

B) $2.12 \cdot 10^{10}$ N

C) $3.12 \cdot 10^{10}$ N

D) $4.12 \cdot 10^{10}$ N

E) $5.12 \cdot 10^{10}$ N

32. What is the gravitational force between the comet and the Sun at the point E?

A) $6.02 \cdot 10^{9}$ N

B) $9.02 \cdot 10^{9}$ N

C) $8.02 \cdot 10^{9}$ N

D) $7.02 \cdot 10^{9}$ N

E) $5.02 \cdot 10^9$ N

33. What is the gravitational force between the comet and the Sun at the point F?

A) $4.02 \cdot 10^9$ N

B) $3.02 \cdot 10^9$ N

C) $2.02 \cdot 10^9$ N

D) $1.02 \cdot 10^9$ N

E) $0.02 \cdot 10^9$ N

34. What is the gravitational force between the comet and the Sun at the aphelion? Aphelion is the point of greatest distance between the Sun and body.

A) $1.85 \cdot 10^9$ N

B) $2.85 \cdot 10^9$ N

C) $3.85 \cdot 10^9$ N

D) $4.85 \cdot 10^9$ N

E) $5.85 \cdot 10^9$ N

35. At which point speed of the comet is the highest?

A) A

B) B

C) C

D) D

E) E

36. At which point speed of the comet is the lowest?

A) A

B) B

C) C

D) D

E) E

37. What is the speed of the comet at the point A?

A) 16798 m/s

B) 14798 m/s

C) 12798 m/s

D) 10798 m/s

E) 8798 m/s

38. What is the speed of the comet at the point B?

A) 12789 m/s

B) 22789 m/s

C) 32789 m/s

D) 42789 m/s

E) 52789 m/s

39. What is the speed of the comet at the point C?

A) 58000 m/s

B) 48000 m/s

C) 18000 m/s

D) 28000 m/s

E) 38000 m/s

40. What is the speed of the comet at the point D?

A) 34180 m/s

B) 24180 m/s

C) 14180 m/s

D) 54180 m/s

E) 44180 m/s

41. What is the speed of the comet at the point E?

A) 17327 m/s

B) 27327 m/s

C) 37327 m/s

D) 47327 m/s

E) 57327 m/s

42. What is the speed of the comet at the point F?

A) 8703 m/s

B) 9703 m/s

C) 10703 m/s

D) 11703 m/s

E) 12703 m/s

43. What is the speed of the comet at the aphelion?

A) 12318 m/s

B) 11318 m/s

C) 10318 m/s

D) 9318 m/s

E) 8318 m/s

44. What is radius of the comet? Assume comet to be sphere.

A) 647 m

B) 1647 m

C) 2647 m

D) 3647 m

E) 4647 m

45. What is gravitational acceleration on the surface of the comet?

A) $5.46 \cdot 10^{-4}$ m/s^2

B) $4.46 \cdot 10^{-4}$ m/s^2

C) $3.46 \cdot 10^{-4}$ m/s^2

D) $2.46 \cdot 10^{-4}$ m/s^2

E) $1.46 \cdot 10^{-4}$ m/s^2

46. What is ratio of the gravitational acceleration of the Earth (10 m/s^2) and gravitational acceleration of the comet?

A) 10650

B) 20650

C) 30650

D) 40650

E) 50650

47. What is the moment of inertia of the comet?

A) $1.085 \cdot 10^{19}$ kg·m2

B) $2.085 \cdot 10^{19}$ kg·m2

C) $3.085 \cdot 10^{19}$ kg·m2

D) $4.085 \cdot 10^{19}$ kg·m2

E) $5.085 \cdot 10^{19}$ kg·m2

48. Period of rotation of the comet is 12.4 hours. What is angular speed of rotation of the comet?

A) $1.407 \cdot 10^{-4}$ rad/s

B) $2.407 \cdot 10^{-4}$ rad/s

C) $3.407 \cdot 10^{-4}$ rad/s

D) $4.407 \cdot 10^{-4}$ rad/s

E) $5.407 \cdot 10^{-4}$ rad/s

49. What is the angular momentum of the comet?

A) $1.527 \cdot 10^{15}$ kg·m^2/s

B) $2.527 \cdot 10^{15}$ kg·m^2/s

C) $3.527 \cdot 10^{15}$ kg·m^2/s

D) $4.527 \cdot 10^{15}$ kg·m^2/s

E) $5.527 \cdot 10^{15}$ kg·m^2/s

50. Let's say you are astronaut on the surface of this comet. At what speed should you jump to become satellite of this comet?

A) 4.636 m/s

B) 3.636 m/s

C) 2.636 m/s

D) 1.636 m/s

E) 0.636 m/s

51. Let's say you are astronaut on the surface of this comet. You jump and become satellite of this comet. What is your orbiting period?

A) 8.51 hours

B) 7.51 hours

C) 6.51 hours

D) 5.51 hours

E) 4.51 hours

52. Let's say you are astronaut on the surface of this comet. At what speed should you jump to escape comet (never return to comet)?

A) 4.9 m/s

B) 3.9 m/s

C) 2.9 m/s

D) 1.9 m/s

E) 0.9 m/s

53. Is comet lighter than water or heavier than water?

A) It is lighter than water

B) It is heavier than water

C) It is same as water

D) It is impossible to determine

E) There is no right answer

54. What is density of comet?

A) 1534.76 kg/m^3

B) 2534.76 kg/m^3

C) 3534.76 kg/m^3

D) 4534.76 kg/m^3

E) 534.76 kg/m^3

55. What is angular momentum of the comet relative to the Sun?

A) 7.068·1028 kg·m^2/s

B) 6.068·1028 kg·m^2/s

C) 5.068·1028 kg·m^2/s

D) 4.068·1028 kg·m^2/s

E) 3.068·1028 kg·m^2/s

1. Which of the following statements concerning the concept of force is/are correct?

I. Forces can be added as an algebraic sum.

II. Force can make an object at rest move or change their shape

III. By changing one of the properties of a force, such as the direction, the line of action, the magnitude or the application point, the force changes.

A) I only

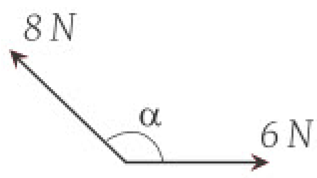
B) II only

C) III only

D) II and III

E) I, II and III

2. Which one of the following cannot be the magnitude of the resultant of two forces with magnitudes of 8 N and 6 N, as shown in the figure? (90<a<180)



A) 3 N

B) 4 N

C) 6 N

D) 8 N

E) 12 N

3. Which one of the following could be the minimum value of the magnitude of the resultant of three vectors of magnitudes 5 N, 10 N and 13 N in the same plane, in newtons?

A) 0

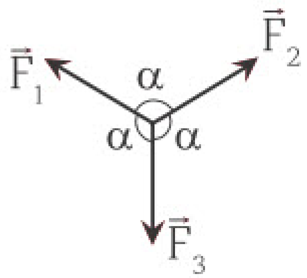
B) 1

C) 2

D) 3

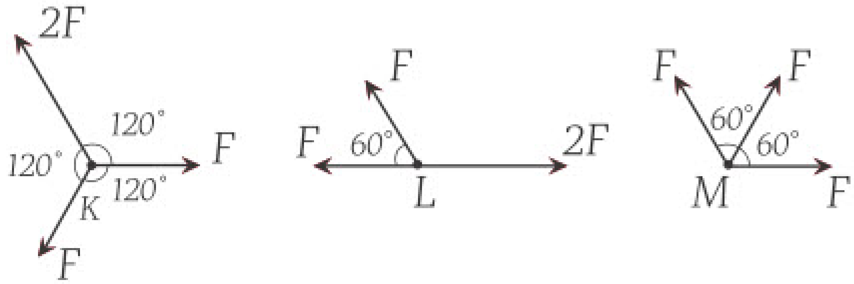
E) 5

4. Forces F_1, F_2 and F_3 lying in the same plane are applied at the same point, as shown in the figure. If the resultant of the forces is zero, which of the following does $F_1+F_2-F_3$ equal?



A) 0 B) $\mathbf{F_1}/2$ C) $\mathbf{F_2}$ D) $2\mathbf{F_3}$ E) $-2\mathbf{F_3}$

5. The magnitudes of the resultants of the forces lying in the same plane applied at the points K, L and M, as shown in the figure, are R_K, R_L and R_M, respectively. What is the relationship between R_K, R_L and R_M?



A) $R_M>R_L>R_K$

B) $R_K=R_L=R_M$

C) $R_K=R_L>R_M$

D) $R_M>R_K=R_L$

E) $R_K=R_M>R_L$

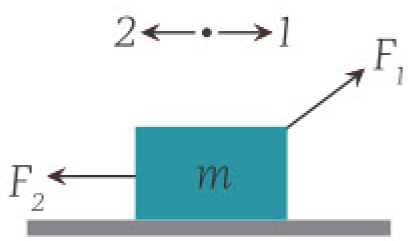
Laws of Motion

1. The forces F_1 and F_2 are applied on an object at rest on a horizontal, frictionless surface, as shown in the figure. Which of the following statements may be correct?

I. The object moves in direction 1.

II. The object moves in direction 2.

III. The object doesn't move.



A) I only

B) II only

C) III only

D) I and II

E) I, II and III

2. A constant force of 10 N is applied to an object of mass 2 kg at rest on a frictionless horizontal plane, as in the figure. After how many seconds will the velocity of the object be 40 m/s?

A) 5

B) 6

C) 7

D) 8

E) 9

3. The forces of 4 N and 8 N are applied to an object of mass 2 kg placed on a horizontal frictionless plane, as shown in the figure. What is the acceleration of the body, in m/s^2?

A) 1

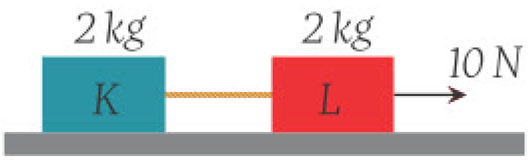
B) 2

C) 3

D) 4

E) 5

4. A force of 10 N is applied to objects K and L of mass 2 kg placed on a horizontal frictionless plane. Objects K and L are connected to each other by a rope of negligible mass, as shown in the figure.How many seconds later does the velocity of objects K and L become 30 m/s?



A) 8

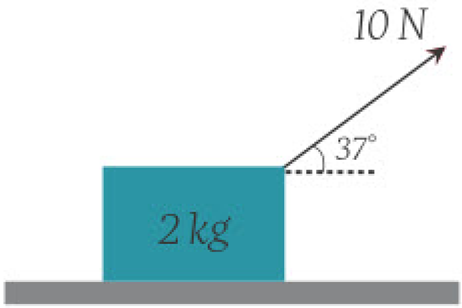
B) 10

C) 12

D) 14

E) 16

5. A force of 10 N acts on an object of mass 2 kg placed on a horizontal frictionless plane, as shown in the figure. After how many seconds does the object reach a velocity of 20 m/s? (Take sin 37°=0.6; cos 37°=0.8)



A) 1

B) 2

C) 3

D) 4

E) 5

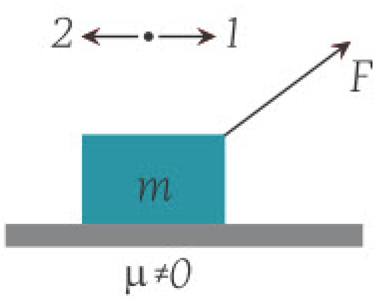
Motion on Surfaces with Friction

1. A force F is applied to an object of mass m placed on a rough horizontal plane, as shown in the figure. If there is friction between the horizontal plane and the object, which of the following statements may be correct?

I. The object doesn't move.

II. The object moves in direction 1.

III. The object moves in direction 2.



A) I only

B) II only

C) III only

D) I and II

E) I and III

2. The forces of 5 N and 10 N are applied to object K placed on a horizontal frictionless plane, as shown in Figure-I. A force of 10 N is applied to object L placed on a rough horizontal surface, as shown in Figure-II. The coefficient of friction between the horizontal plane and object L is 0.1. What is the ratio of the accelerations of the objects, a_K/a_L? (Take g=10 N/kg)

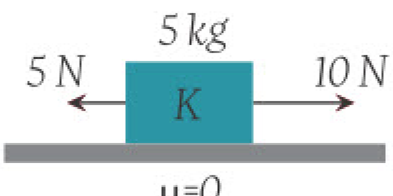


Figure-I

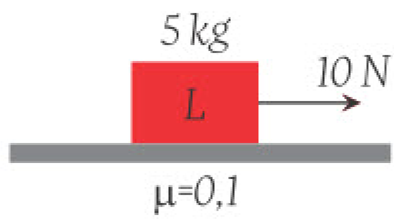


Figure-II

A) 4/5

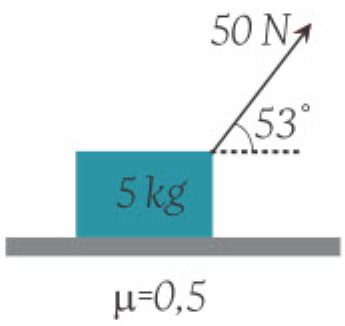
B) 1

C) 3/2

D) 3

E) 4

3. A 50 N force is applied to an object of mass 5 kg, as shown in the figure. If the coefficient of friction between the object and the horizontal plane is 0.5, what is the acceleration of the object, in m/s^2?



(Take g=10 N/kg, sin 53º=0.8; cos 53º=0.6)

A) 3

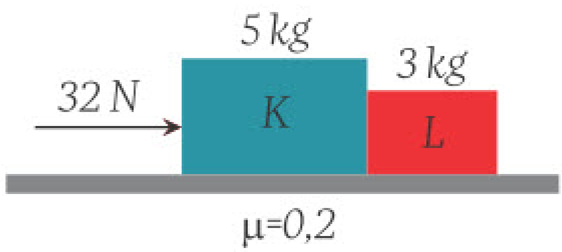
B) 4

C) 5

D) 6

E) 7

4. A 32 N force acts on the objects K and L of mass 5 kg and 3 kg, as shown in the figure.Coefficient of friction between the horizontal plane and objects K and L is 0.2. What is the magnitude of the reaction force applied by object L on object K, in Newtons? (Take g=10 N/kg)



A) 2

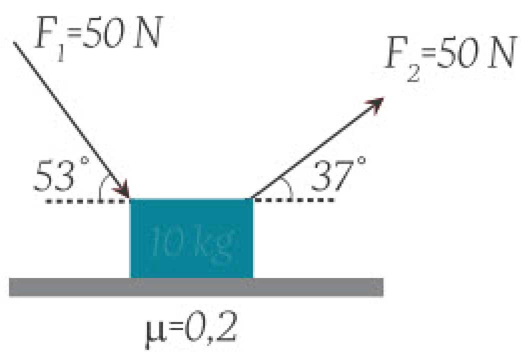
B) 3

C) 6

D) 12

E) 15

5. The forces F_1 and F_2 of 50N act on an object of mass 10 kg placed on a rough horizontal plane, as shown in the figure. The coefficient of friction between the object and the horizontal plane is 0.2. Which of the following statements is/are correct?



I. The acceleration of the object is 4.8 m/s2

II. If the force F_1 is removed, the friction force acting on the object decreases.

III. If the force F_2 is removed, the acceleration of the object decreases.

A) I only

B) II only

C) III only

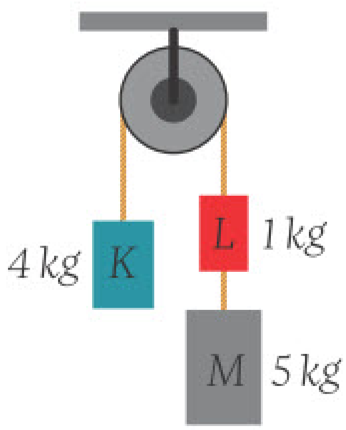
D) I and II

E) I, II and III

System of blocks and inclined plane

1. The frictionless system consisting of objects K, L and M, as shown in the figure is allowed to move freely. If after a while, the rope connecting L and M snaps, how does L continue its motion?

(Take g=10 N/kg)



A) Decelerates and stops.

B) Continues moving with constant speed

C) Decelerates, stops and then accelerates in the opposite direction

D) Accelerates, decelerates and stops

E) Decelerates and carries on moving with constant speed.

2. When a force F is applied to objects K and L on a frictionless surface, separately, object K has an acceleration of a and object L has an acceleration of 2a. If the same force is applied to the objects K and L

simultaneously, what is the acceleration of the system of objects K and L, in terms of a?

A)1/2

B)2/3

C)3/4

D)4/3

E)5/6

3. A 2 N friction force acts on an object of mass 1 kg moving under the action of a force F, as shown in Figure I. The velocity-time graph of the object is as shown in Figure-II.

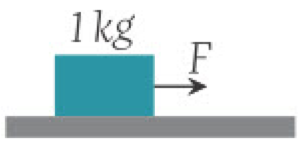


Figure-I

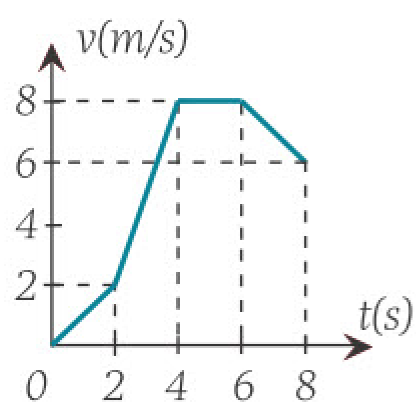


Figure-II

What is the ratio of the maximum value of the force to the minimum value of the force in the interval 0-8 s?

A) 1

B) 2

C) 3

D) 4

E) 5

4. The dynamometer in a lift at rest indicates the weight of a child as 600 N. If the lift accelerates vertically upwards at 2 m/s^2, what is the weight of the child, indicated by the dynamometer, in newtons? (Take g=10 N/kg)

A) 480

B) 500

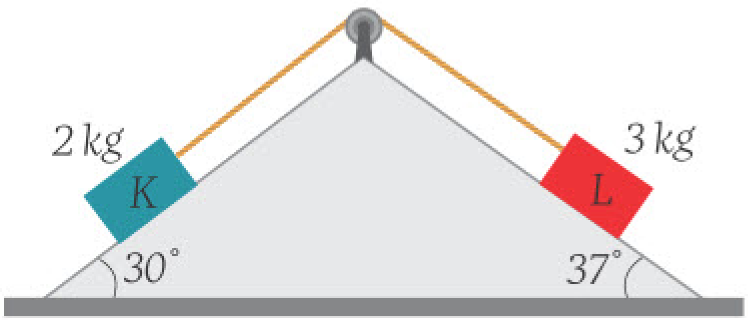
C) 620

D) 720

E) 780

5. A frictionless system composed of objects of mass 2 kg and 3 kg, as shown in the figure is allowed to move freely. What is the acceleration of the system, in m/s^2?

(Take g=10 N/kg; sin30°=0.5; sin37°=0.6)



A) 4/5

B) 8/5

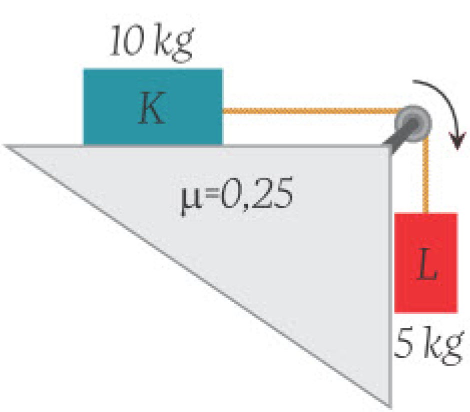
C) 5/3

D) 3

E) 4

6. In the figure, the coefficient of friction between an object of mass 10 kg and the horizontal plane is 0.25. When the system is allowed to move freely, it starts moving in the direction of the arrow.

In order for the system to move at constant speed, what must the value of a mass placed on object K be, in kilograms? (Take g=10 N/kg)



A) 10

B) 12

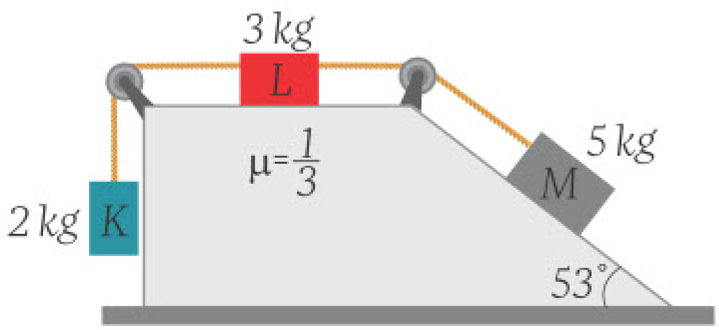
C) 15

D) 18

E) 20

7. In the figure, the coefficient of friction between object L and the horizontal plane is 1/3 and the coefficient of friction between object M and the inclined plane is ignored. When the system is allowed to move freely, what is the tension force in the string between objects L and M, in newtons?

(Take g=10 N/kg; sin 53°=0.8; cos 53°=0.6)



A) 20

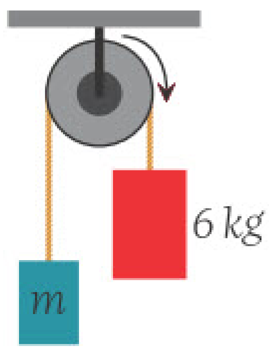
B) 25

C) 30

D) 35

E) 40

8. The frictionless system shown in the figure moves in the direction of the arrow when it is released from rest. If the string endures 48 N of tension, what may the maximum value of mass m be, in kilograms? (Take g=10 N/kg)



A) 2

B) 3

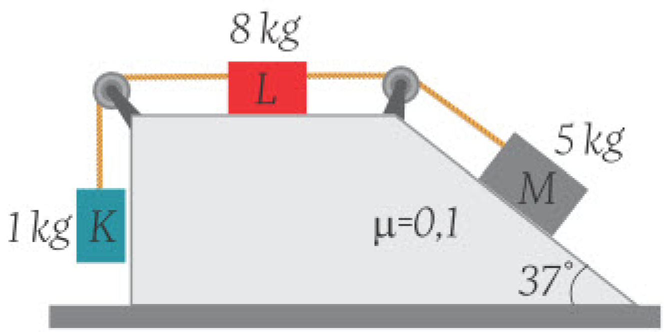
C) 4

D) 5

E) 6

9. The coefficient of friction between M and the inclined plane is 0.1. If the system is allowed to move freely object L gains an acceleration of 1 m/s2. What is the coefficient of friction between object L and the horizontal plane?

(Take g=10 N/kg, sin 37°=0.6; cos 37°=0.8)



A) 1/40

B) 1/30

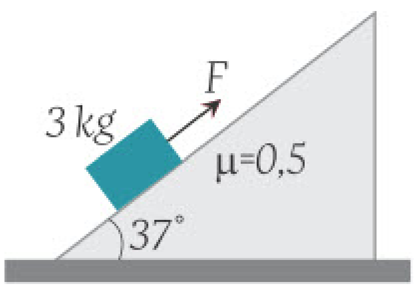
C) 1/20

D) 1/15

E) 3/40

10. An object of 3 kg is pulled by a force F at a constant speed upwards on the inclined plane shown in the figure. If the coefficient of friction between the object and the inclined plane is 0.5, what is force F, in newtons?

(Take g=10 N/kg; sin 37°=0.6; cos 37°=0.8)



A) 10

B) 15

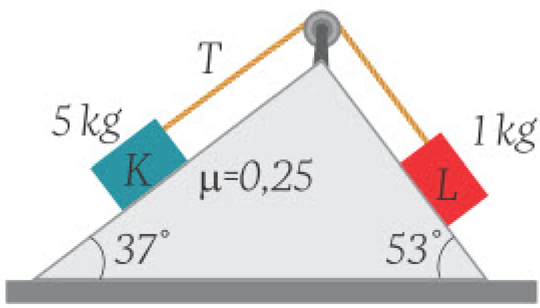
C) 20

D) 25

E) 30

11. In the system shown in the figure, the coefficient of friction between object K and the inclined plane is 0.25 and object L is on a smooth, frictionless inclined plane. If the system is allowed to move freely, what is the tension force in the rope, in newtons?

(Take g=10 N/kg, sin 53°=cos 37°=0.8; cos 53°=sin 37°=0.6)



A) 5

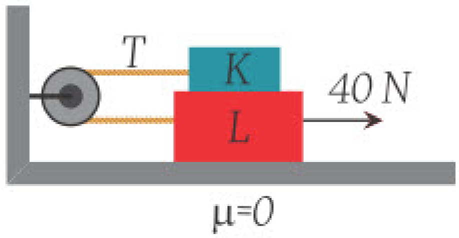
B) 10

C) 15

D) 20

E) 25

12. In the system formed by the objects K and L, the coefficient of friction between K and L is 0.1, there is no friction between object L and the horizontal plane. The system moves with the aid of a 40 N force applied on object L, as shown in the figure.



If m_K=5 kg and m_L=10 kg, what is the tension force in the rope, in newtons? (Take g=10 N/kg)

A) 5

B) 10

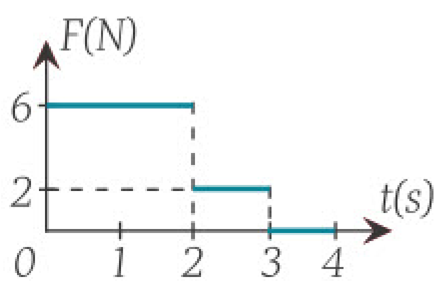
C) 15

D) 20

E) 25

General Problems

1. The force applied on an object of 1 kg which is initially at rest placed on a horizontal rough surface changes with time, as shown in the graph.



If the surface has a constant friction force of 2 N, what is the velocity of the object, in m/s, after 4 s? (Take g=10 N/kg)

A) 6

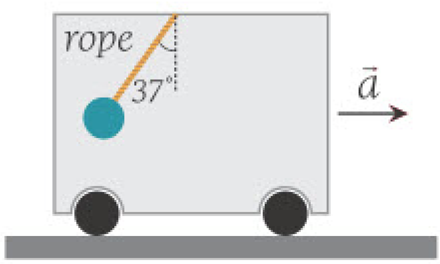
B) 8

C) 10

D) 12

E) 14

2. An object is attached by a string to the ceiling of a vehicle. When the vehicle moves with an acceleration the string makes an angle of 37° with the vertical axis.



What is the acceleration of the vehicle in terms of g?

(Take sin 37°=0.6; cos 37°=0.8)

A)1/3

B)1/2

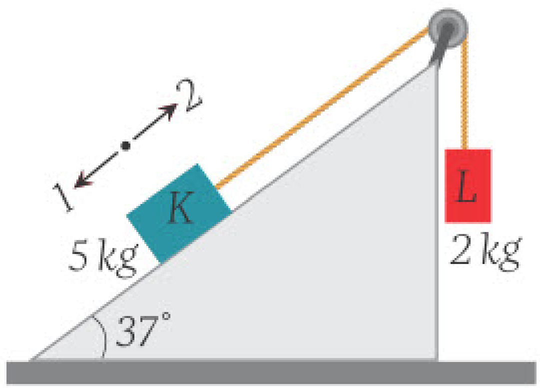
C)3/4

D) 1

E)4/3

3. The objects K and L, in the system shown in the figure, move with constant speed.What is the direction of motion and the coefficient of friction between object K and the inclined plane?

(Take g=10 N/kg, sin 37°=0.6; cos 37°=0.8)



A) 1, 1/4 B) 1, 1/2 C) 2, 1/4 D) 2, 1/2 E) 1, 2/3

4. Which of the following statements related to the friction force must be true?

I. Moving objects decelerate and then stop when they travel on a rough surface.

II. Moving objects continue their motion with constant speed on a rough surface.

III. Friction forces cannot make stationary objects move.

A) I only

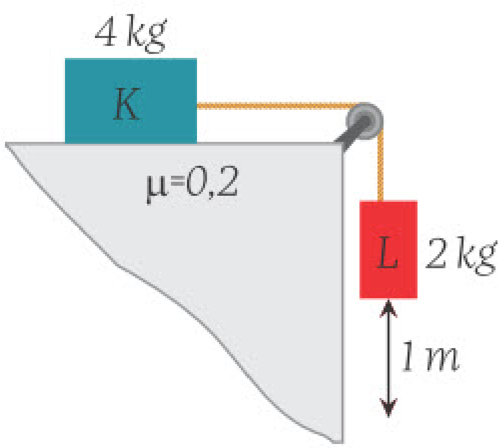
B) II only

C) III only

D) II and III

E) I, II and III

5. In the system shown in the figure, consisting of objects K and L of mass 4 kg and 2 kg, respectively, the coefficient of friction between object K and the horizontal plane is 0.2.



If the system is released, after how many seconds does object L strike the ground? (Take g=10 m/s^2)

A) 1

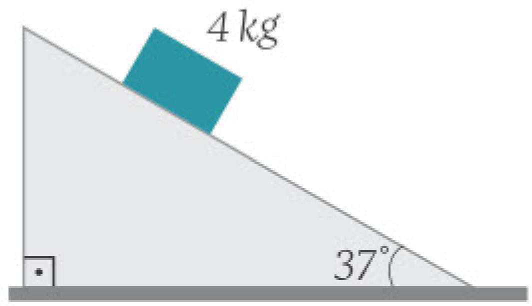
B) 2

C) 4

D) 5

E) 6

6. An object of 4 kg is released from rest and allowed to move freely on a rough inclined plane.



If the speed of the object is 6 m/s after 3 s, what is the coefficient of friction between the object and the inclined plane?

(Take g=10 N/kg, sin 37°=0.6; cos 37°=0.8)

A)1/5

B)1/4

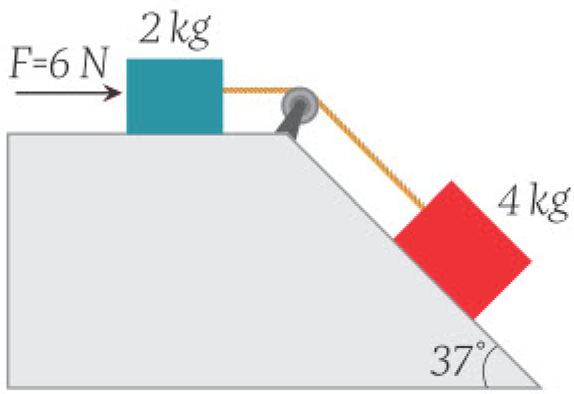
C)1/3

D)1/2

E) 1

Laws of motion

1.



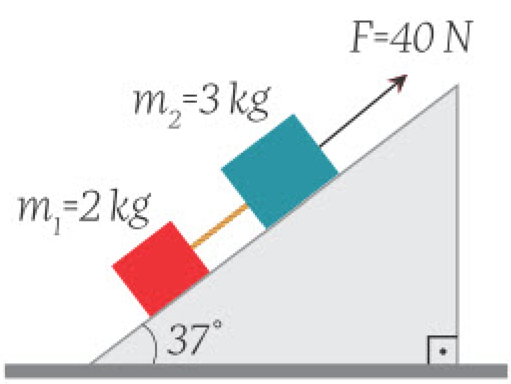
For the frictionless system shown in the figure, find:

a) the acceleration of the system

b) the tension T in the string.

(sin 37°=0.6; cos 37°=0.8)

2.



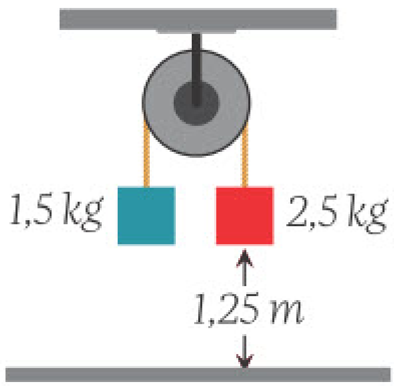
If masses m_1 and m_2 on the inclined frictionless surface are pulled by a force F=40 N, as shown in the figure,

a) what is the acceleration of the system

b) find the tension in the string connecting the masses.

(sin 37°=0.6, cos37°=0.8)

3. The masses in an Atwood machine are 1.5 kg and 2.5 kg (shown on the figure). If the masses are at a height of 1.25 m when the system is released .



a) How many seconds does it take for the greater mass to reach the ground?

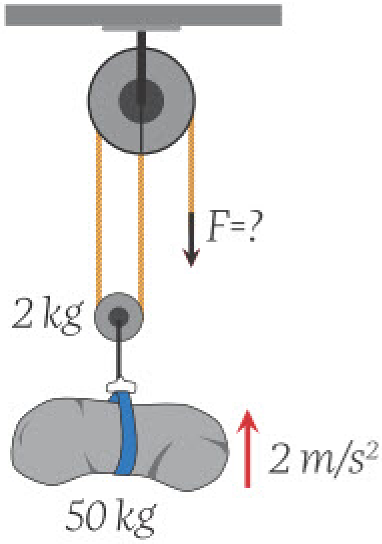
b) What is the velocity of the smaller mass when the greater one strikes the ground?

c) If this experiment were carried out on the Moon, how many seconds would it take for the 2.5 kg mass to fall?

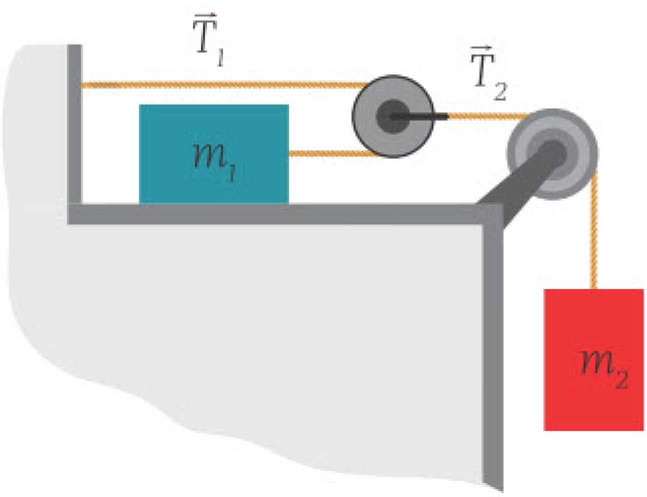
(g_E=10 N/kg, g_M=g_E/6)

4. The cement bag shown in the figure has a mass of 50 kg and the small pulley has a mass of

2 kg. If the cement bag is pulled upwards with an acceleration of 2 m/s^2, find the force F pulling the rope.



5.

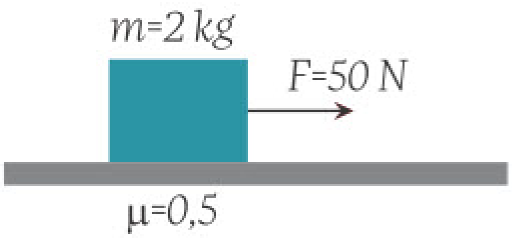


The masses m_1=1 kg and m_2=6 kg, in the system shown in the figure, are attached to each other with weightless pulleys and strings. If the pulleys and the surface are smooth

a) what are the accelerations of m_1 and m_2?

b) what are the tensions in the strings?

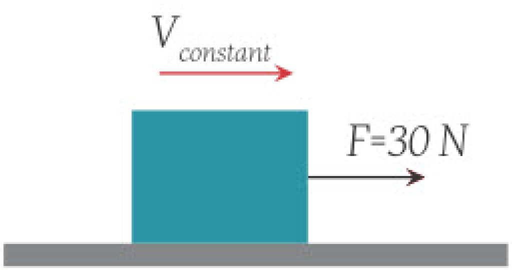
6.



Find the acceleration of the object of mass m=2 kg if a horizontal force of 50 N acts on it, on a rough surface where the coefficient of kinetic friction is 0.5, as shown in the figure.

(Take g =10 N/kg)

7.



When a horizontal force of 30 N acts upon a 5kg object on a rough surface, as shown in the figure, the object moves with a constant velocity. Find the coefficient of kinetic friction, μ_k between the object and the surface. (Take g=10 N/kg)

CHAPTER 3: EQUILIBRIUM

3.1 Center of mass. Types of equilibrium

You will

- determine centre of mass of rigid body, determine centre of mass of system of bodies.
- determine cause-effect relationship for different types of equilibrium.

Question

Why "Leaning Tower of Pisa" in Italy does not fall despite earthquakes?

Centre of mass

The centre of mass is a point where whole mass of a body is assumed to be concentrated. In case when gravitational field is uniform, the centre of gravity and centre of mass are at the same point.

It's often possible to guess the location of the centre of gravity. The centre of gravity of a homogeneous, symmetric body must lie on the axis of symmetry.

- For the rectangular frame the centre of mass is at the intersection point of its diagonals, Figure 28a.

- For the triangular plate shown the centre of mass is at the intersection point of the medians. The intersection of the medians is at 2/3 of the distance from the vertex, Figure 28b.
- For the circular plate the centre of mass is at its geometrical centre, Figure 28c.

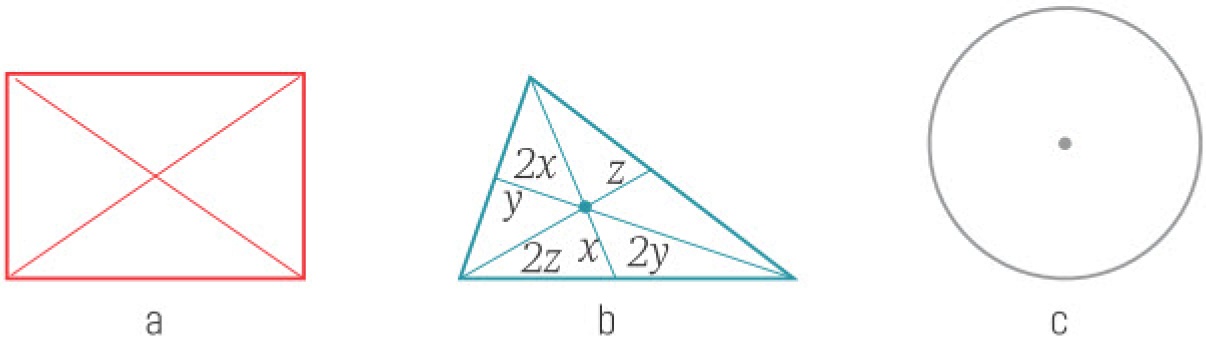


Figure 28

The centre of gravity of an irregularly shaped object can be determined experimentally by suspending it from two different points, Figure 29.

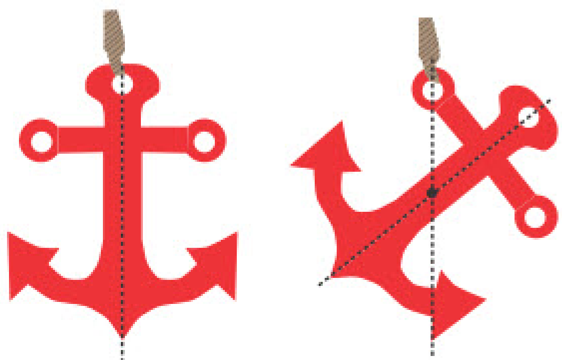


Figure 29

The centre of mass of several objects can be calculated by formula

$$x_{CM} = \frac{m_1x_1 + m_2x_2 + \ldots + m_nx_n}{m_1 + m_2 + \ldots + m_n}$$

Equilibrium

An object which remains at rest is said to be in static equilibrium. An object moving or rotating at a constant rate is in dynamic equilibrium.

There are three types of equilibrium.

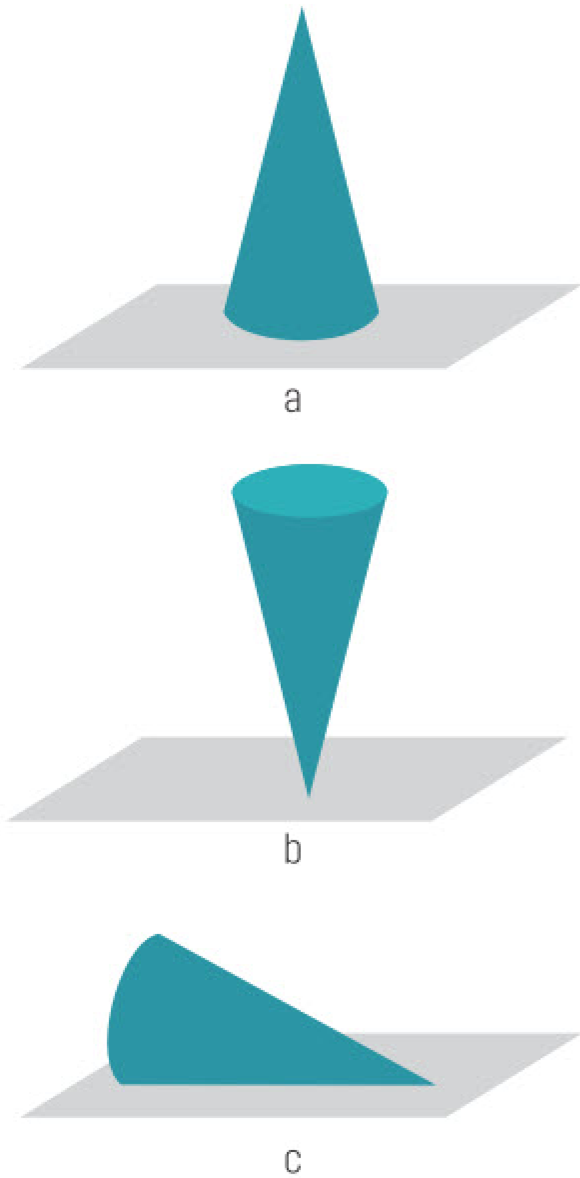


Figure 30

Stable equilibrium

After a small displacement the body returns to its original equilibrium position, Figure 30a.

Unstable equilibrium

After a small displacement the body does not return to the original equilibrium position and moves to a new equilibrium position, Figure 30b.

Neutral equilibrium

After a displacement the body remains in the displacement position, Figure 30c.

For an object to be in equilibrium, two conditions must be fulfilled.

- 1st condition

The resultant force acting on object must be equal to zero.

$\mathbf{F_{net} = 0}$

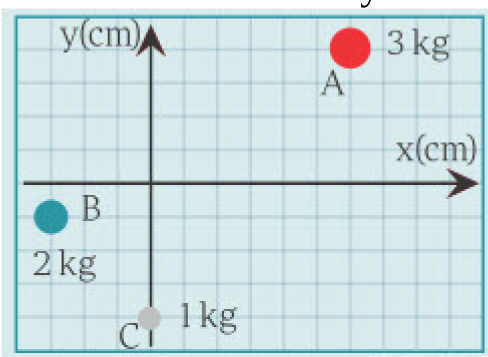
- 2nd condition

The resultant torque acting on object must be equal to zero.

$\boldsymbol{\tau_{net} = 0}$

Example

Objects A, B and C are shown in the xy coordinate system. If the masses of the objects are 3 kg, 2 kg and 1 kg respectively, find the coordinates of the centre of mass of the system formed by these objects.



Given:

$x_A = 6\ cm = 0.06\ m$

$y_A = 4\ cm = 0.04\ m$

$x_B = -3\ cm = -0.03\ m$

$y_B = -1\ cm = -0.01\ m$

$x_C = 0\ cm = 0\ m$

$y_C = -4\ cm = -0.04\ m$

$m_A = 3\ kg$

$m_B = 2\ kg$

$m_C = 1\ kg$

Formulas:

$$x_{CM} = \frac{m_1x_1 + m_2x_2 + \ldots + m_nx_n}{m_1 + m_2 + \ldots + m_n}$$

$$y_{CM} = \frac{m_1y_1 + m_2y_2 + \ldots + m_ny_n}{m_1 + m_2 + \ldots + m_n}$$

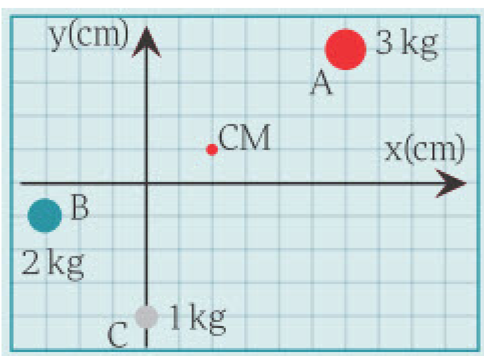
Calculations:

$$x_{CM} = \frac{3 \cdot 0.06 + 2 \cdot (-0.03) + 1 \cdot 0}{3 + 2 + 1}$$

$$x_{CM} = 0.02\ m = 2\ cm$$

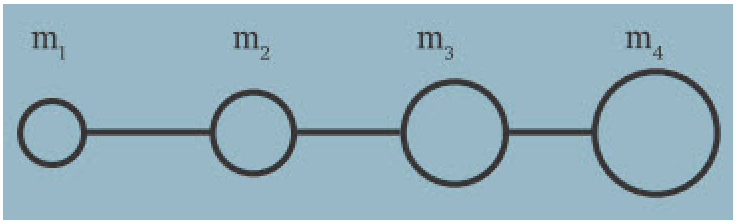
$$y_{CM} = \frac{3 \cdot 0.04 + 2 \cdot (-0.01) + 1 \cdot (-0.04)}{3 + 2 + 1}$$

$$y_{CM} = 0.01\ m = 1\ cm$$

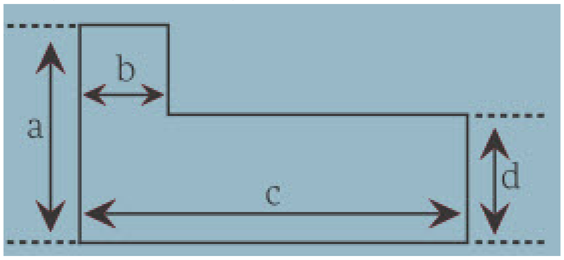


Literacy

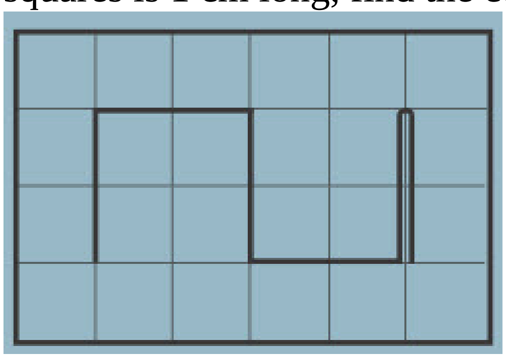
1. How many types of equilibrium do you know? What is the difference between them?
2. What is difference between centre of mass and centre of gravity?
3. Calculate position of centre of mass of the system shown on the figure. Length of rod is 1 metre, mass of rod is 1 kg. Distance between centres of balls is same. Masses are given as m_1=1 kg, m_2=3 kg, m_3=4 kg, m_4= 5 kg.



4. Calculate centre of mass of body shown on the figure. a = 30 cm, b = 10 cm, c = 80 cm, d = 20 cm.



5. Two solid spheres that have same volume of 5000 cm^3 are attached to each other. First sphere is aluminium and second sphere is copper. Calculate position of centre of mass of these two spheres.
6. The homogeneous cable is bent as shown in the figure. If each side of the squares is 1 cm long, find the coordinates of the centre of mass of the cable.



Activity

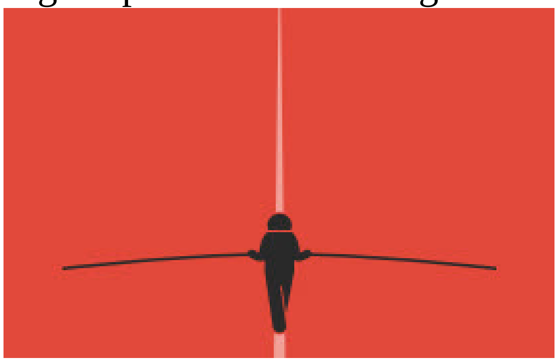
Find centre of mass of your pen/pencil. Then find the centre of mass of a key. Is there method of finding centre of mass of anything?

Career

Civil engineers use principles of statics to plan and construct buildings.

Physics in life

Tightrope walkers use long sticks to reach equilibrium better.



Research time

Where is the centre of mass of human body? Does it depend on age?

Is it true?

Mass does not matter for this bird toy to be in equilibrium.

LAB WORK #4

Title:

Addition of forces at angle to each other

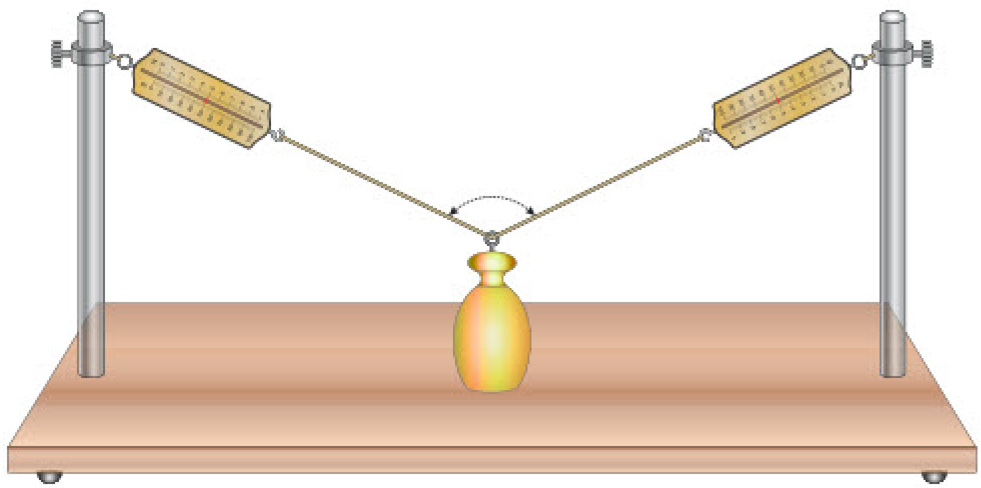
You will

- experimentally prove law of addition of forces at an angle to each other

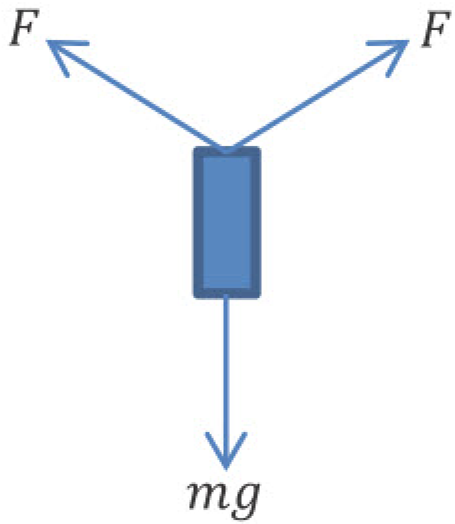
Theory:

Force is vector quantity, which means forces should be divided into vertical and horizontal components to perform force addition.

Let's show forces acting on a body shown on the figure.



There are three forces acting on the body: mg ,F and F.



Body is not moving that means
a=0.
Newton's second law of motion is
F=ma.
Then we write this law in scalar form for x-axis and y axis.

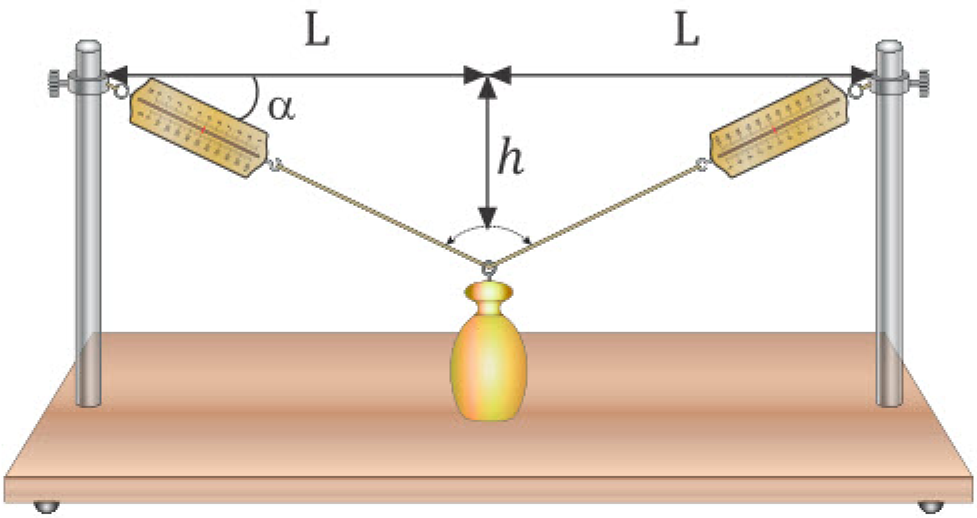
$$x: \quad F\cos\alpha - F\cos\alpha = 0$$

$$y: \quad -mg + F\sin\alpha + F\sin\alpha = 0$$

Next:

$$mg = 2F\sin\alpha$$

$$F = \frac{mg}{2\sin\alpha}$$



$$\sin\alpha = \frac{h}{\sqrt{L^2 + h^2}}$$

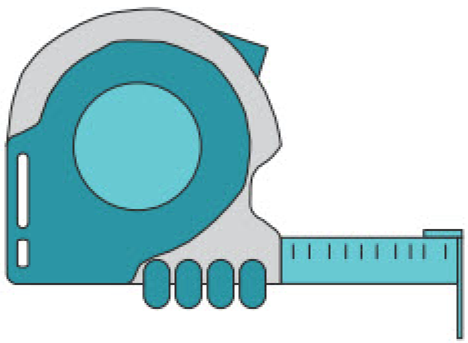
$$F = mg\frac{\sqrt{L^2 + h^2}}{2h}$$

You will prove law of addition of forces by using this final formula.

Equipment:

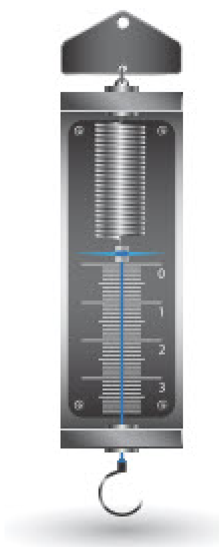
1. Safety glasses

2. Measuring tape or ruler



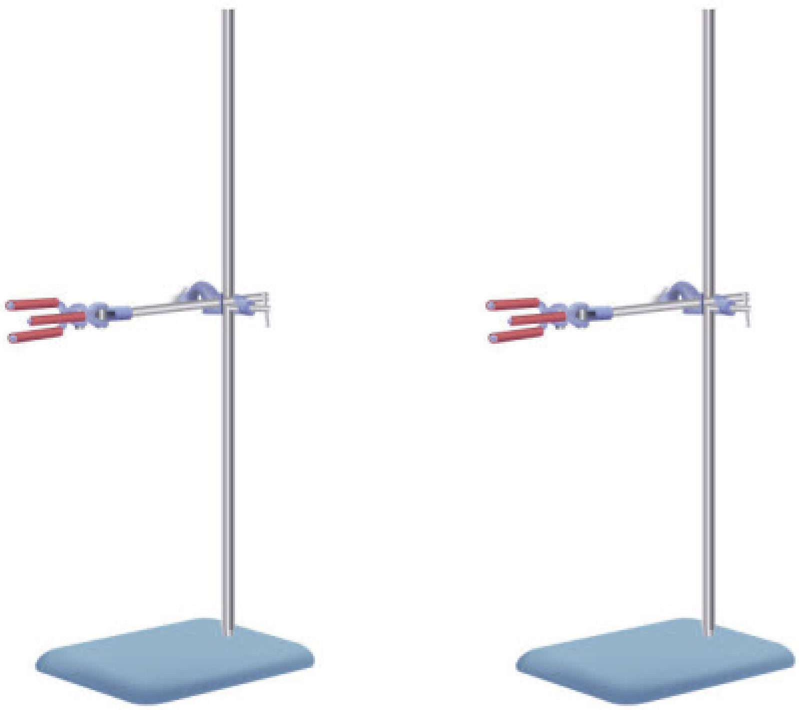
3. Nylon thread

4. Dynamometer (two or one)



5. Set of known masses

6. Two tripods



Procedure:

1. Put known mass in the middle of the nylon thread as shown in the figure.
2. Use measuring tape to measure and .
3. Use dynamometer to measure
4. Use formula to calculate . Use .
5. Record all measurements and calculations in table.
6. Change mass and repeat steps 1-5 four more times.
7. Fill the table.

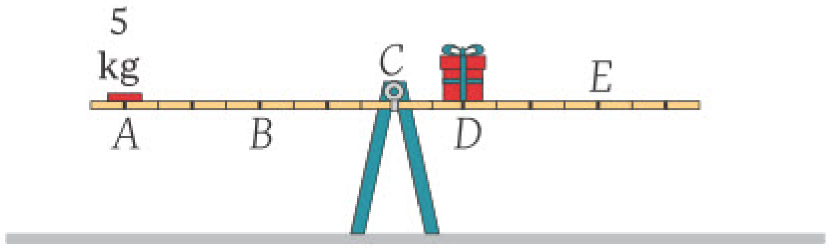
№	$m\ (kg)$	$h\ (m)$	$L\ (m)$	$F_{theory}\ (N)$	$F_{dynamometer}\ (N)$
1					
2					
3					
4					
5					

Conclusion:

1. Compare $F_{dynamemeter}$ and F_{theory} . Which one is larger and why?

CHECK YOURSELF

There are 5 kg brick, package of unknown mass and 10 kg rod shown on the figure. Rod can freely rotate at point C. Distance CD is 1 metre. Initially system is in equilibrium.



1. What is normal contact force acting on brick at point A?
A) 50 Newton
B) 100 Newton
C) 200 Newton
D) 300 Newton
E) 400 Newton

2. What is moment of force (torque) of brick relative to point C?
A) 50 N·m
B) 100 N·m
C) 200 N·m
D) 300 N·m
E) 0 N·m

3. What is moment of force (torque) of rod relative to point C?
A) 50 N·m
B) 100 N·m
C) 200 N·m
D) 300 N·m
E) 0 N·m

4. What is moment of force (torque) of package relative to point C?
A) 50 N·m

B) 100 N·m
C) 200 N·m
D) 300 N·m
E) 0 N·m

5. What is normal contact force acting on package at point D?
A) 50 Newton
B) 100 Newton
C) 200 Newton
D) 300 Newton
E) 400 Newton

6. What is mass of package?
A) 5 kg
B) 10 kg
C) 20 kg
D) 30 kg
E) 40 kg

7. What is normal contact force acting on rod at point C?
A) 50 Newton
B) 100 Newton
C) 200 Newton
D) 350 Newton
E) 250 Newton

8. What is moment of force (torque) of brick relative to point C when brick is at point B?
A) 50 N·m
B) 100 N·m
C) 200 N·m
D) 300 N·m
E) 0 N·m

9. What is moment of force (torque) of package relative to point C when package is at point E?
A) 800 N·m

B) 700 N·m
C) 600 N·m
D) 500 N·m
E) 0 N·m

10. What is moment of inertia of brick relative to axis C when brick is at point A?
A) 80 kg·m^2
B) 60 kg·m^2
C) 40 kg·m^2
D) 20 kg·m^2
E) 0 kg·m^2

11. What is moment of inertia of brick relative to axis C when brick is at point B?
A) 80 kg·m^2
B) 60 kg·m^2
C) 40 kg·m^2
D) 20 kg·m^2
E) 0 kg·m^2

12. What is moment of inertia of package relative to axis C when package is at point D?
A) 80 kg·m^2
B) 60 kg·m^2
C) 40 kg·m^2
D) 20 kg·m^2
E) 0 kg·m^2

13. What is moment of inertia of package relative to axis C when package is at point E?
A) 120 kg·m^2

B) 140 kg·m^2

C) 160 kg·m^2

D) 180 kg·m^2

E) 200 kg·m^2

14. What is moment of inertia of rod relative to axis C?

A) 27.5 kg·m^2

B) 37.5 kg·m^2

C) 47.5 kg·m^2

D) 57.5 kg·m^2

E) 67.5 kg·m^2

15. What is net torque acting on system when brick is at point B and package is at point D?

A) 50 N·m

B) 100 N·m

C) 200 N·m

D) 250 N·m

E) 300 N·m

16. What is angular acceleration of the system when brick is at point B and package is at point D?

A) 0.93 rad/s^2

B) 1.93 rad/s^2

C) 2.93 rad/s^2

D) 3.93 rad/s^2

E) 4.93 rad/s^2

17. What is angular speed of the system after 2 seconds when brick is at point B and package is at point D?

A) 1.86 rad/s

B) 3.86 rad/s

C) 5.86 rad/s
D) 7.86 rad/s
E) 9.86 rad/s

18. What is angular momentum of the system after 3 seconds when brick is at point B and package is at point D?
A) 1589.925 kg·m^2/s
B) 1267.425 kg·m^2/s
C) 944.925 kg·m^2/s
D) 622.425 kg·m^2/s
E) 299.925 kg·m^2/s

19. Where should you put package to achieve equilibrium if brick is at point E?
A) 0.75 m from point C
B) 12 m from point C
C) 4.5 m from point C
D) 1 m from point C
E) There is no right answer
20. Where should you put brick to achieve equilibrium if package is at point E?
A) 0.75 m from point C
B) 12 m from point C
C) 4.5 m from point C
D) 1 m from point C
E) There is no right answer

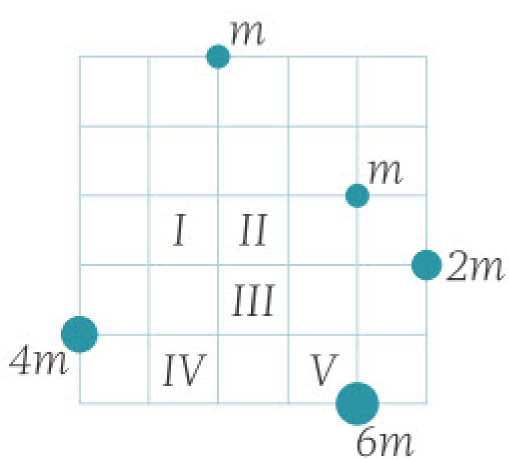
Centre of Mass

1. Which of the following must be true in relation to the centre of gravity of an object?

I. It is located at the geometric centre of an object.
II. It lies on a vertical line passing through the point at which the object is suspended.
III. It is located at the same point as the centre of mass of the object.

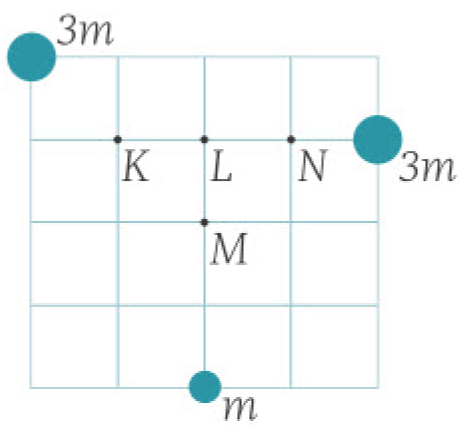
A) I only
B) II only
C) III only
D) II and III
E) I, II and III

2. A system consists of five particles located at various points in the same plane, as shown in the figure.



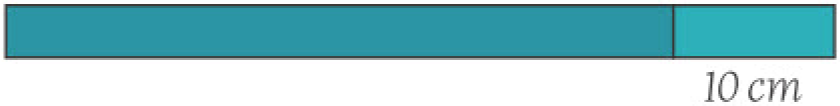
In which region does the centre of mass of the system exist?
A) I
B) II
C) III
D) IV
E) V

3. A system consists of three objects located at various points in the same plane, as shown in the figure.



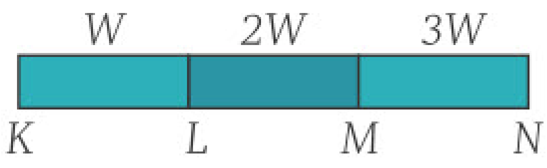
Where is the centre of mass of the system?
A) between K-L
B) at L
C) between L-M
D) between L-N
E) at M

4.



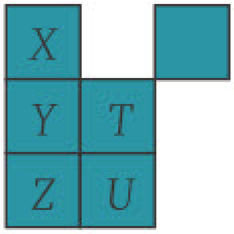
How many centimetres will the centre of mass of a uniform strip of length 1 m change if 10 cm of the strip is folded back upon itself, as shown in the figure?
A)1/3
B)1/2
C) 1
D) 2
E) 3

5.



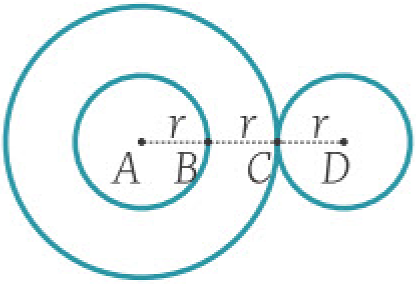
Three uniform rods of the same length and weights W, 2W, and 3W are connected to each other, as shown in the figure.
Where is the centre of gravity of the merged rods?
A) between K-L
B) at L
C) at M
D) between L-M
E) between M-N

6. Where is the centre of gravity of the object consisting of uniform and identical square plates?



A) X
B) Y
C) Z
D) T
E) U

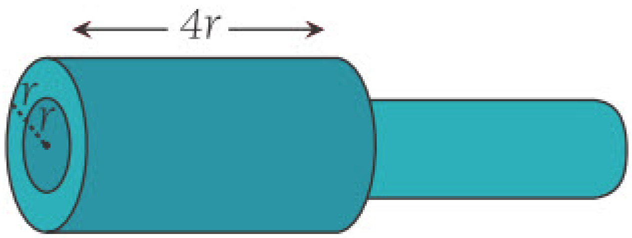
7. Two uniform circles of radii r and 2r are made of the same material and placed as shown in the figure.



Where is the centre of gravity of the system?
A) between A-B
B) at B
C) between B-C

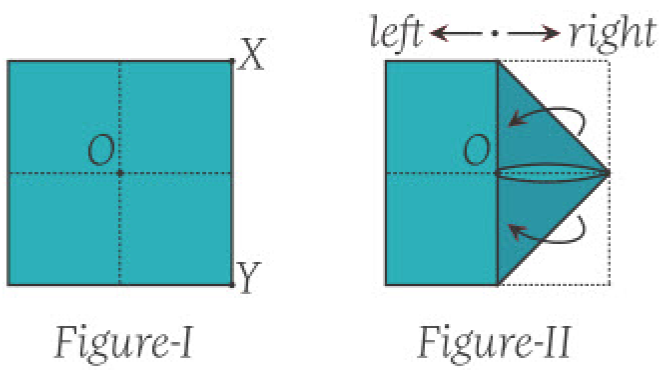
D) at C
E) between C-D

8.



A cylinder of length 4r and radius r is removed from a cylinder of length 4r and radius 2r and then attached to the same cylinder, as shown in the figure. What is the magnitude of the change in the position of the centre of mass of the system, in terms of r?
A)1/2
B) 1
C) 2
D)5/2
E) 7/2

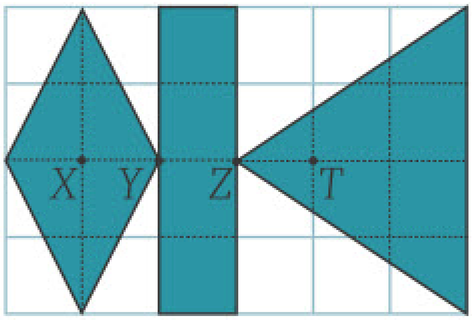
9.



A square plate with side length 24 cm is folded up from corners X and Y, as shown in the figure.
What is the direction and magnitude of displacement of the centre of mass of the plate relative to point O?
A) Right, 1 cm
B) Left, 2 cm

C) Right, 2 cm
D) Left, 1/2 cm
E) Left, 1 cm

10. The pieces shown in the figure are cut from a uniform plate and then connected with each other, as shown in the figure.



Where is the centre of mass of the pieces?
A) Between X and Y
B) At Y
C) Between Y and Z
D) At Z
E) Between Z and T

11.

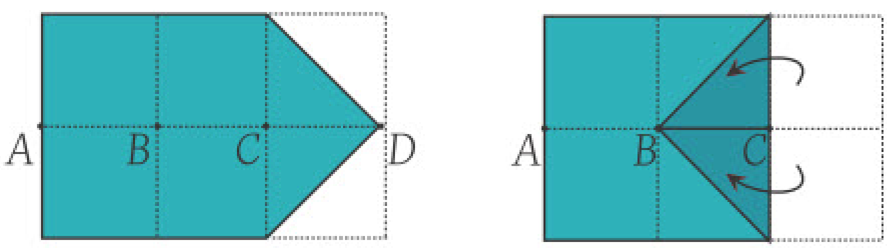


Figure-I

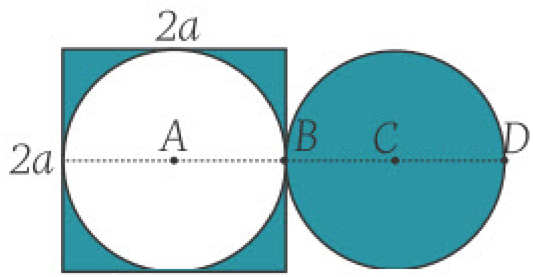
Figure-II

The distance between two successive points on the uniform plate in Figure-I is 3 cm. The plate is folded up, as shown in Figure-II in such a way that points B and D overlap. The area of each part of the plate is equal.
How many centimetres is the centre of mass of the system displaced?

A) 0.1
B) 0.2

C) 0.3
D) 0.4
E) 0.5

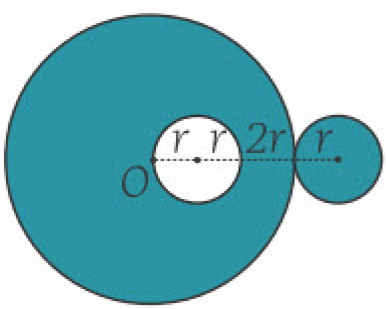
12.



A circular plate is removed from the uniform square plate with a side of length 2a and joined onto the side of the square plate, as shown in the figure.

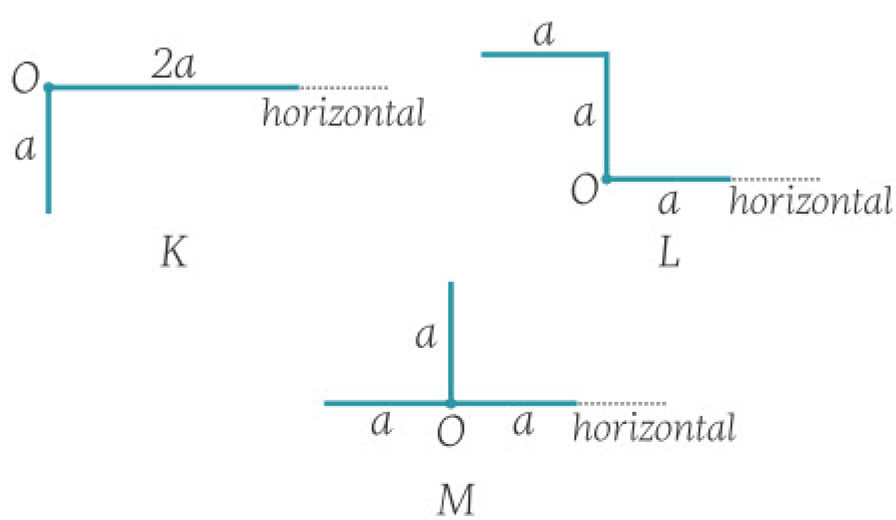
Where is the centre of mass of the new system? (Take p=3)
A) Between A and B
B) At B
C) Between B and C
D) At C
E) Between C and D

13. The circular plate of radius r is removed from a uniform circular plate of radius 4r and joined onto it, as shown in the figure.



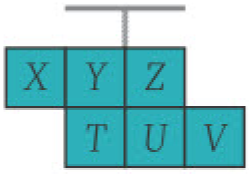
What is the magnitude of the displacement of the centre of mass of the new system, in terms of r?
A)1/4
B)1/3
C)1/2
D) 1
E) 2

Centre of Mass and Equilibrium
1.



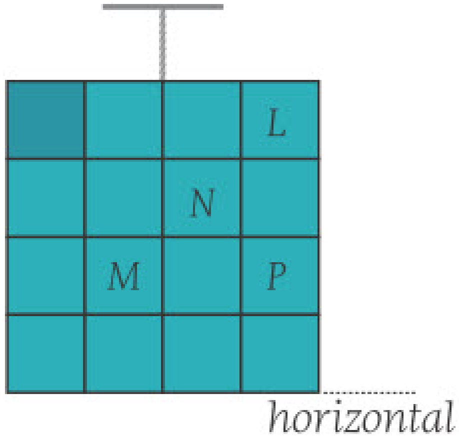
Three uniform wires K, L, and M, as shown in the figure are suspended from point O.
When they are free to move, which of the wires will be in equilibrium at the same position?
A) K only
B) L only
C) K and M
D) L and M
E) K, L and M

2. The system consisting of uniform, identical square plates is in equilibrium, as shown in the figure.



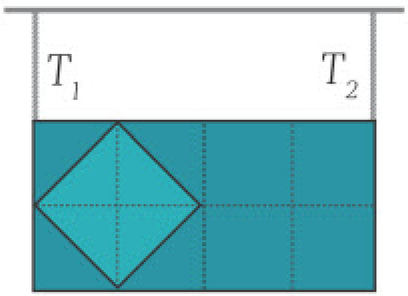
Which two plates must be removed from the system simultaneously so that the system remains in equilibrium?
A) X and Y
B) T and V
C) Z and T
D) V and Y
E) X and U

3. The shaded square plate is removed from the object consisting of identical and uniform square plates.



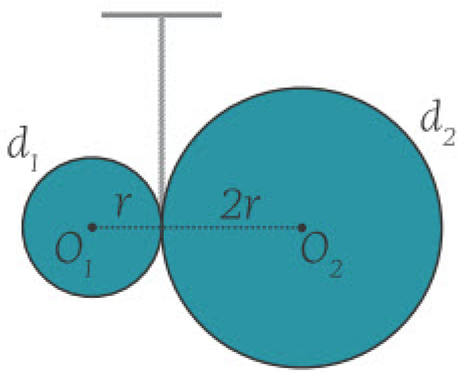
Which of the following square plates must also be removed in order for the object to remain in equilibrium horizontally?
A) L only
B) N only
C) M and L
D) K and P
E) M, L and P

4. The system consisting of uniform, identical square plates is suspended with two ropes from the ceiling and a piece is removed from the system, as shown in the figure.



If the system is in equilibrium, what is the ratio of the tensions in the ropes, T_1/T_2?

5. A circular plate of density d_1 and radius r is attached to another circular plate of density d_2 and radius 2r.



If the circular plates are in equilibrium as shown in the figure, what is the ratio of the
densities, d_1/d_2?

CHAPTER 4: ENERGY AND MOMENTUM

4.1. Conservation of Momentum

You will

- apply law of conservation of momentum and energy for solving analytical and experimental problems.

Question

What principles can you use to win billiard game?

Linear momentum is defined as the product of a system's mass multiplied by its velocity:

$$\vec{p} = m\vec{v}$$

Collisions

The law of conservation of momentum states that, in the absence of external forces, when two or more objects collide with each other, the total momentum before the collision is equal to the total momentum after the collision.

1. Inelastic collision

Inelastic collision is a collision in which momentum is conserved but kinetic energy is not. Completely inelastic collision is a collision in which colliding objects stick together after collision, Figure 31.

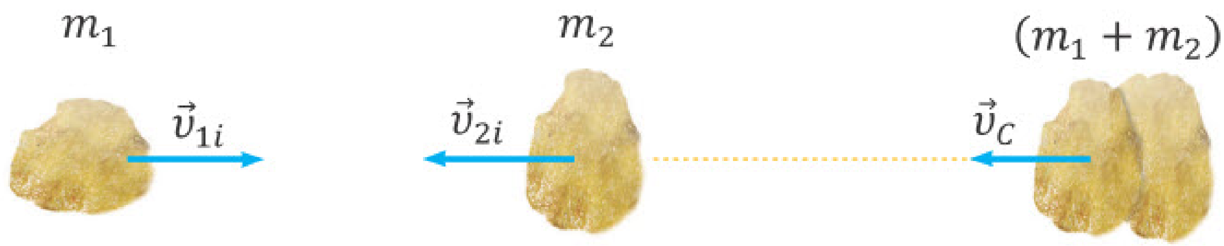


Figure 31

If the law of conservation of momentum is applied to this collision,

$$\vec{p}_1 + \vec{p}_2 = \vec{p}_C$$

where p_1 and p_2 are the momenta of the particles before collision and pc is the common momentum after collision.

$$m_1\vec{v}_1 + m_2\vec{v}_2 = (m_1 + m_2)\vec{v}_C$$

Since velocity is a vector quantity, the signs of the velocities representing directions must be taken into account. In solving problems, first positive and negative directions must be established, and then the values of velocities must be substituted into the equation along with their signs.

2. Elastic collision

$$m_1\vec{v}_{1i} + m_2\vec{v}_{2i} = m_1\vec{v}_{1f} + m_2\vec{v}_{2f}$$

$$\frac{1}{2}m_1v_{1i}^2 + \frac{1}{2}m_2v_{2i}^2 = \frac{1}{2}m_1v_{1f}^2 + \frac{1}{2}m_2v_{2f}^2$$

Collisions in which both momentum and kinetic energy are conserved are called elastic collisions, Figure 32.

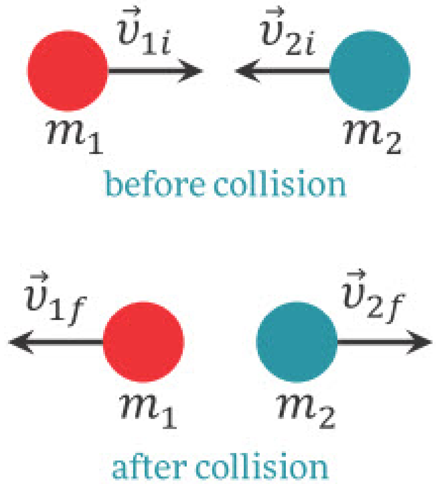


Figure 32

υ_{1i} and υ_{2i} are velocities before collision (initial), υ_{1f} and υ_{2f} are velocities after collision (final). After simplification of equations we will obtain:

$$\vec{\upsilon}_{1i} + \vec{\upsilon}_{1f} = \vec{\upsilon}_{2i} + \vec{\upsilon}_{2f}$$

As in the inelastic collisions, first the signs for the negative and positive directions must be established, then the values of the velocities must be substituted into the equations with these signs, Figure 33.

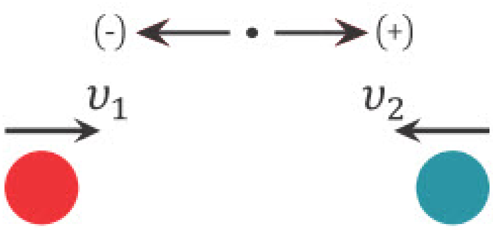
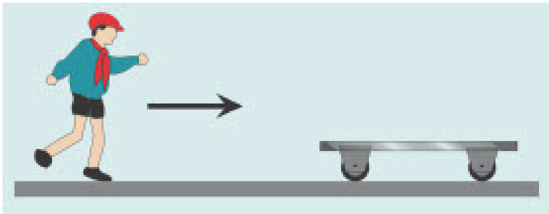


Figure 33

Example

30 kg child runs with velocity of 4 m/s and jumps on 20 kg stationary cart. What is the velocity of child and cart?



Given:

$m_{child} = 30\ kg$

$v_{child} = 4\ \dfrac{m}{s}$

$m = 20\ kg$

$v = 0$

Formulas:

$p = mv$

$\vec{p}_{before} = \vec{p}_{after}$

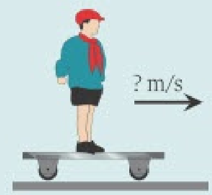
Calculations:

$$m_{child}v_{child} + mv = (m_{child} + m)v_{common}$$

$$v_{common} = \frac{m_{child}v_{child} + mv}{(m_{child} + m)}$$

$$v_{common} = \frac{30 \cdot 4 + 20 \cdot 0}{30 + 20}$$

$$v_{common} = 2.4\ m/s$$



Activity

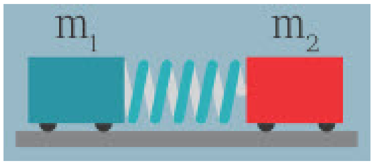
Draw a 10 cm ×10 cm box. Divide into 4 boxes. Into the first, write the word "Conservation". Into the second, write your own definition. Into the third, draw a picture that resembles the word. Into the fourth, write a translation in your native language.

Word:	Your own definition:
Picture:	Translation:

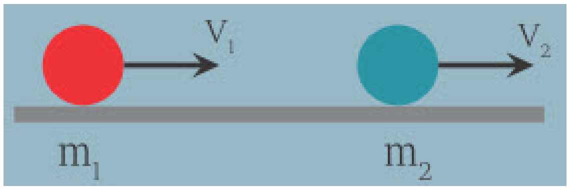
Literacy

1. How do you understand "invariance of physical systems with respect to spatial translation"? Give some examples about it.

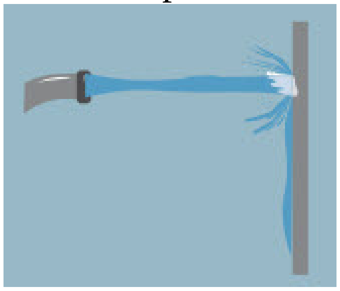
2. How do you understand “invariance with respect to time”? Give some examples about it.
3. Two objects are connected by coiled spring which has energy of 3 Joules. What will be the velocities of m_1=1 kg and m_2=2 kg after spring is released?



4. Calculate velocities of m_1=1 kg and m_2=2 kg that move with v_1=7 m/s and v_2=1 m/s after they collide elastically.



5. Water from garden hose hits wall at 10 m/s and flows downwards. Calculate pressure of water stream.



6. Flyboard is a device that uses water stream to fly. Assume mass of flyboard is 20 kg, mass of person is 80 kg, velocity of water stream is 25 m/s. Calculate mass flow rate of water in kg/sec so that person can fly.

Career

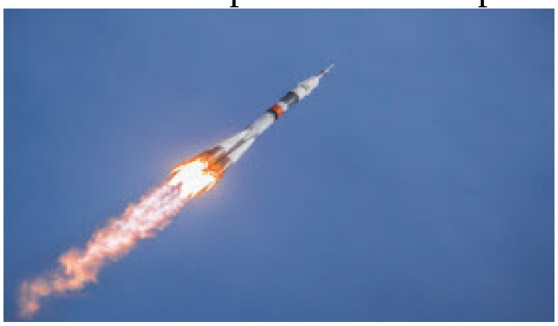
Professional billiard players are probably the best in the world at understanding conservation of momentum.

Important note

Apply conservation of momentum to an isolated system only.

Is it true?

Conservation of momentum is used to design rockets. Expressed as percentages, 98.9% of the rocket is fuel, while payload, engines, fuel tanks, and other components make up only 1.10%.



Physics in life

Air bags in automobiles can minimise the effect of the force on human involved in a collision. Air bags accomplish this by extending the time required to stop the motion of the driver and passenger.

4.2 Conservation of energy

You will

- apply law of conservation of momentum and energy for solving analytical and experimental problems.

Question

Which object has more energy: 5 gram bullet moving at 1000 m/s or 2000 kg car moving at 2 m/s?

Work

Work is done when object moves distance x under the influence of force F. Unit of work is Joule. Formula of work is

$$W = Fx$$

Power

Power is rate of work. Unit of power is Watt. Formula of power is

$$P = \frac{W}{t}$$

Energy

Energy can be defined as the capacity of a physical system to do work. Energy is a scalar quantity, it does not have a direction. In this section we will study three types of energy: kinetic energy, gravitational potential energy, elastic potential energy.

Kinetic energy

Kinetic energy is the energy of an object that is moving. An object at rest does not have kinetic energy.

$$E_K = \frac{mv^2}{2}$$

Where m is mass (kg) and v is velocity (m/s).

Gravitational potential energy

Potential energy is the energy due to physical position of the body.

$$E_P = mgh$$

where g is the acceleration of gravity and h is the vertical position of the mass relative the surface of Earth (or some other reference point).

Elastic potential energy

Assume that a spring is stretched a distance x by an external force. Work done by the external force in pulling the spring is stored as the elastic potential energy of the spring. The work done by the external force equals the area under the force-extension graph, Figure 34.

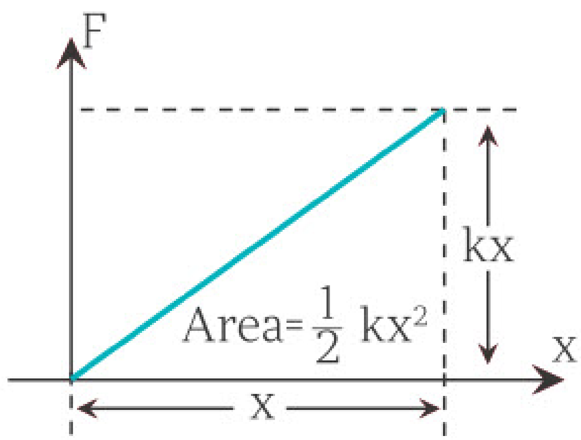


Figure 34

$$W = \frac{1}{2}kx \cdot x$$

$$E_{PE} = \frac{1}{2}kx^2$$

where k is spring constant measured with N/m and x is compression of spring in m.

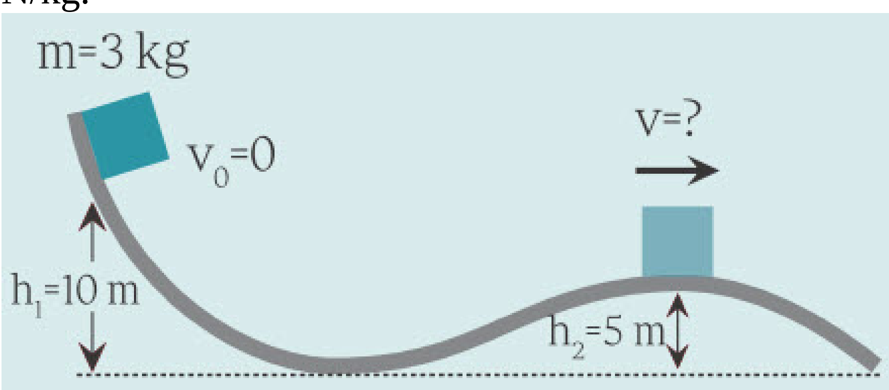
Conservation of mechanical energy

In any isolated system of objects interacting only through conservative forces, the total mechanical energy of the system remains the same at all times.

$$(E_K + E_P + E_{PE})_{initial} = (E_K + E_P + E_{PE})_{final}$$

Example

Calculate the speed of a 3 kg object, released from a height h_1 =10 m, at the moment it passes a height h_2 =5 m. Neglect any friction effects. Take g=10 N/kg.



Given:

$m = 3\ kg$

$h_1 = 10\ m$

$h_2 = 5\ m$

$g = 10\ m/s^2$

$v_0 = 0$

Formulas:

$E_i = E_f$

$$mgh_1 + \frac{1}{2}mv_0^2 = mgh_2 + \frac{1}{2}mv^2$$

Calculations:

$$v = \sqrt{2g(h_1 - h_2)}$$

$$v = \sqrt{2 \cdot 10 \cdot (10 - 5)}$$

$$v = \sqrt{100}$$

$$v = 10\ m/s$$

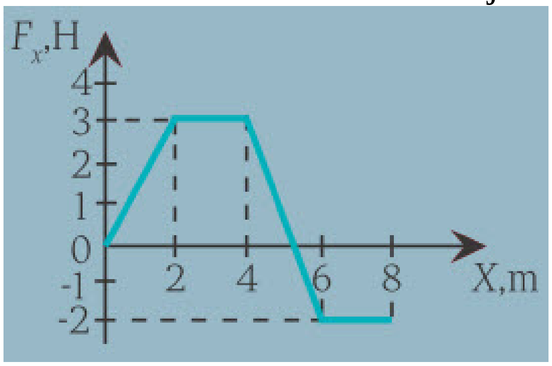
Activity

Download a mobile application that can measure the speed of an object in real time. Take two balls and measure their masses by using scale. Arrange the phone app so that it can measure the speed of a ball. Leave one ball at rest. Roll the second ball to the ball at rest and make them collide. Find the energy lost during collision.

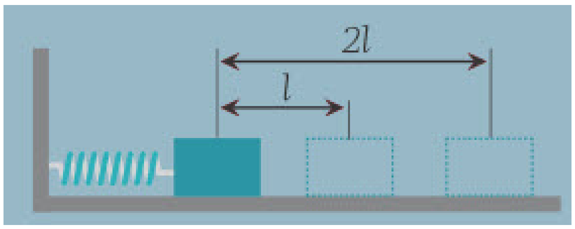
Literacy

1. Why there is conservation of momentum?
2. Why there is conservation of energy?

3. Supersonic aircraft provides thrust of 220 kN at velocity of 2340 km/h. Calculate power of jet engine and work done in 45 minutes.
4. There is force-distance graph that shows force acting on a 1.333 kg object. Calculate work done on the object and speed of object at x=8 m.



5. There is an object attached to wall by spring. Work of 20 mJ must be done to move object by l=2 cm. Three times more work must be done to move object by l_1=4 cm. Calculate spring constant and friction force.



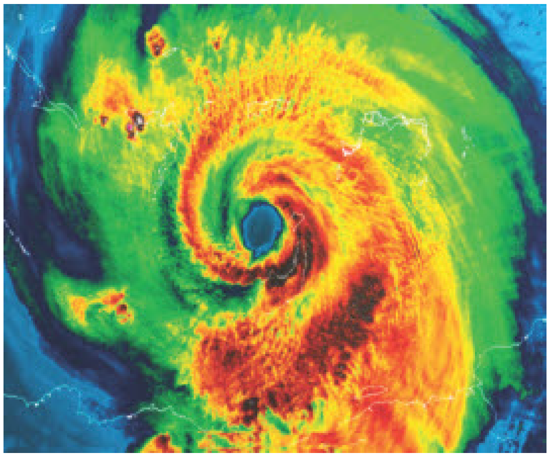
6. An object that has mass of m=1 kg is thrown vertically upwards at velocity of v_0=20 m/s. Calculate potential energy of the object at t_1= 2 sec. Plot velocity-time graph and potential energy-time graph. Neglect air resistance.

Research time

When you sneeze the speed of the liquid droplets is nearly 170 km/h. When you cough, it can reach the speed of 900 km/h. How does the droplets get such speed? Find the kinetic energy of 1 g droplets when sneezing and coughing.

Is it true?

A hurricane releases 50 trillion to 200 trillion Joules of heat energy.

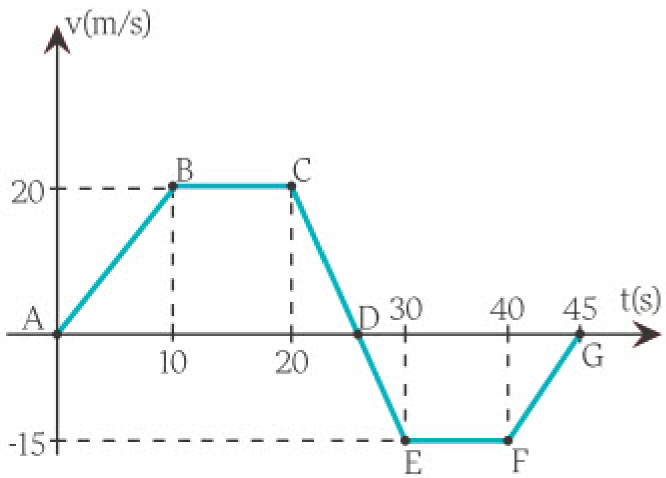


Physics in life

Chemical energy of fuel of the rocket is changed into gravitational potential energy, kinetic energy, and heat energy.

CHECK YOURSELF

There is velocity-time graph of 2000 kg car. Use graph to answer questions 1-25. g=10 N/kg, 1 horsepower=746 Watt.



1. What is maximum velocity of car?

A) 10 m/s

B) 20 m/s

C) 15 m/s

D) 5 m/s

E) 0 m/s

2. At what interval car is braking?

A) AB

B) BC

C) CD

D) DE

E) EF

3. What is velocity of car on interval EF in km/h?

A) 20 km/h

B) 15 km/h

C) 36 km/h

D) 48 km/h

E) 54 km/h

4. What does happen in interval EF?

A) Car brakes

B) Car accelerates

C) Car slows down

D) Car moves in the negative direction

E) No right answer

5. What is distance travelled by car in interval BC?

A) 100 m

B) 200 m

C) 300 m

D) 400 m

E) 500 m

6. What is time at point D?

A) 25.7 sec

B) 24.6 sec

C) 15 sec

D) 27 sec

E) 28 sec

7. What is acceleration in interval AB?

A) 1 m/s^2

B) 2 m/s^2

C) 3 m/s^2

D) 4 m/s^2

E) 0 m/s^2

8. What is distance travelled by car in interval AD?

A) 157 m

B) 257 m

C) 357 m

D) 457 m

E) 557 m

9. What is average speed in interval AG?

A) 11 m/s

B) 12 m/s

C) 13 m/s

D) 14 m/s

E) 0 m/s

10. What is displacement in interval AG?

A) 137 m

B) 268 m

C) 577 m

D) 404 m

E) 0 m

11. In which interval does car have maximum acceleration?

A) AB

B) BC

C) CD

D) FG

E) EF

12. What is distance travelled in interval FG?

A) 57.5 m

B) 20.5 m

C) 45 m

D) 57 m

E) 37.5 m

13. What is coefficient of friction in interval CD if wheels are locked?

A) 0.35

B) 0.2

C) 0.45

D) 0.5

E) 0.25

14. What is work done by engine of car in interval AB?

A) 0 kJ

B) 20 kJ

C) 400 kJ

D) 40 kJ

E) 200 kJ

15. What force is generated by engine in interval BC if power of engine is 50 hp (horsepower)?

A) 885 Newton

B) 3425 Newton

C) 2565 Newton

D) 1865 Newton

E) 1445 Newton

16. What is momentum of car at t=6 sec?

A) 333.33 kg·m/s

B) 12000 kg·m/s

C) 28000 kg·m/s

D) 20000 kg·m/s

E) 24000 kg·m/s

17. What is impulse in interval DE?

A) 24000 kg·m/s

B) 114200 kg·m/s

C) 40000 kg·m/s

D) 30000 kg·m/s

E) 0 kg·m/s

18. What is work done by engine in interval BC?

A) 400 kJ

B) 0

C) 40 kJ

D) 200 kJ

E) 800 kJ

19. What is kinetic energy of car at t=42 sec?

A) 400 kJ

B) 225 kJ

C) 0

D) 81 kJ

E) 441 kJ

20. What amount of heat is generated by friction in interval FG if wheels are locked?

A) 400 kJ

B) 225 kJ

C) 0

D) 81 kJ

E) 441 kJ

21. What is maximum kinetic energy of car?

A) 400 kJ

B) 225 kJ

C) 0

D) 81 kJ

E) 441 kJ

22. At which points momentum of car is zero?

A) A, B, C

B) B, C, E, F

C) A, D, G

D) A, B, C

E) C, D, E

23. At which point does car turn?

A) A

B) D

C) G

D) C

E) E

24. At what time kinetic energy is not equal to 100 kJ?

A) 28.57 sec

B) 22.86 sec

C) 5 sec

D) 25.72 sec

E) 41.67 sec

25. At what time absolute value of momentum is not equal to 10000 kg·m/s?

A) 43.33 sec

B) 27.14 sec

C) 24.29 sec

D) 2.5 sec

E) 41.14 sec

Momentum and Impulse

1. Which of the following conditions cause(s) the momentum of an object to increase?

I. Moving with constant speed.

II. Accelerating.

III. Decelerating

A) I only

B) II only

C) III only

D) I and II

E) I, II and III

2. Which of the following is/are the unit(s) of momentum?

I. N·s

II. kg·m/s

III. kg·s/m

A) I only

B) II only

C) I and II

D) II and III

E) I, II and III

3. What is the magnitude of the momentum of a 100 g bullet moving with a constant speed of 200 m/s, in kg.m/s?

A) 0.2

B) 2

C) 20

D) 200

E) 2000

4. Objects K, L and M are released from rest and allowed to fall freely from the same height. After striking a surface of sand they fall through it and take the paths x_K, x_L and x_M, inside the sand vertically.

If $x_K > x_L > x_M$, what is the relationship between the magnitudes of the momenta of the objects P_K, P_L and P_M at the moment they strike the sand?

A) $P_K > P_L > P_M$

B) $P_M > P_L > P_K$

C) $P_K = P_L = P_M$

D) $P_K = P_M > P_L$

E) $P_K > P_L = P_M$

5. An object is thrown vertically upwards. Which of the following statements related to the motion of the object during the time of flight is/are correct?

I. The momentum of the object increases.

II. The direction of the impulse applied to an object due to its weight is downwards.

III. The direction of the change in momentum vector is downwards.

A) I only

B) III only

C) I and III

D) II and III

E) I, II and III

6. The momentum of an object of mass m, decreases as it travels along distance x.

Which of the following statements may be correct?

I. The speed of the object decreases.

II. There is friction throughout distance x.

III. The impulse acting on the object throughout distance x is zero.

A) I only

B) II only

C) III only

D) I and II

E) I, II and III

7. A 2 kg object is released from rest and allowed to fall freely from a height of 20 m. After striking the ground, it stops within 0.2 s.

What is the magnitude of the average force acting on the object due to the ground, in newtons?(Take $g=10\ m/s^2$)

A) 50

B) 100

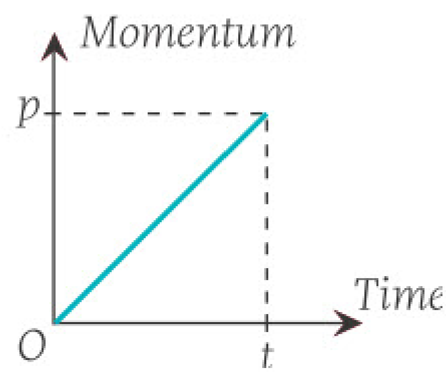
C) 200

D) 225

E) 250

Impulse and Change of Momentum

1. The momentum-time graph of an object is shown in the figure.



If p and t are known, which of the following quantities can be calculated?

I. The force acting on the object.

II. The change in momentum of the object within interval 0-t.

III. The acceleration of the object.

A) I only

B) II only

C) I and II

D) I and III

E) I, II and III

2. Which of the following quantities must the change of momentum of the object depend on?

I. The mass of the object.

II. The change in velocity of the object

III. The displacement of the object.

A) I only

B) II only

C) III only

D) I and II

E) I, II and III

3. If the changes in momentum of two objects are equal, which of the following properties of the objects must be equal?

I. Their masses.

II. Their changes in velocity.

III. Their applied impulses.

A) I only

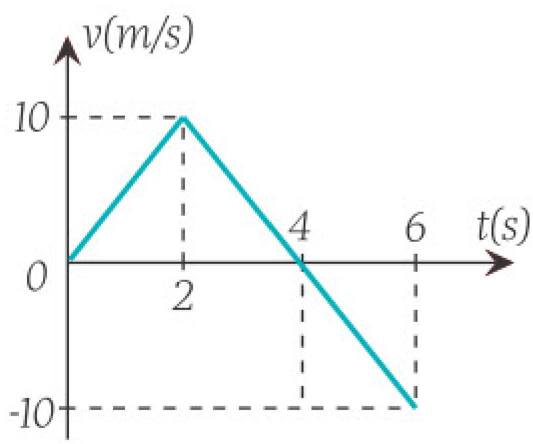
B) II only

C) III only

D) I and II

E) I, II and III

4. The velocity-time graph of an object of 4 kg is shown in the figure.



What is the total impulse acting on the object between t=0 and t=6 s, in N·s?

A) –40

B) –20

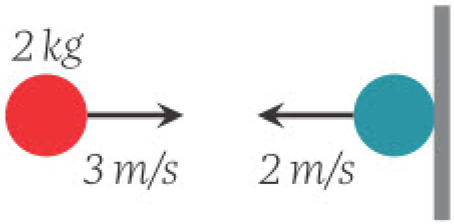
C) 0

D) 20

E) 40

5. As shown in the figure, a ball of 2 kg strikes a wall with a speed of 3 m/s and rebounds with a speed of 2 m/s. If the contact between wall and ball

occurs for 0.1 s, what is the magnitude of the force exerted on the ball by the wall, in newtons?



A) 20

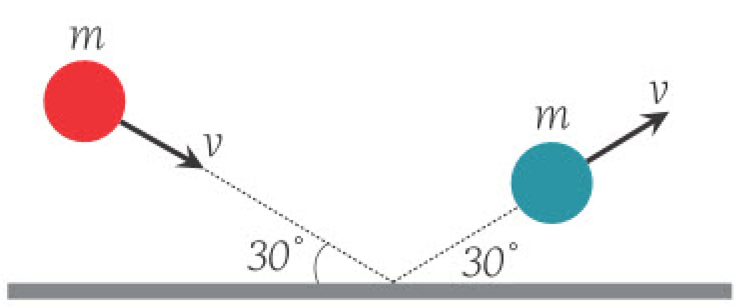
B) 40

C) 50

D) 60

E) 100

6. An object of mass m strikes the ground at an angle of 30° with the horizontal at a velocity of v and moves as shown in the figure. What are the magnitude and direction of the impulse acting on the object due to the ground?



A) → mv

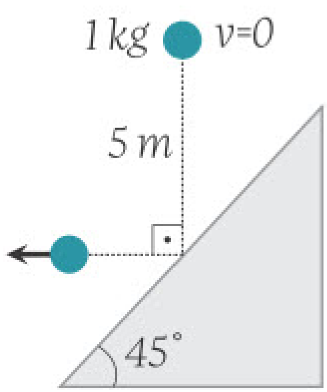
B) ↑ mv

C) ↑ $mv\sqrt{3}$

D) ← 2mv

E)↓ 2mv

7. An object of 1 kg released from rest and allowed to fall freely from a height of 5m strikes the inclined plane, as shown in the figure. If the speed of the object at the moment it strikes the plane is equal to the speed of the object at the moment it rebounds from the surface of the inclined plane, what is the magnitude of the change in momentum, in kg · m/s? (Take g=10 N/kg)



A) 5

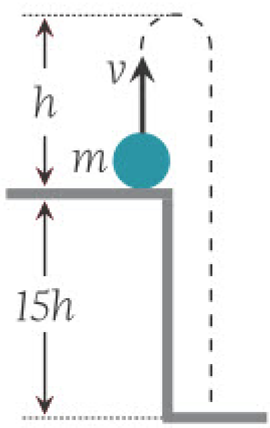
B) $5\sqrt{2}$

C) 10

D) $10\sqrt{2}$

E) 20

8. What is the magnitude of the impulse acting on the object thrown vertically upwards with a velocity of v, as shown in the figure, during its time of flight? (Take g=10 m/s^2)



A) ↓2mv

B) ↓ 5mv

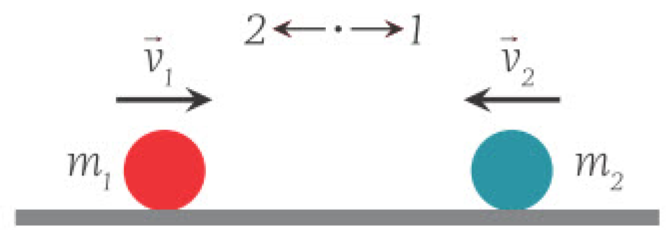
C) ↓ 4mv

D) ↑ 5mv

E)↑ 6mv

Collisions

1. The velocities of the objects of masses m_1 and m_2 moving on a frictionless surface as shown in the figure are v_1 and v_2, respectively.



If the objects undergo a head-on inelastic collision, which of the following statements related to the common motion of the objects must be true?

I. If $m_1 > m_2$, they move in direction 1.

II. If $\upsilon_1 > \upsilon_2$, they move in direction 1.

III. If $m_1\upsilon_1 > m_2\upsilon_2$, they move in direction 1.

A) I only

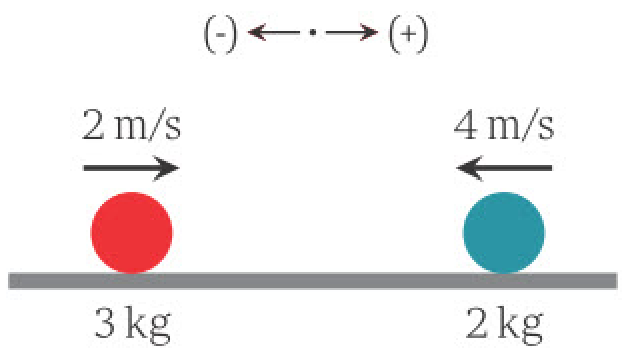
B) II only

C) III only

D) I and III

E) II and III

2. A 3 kg object moving with a velocity of 2 m/s on a frictionless horizontal surface and a 2 kg object moving with a velocity of 4 m/s in the opposite direction undergo a head-on inelastic collision and stick together. What is the common velocity of the objects after collision, in m/s?



A) –2.8

B) –0.4

C) 0.4

D) 1

E) 2.8

3. X, Y and Z are identical marbles. When marbles Y and Z are at rest side by side, marble X collides with marble Y. If the collision is head-on and elastic, which of the following is/are incorrect?

I. Marble X stops, and marbles Y and Z move.

II. Marbles X, Y and Z move together.

III. Marbles X and Y stop, marble Z moves.

A) I only

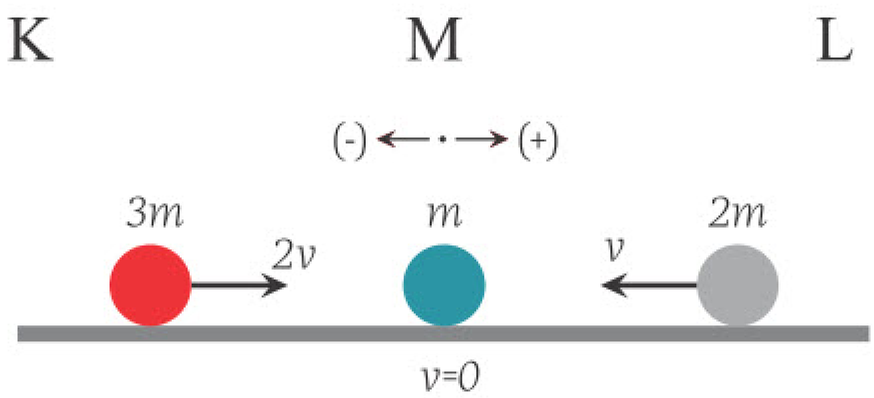
B) II only

C) I and II

D) I and III

E) III only

4. The objects K and L moving on the frictionless horizontal surface in the directions shown in the figure undergo a head-on inelastic collision with object M. What are the direction and magnitude of the common velocity of the objects after collision?



A) + direction, 2υ/3

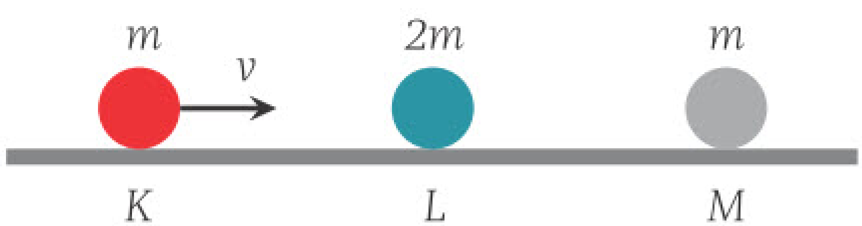
B) – direction,3υ/2

C) + direction, 3υ

D) + direction, υ

E) – direction,υ/2

5. The object K moving with a velocity v on a frictionless surface strikes the object L at rest and sticks to it. After a while objects K and L strike object M at rest, and stick to it. The objects K, L and M then move off together with a common velocity of 5 m/s. What was the magnitude of the initial velocity v of the object K, in m/s?



A) 5

B) 10

C) 15

D) 20

E) 2

6. An object of mass m1 moving on a frictionless surface undergoes a head-on elastic collision with a stationary object of mass m_2, as shown in the figure.If the object of mass m_2 moves with a velocity of υ/2 after the collision, what is the ratio, m_1/m_2 ?

A) 1

B) 2

C) 3

D) 4

E) 5

Conservation of Momentum

1. At the moment the rocket leaves the ground, it ejects gas with a velocity of υ and gains a velocity of υ/19. What percentage of its initial mass does the ejected gas represent?

A) 3

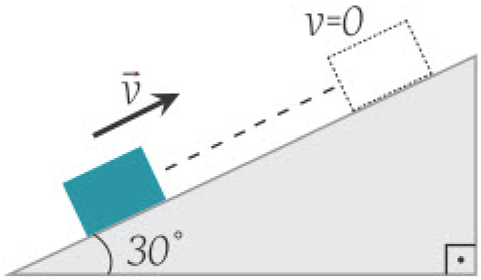
B) 5

C) 11

D) 19

E) 20

2. A 6 kg object pushed with a velocity of v on the smooth, frictionless inclined plane, as shown in the figure, stops after 3 s. What is the change in momentum of the object during its motion, in kgm/s? (Take g=10 m/s^2, sin 30°=0.5)



A) 60

B) 80

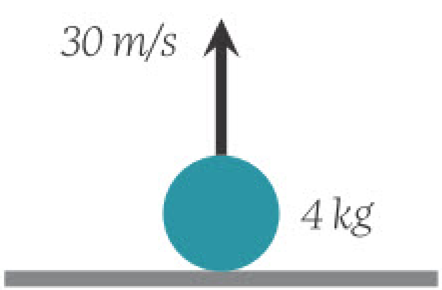
C) 90

D) 120

E) 180

3. As shown in the figure, a 4 kg object thrown vertically upwards with a velocity of 30 m/s undergoes an explosion 3 s after leaving the ground and is split into two identical parts.

If one of the pieces falls vertically downwards with an initial velocity 10 m/s, what is the direction and magnitude of the velocity of the second piece just after the explosion?



A) ↓5 m/s

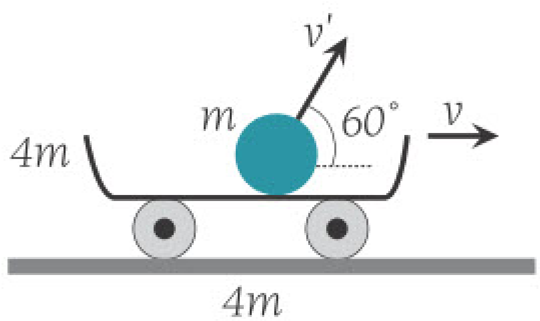
B) ↑5 m/s

C) ↓ 10 m/s

D) ↑ 8 m/s

E) ↑ 10 m/s

4. When a toy car of mass 4 m, containing an object of mass m, moves with a velocity υ, the object in the car is projected at an angle of 60º to the horizontal with a velocity of υ' with respect to the ground. If the velocity of the car remains the same, what is the velocity υ', in terms of υ?



A) 1/8

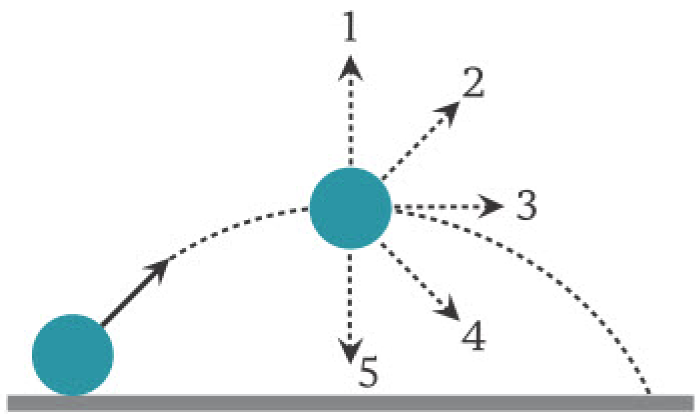
B) 1/4

C) 1/2

D) 1

E) 2

5. When an object thrown at an angle to the horizontal reaches its maximum height, it is split into two parts because of an internal explosion, as shown in the figure. If one of the pieces moves vertically upwards, which of the numbered directions indicated in the figure will the second piece follow?



A) 1

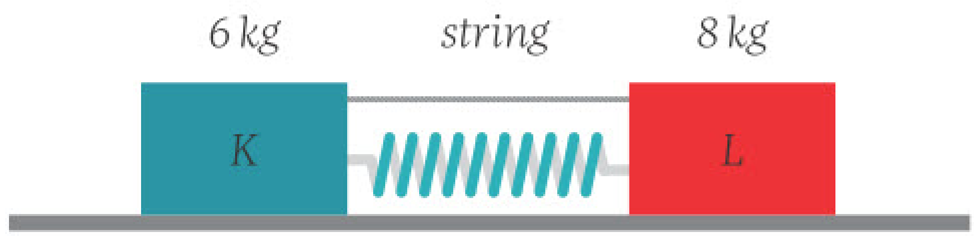
B) 2

C) 3

D) 4

E) 5

6. A spring on a frictionless horizontal surface is compressed by objects K and L of mass 6 kg and 8 kg, respectively. The objects are connected to each other by a string. If the string is cut, object K starts moving with a speed of 4 m/s. What is the speed of object L, in m/s?



A) 2

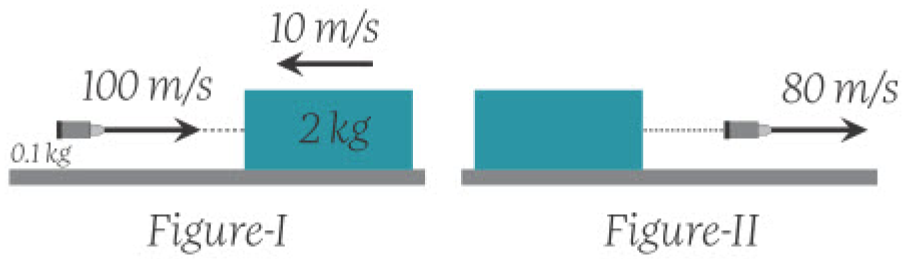
B) 2.5

C) 3

D) 3.5

E) 4

7. As shown in Figure-I, a 0.1 kg bullet moving with a velocity of 100 m/s collides with a 2 kg block of wood, moving at a velocity of 10 m/s in the opposite direction and penetrates a wooden block. If the bullet leaves the block of wood with a velocity of 80 m/s, as shown in Figure-II, what is the speed of the block, in m/s?



A) 5

B) 9

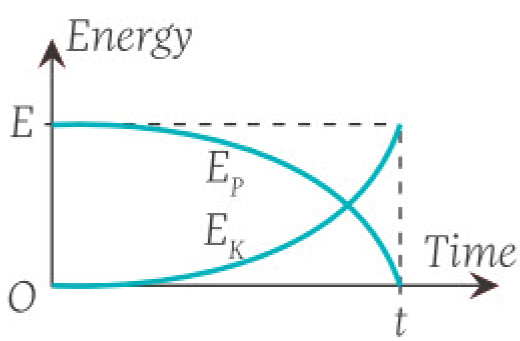
C) 10

D) 11

E) 15

Conservation of Mechanical Energy

1. The kinetic energy and potential energy versus time graphs of an object performing projectile motion is shown in the figure. Which of the following types of projectile motion could this object be undergoing?



I. Free fall.

II. Projectile motion at an angle.

III. Projectile motion after being thrown vertically downwards.

A) I only

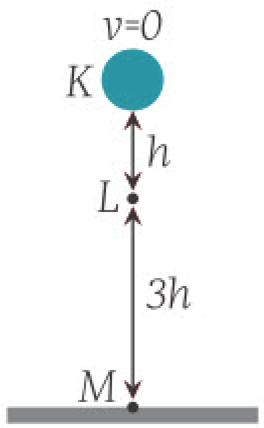
B) II only

C) I and III

D) II and III

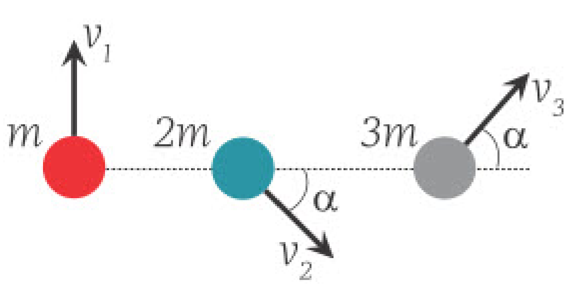
E) I, II and III

2. An object is released from rest to fall freely from point K. If the kinetic energy of the object at point L is E_L and at point M is E_M, what is the ratio E_M/E_L ?



A) 1 B) 2 C) 3 D) 4 E) 6

3. The kinetic energies of the objects of masses m, 2m and 3m thrown with velocities υ_1, υ_2 and υ_3 from the same height, as shown in the figure, are the same when they strike the ground. What is the relationship between υ_1, υ_2 and υ_3?



A) $\upsilon_1=\upsilon_2=\upsilon_3$

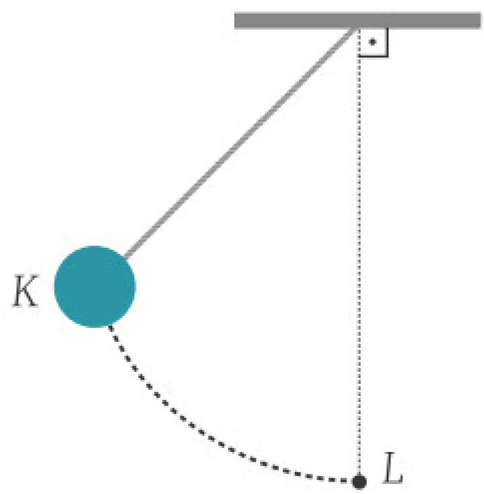
B) $\upsilon_3<\upsilon_2<\upsilon_1$

C) $\upsilon_1<\upsilon_2<\upsilon_3$

D) $\upsilon_2<\upsilon_1<\upsilon_3$

E) $\upsilon_3<\upsilon_1<\upsilon_2$

4. An object suspended from the ceiling with a string is released from point K as shown in the figure. Which of the following statements is/are correct?



I. The potential energy of the object with respect to the ground firstly decreases, then increases.

II. The kinetic energy of the object firstly increases, then decreases.

III. The velocity of the object reaches its maximum as it passes point L.

A) I only

B) II only

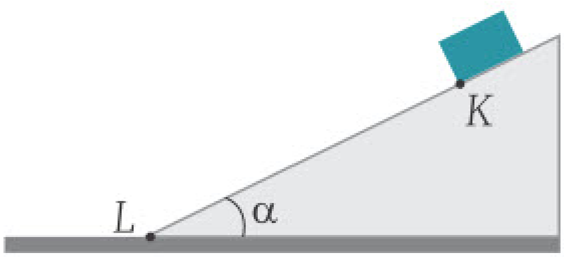
C) III only

D) II and III

E) I, II and III

5. An object released from rest at point K on the rough inclined plane shown in the figure passes point L with a kinetic energy of E.

If the object is released again from rest at point K on the same inclined plane after the angle of inclination has been increased, which of the following statements is/are correct? (There is friction between the object and surface of the inclined plane)



I. E increases

II. The potential energy of the object at point K increases

III. The energy loss due to friction decreases

A) I only

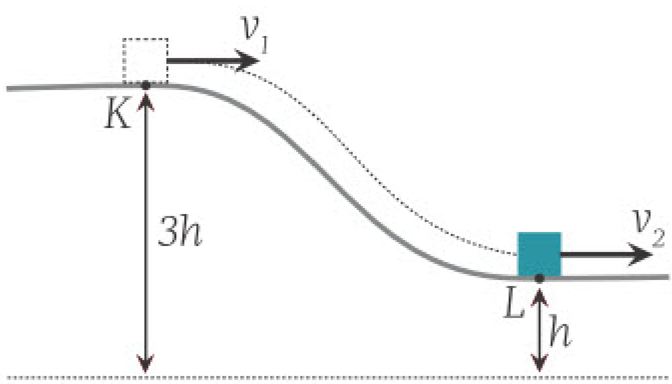
B) II only

C) III only

D) I and II

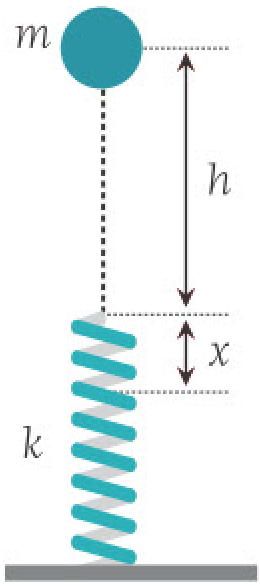
E) I, II and III

6. An object of mass m passes point K of the frictionless path shown in the figure at velocity υ_1 and it passes point L of the same path with velocity υ_2. What is the magnitude of the change in kinetic energy of the object between points K and L, in terms of mgh?



A) 1/2 B) 1 C) 3/2 D) 2 E) 3

7. When an object of mass m is released from rest at a height h, it can compress a spring of constant k a distance of x. In addition to the gravitational acceleration, which of the following quantities must be known to calculate x?



A) m only

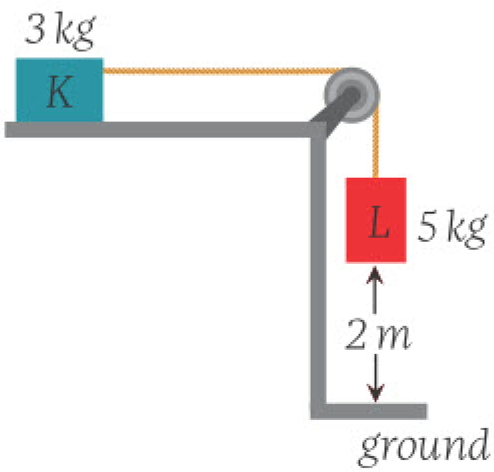
B) h only

C) k only

D) m and h

E) m, h and k

8. If the system shown in the figure is released from rest, object L strikes the ground with a velocity of 4 m/s. What is the friction force between object K and the horizontal surface, in newtons? (Take g=10 N/kg)



A) 12

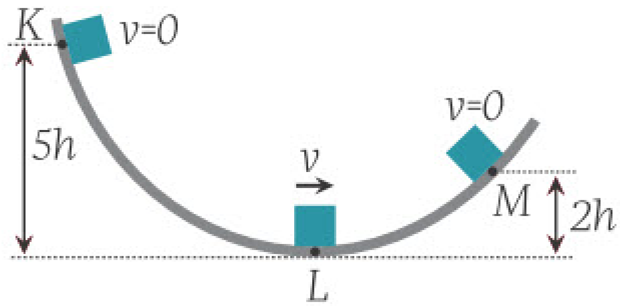
B) 16

C) 18

D) 24

E) 26

9. An object released from rest at point K of the path shown in the figure stops at point M after passing point L with velocity υ. Which of the following statements must be correct?



I. There is friction along the section of path between points K and L.

II. There is friction along the section of path between points L and M.

III. The mechanical energy of the object is conserved between points K and L.

A) I only

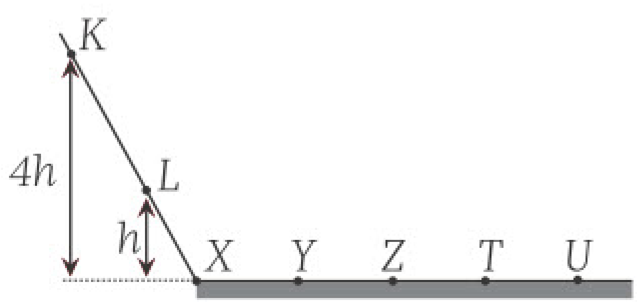
B) II only

C) III only

D) II and III

E) I, II and III

10. The inclined section K-X of the path shown in the figure is frictionless, however, there is friction along the horizontal section X-U of the same path. An object of mass 4m, released from rest at point L, stops at point Y. Where does an object of mass m released from rest at point K stop? (The distance between two successive points are equal)



A) At U

B) At T

C) Between Z and T

D) At Y

E) Between Y and Z


CHIN UP
STRAIGHTEN LEGS
FLYSPOT

CHAPTER 5: FLUID DYNAMICS

5.1 Laminar and turbulent flow. Equation of continuity. Bernoulli's principle

You will

- describe laminar and turbulent flow of fluids (liquids and gases).
- apply equation of continuity and Bernoulli's principle for solving experimental and analytical problems.

Question

Why do some aircrafts have rounded nose while some have pointed nose?

Fluid. Laminar and turbulent flow

A fluid is either a liquid or a gas.

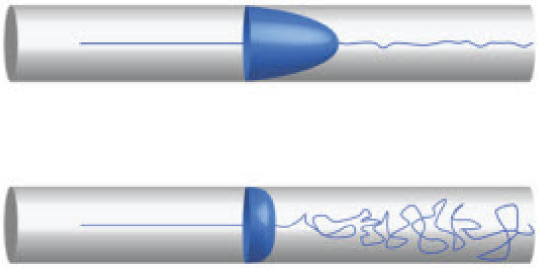


Figure 35

When a fluid is in motion, its flow can be characterised in two ways, Figure 35:

Laminar flow - the flow when each particle of the fluid follows a smooth paths which never interfere with one another. Velocity of the fluid is constant at any point in the fluid.

Turbulent flow - irregular flow that is characterised by tiny whirlpool regions. The velocity of this fluid is definitely not constant at every point.

Many features of fluid motion can be understood by considering the behaviour of an ideal fluid, which satisfies the following conditions:

1. The fluid is nonviscous
2. The fluid is incompressible (density is constant)
3. The fluid motion is steady
4. The fluid moves without turbulence

Equation of continuity

Imagine that an ideal fluid flows through a pipe, Figure 36. The diameter of the pipe is different at each end. How does the speed of fluid flow change as the fluid passes through the pipe?

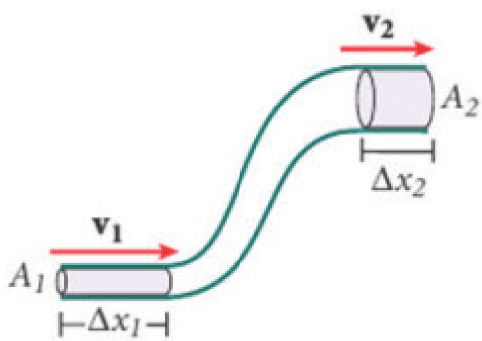


Figure 36

The mass flowing into the pipe must be equal to the mass flowing out of the pipe in the same time interval.

$$m_1 = m_2$$

Since

$m = \rho V$ and $V = A\Delta x$

$$\rho V_1 = \rho V_2$$

$$\rho A_1 \Delta x_1 = \rho A_2 \Delta x_2$$

The length of the cylinder is also the distance the fluid travels (Δx = Δt).

$$\rho A_1 v_1 \Delta t = \rho A_2 v_2 \Delta t$$

The time interval and the density are the same on each side of the equation, so they are cancelled. The resulting equation is called the equation of continuity and it is valid for any incompressible fluid :

$$A_1 v_1 = A_2 v_2$$

The speed of fluid flow depends on cross-sectional area.

Fluid speed is faster where the pipe is narrow and slower where the pipe is wide. The product , which has units of volume per unit time, is called the flow rate. The flow rate is constant throughout the pipe.

Bernoulli's principle

As a fluid moves through a pipe of varying cross section and elevation, the pressure changes along the pipe, Figure 37. Bernoulli's principle states that, as the velocity of a fluid increases, the pressure exerted by that fluid decreases. This principle is a statement of energy conservation as applied to fluids.

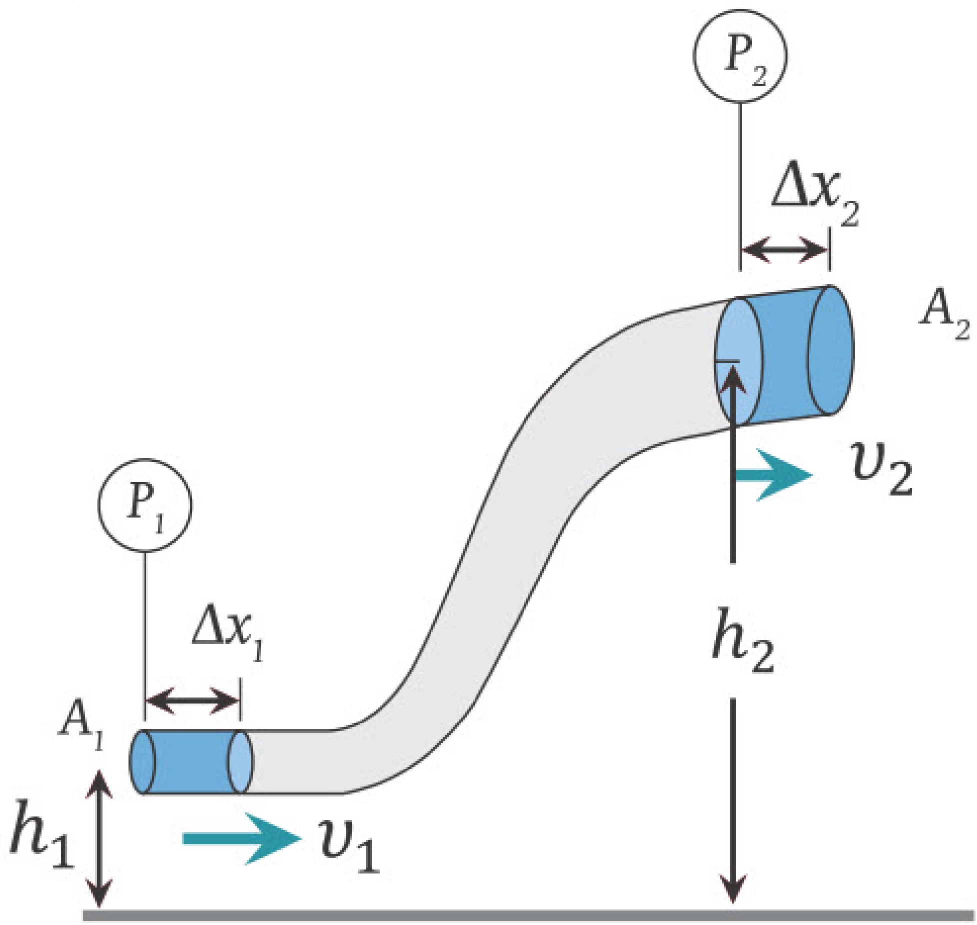


Figure 37

This is Bernoulli's equation, often expressed as

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

If the speed of a fluid element increases as the element travels along a horizontal streamline, the pressure of the fluid must decrease, and vice versa.

Example

A nozzle with a radius of 0.4 cm is attached to a garden hose with a radius of 0.8 cm. The speed of the water in the hose is 3 m/s. Calculate the speed of water in the nozzle.

Given:

$r_1 = 0.8\ cm = 0.008\ m$

$r_2 = 0.4\ cm = 0.004\ m$

$v_1 = 3\ m/s$

Formulas:

$A = \pi r^2$

$A_1 v_1 = A_2 v_2$

Calculations:

$A_1 v_1 = A_2 v_2$

$$v_2 = \frac{A_1 v_1}{A_2} = \frac{\pi r_1^2 v_1}{\pi r_2^2}$$

$$v_2 = \frac{\pi \cdot 0.008^2 \cdot 3}{\pi \cdot 0.004^2}$$

$v_2 = 12\ m/s$

Discussion:

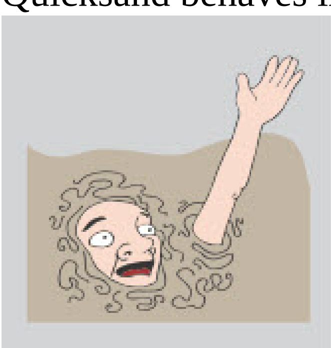
As you can see, if radius decreases two times then speed increases four times.

Activity

Place two empty cans 2 cm apart from each other. Then blow air through straw in between them. What do you expect and what is your result? Explain your observation.

Is it true?

Quicksand behaves like liquid and it is so dangerous that you can drown.



Career

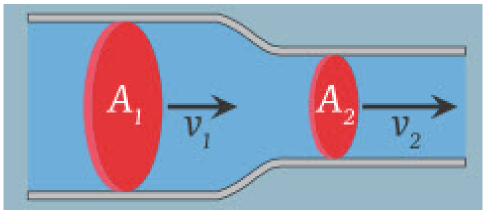
Bernoulli's principle is essential for engineers-constructors, pilots and aviators.

Physics in life

Prairie dogs build their complex burrows one higher than another for ventilation.

Literacy

1. Give three example of laminar and three examples of turbulent flow.
2. Calculate velocity of a wind that blows perpendicular to the wall and applies 200 Pascal pressure. Density of air is 1.29 kg/m^3.
3. Water flows from large pipe to small pipe. Speed of water in large pipe is 20 cm/sec. Calculate speed of water in small pipe that has diameter 1.5 times smaller than diameter of large pipe.



4. At what height area of water stream of fountain will be three times bigger than area of water pipe of fountain? Speed of water in water pipe is 15 m/s.

5.2 Torricelli's law

You will

- apply Torricelli's law for solving experimental and analytical problems.

Question:

Why does water flow slow down when water level in the tank decreases?

Torricelli's law

Let us remember Bernoulli's law.

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g h_2$$

This law can be applied to any ideal fluid. Italian scientist Evangelista Torricelli, in 1643, applied it to the fluid flowing out from the orifice in the tank, Figure 38.

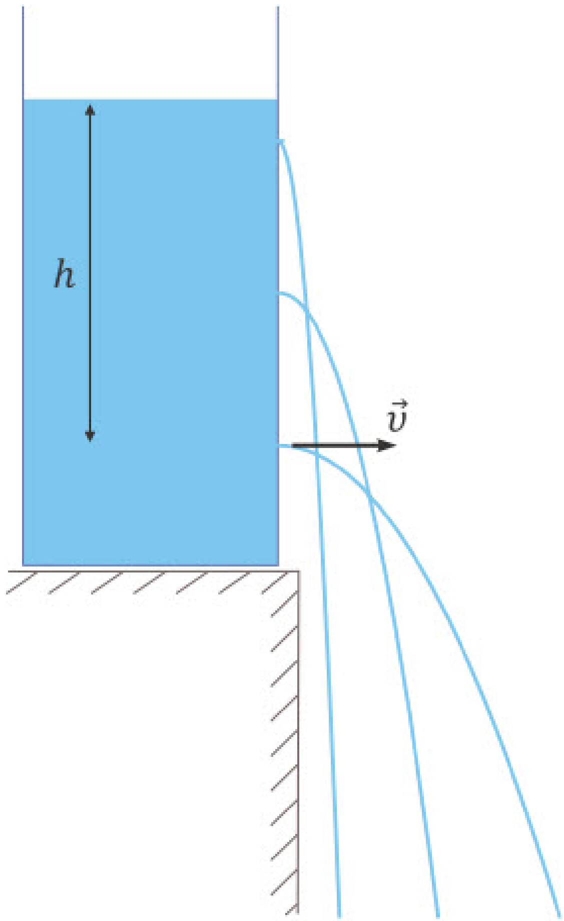


Figure 38

As we know from our daily experience, speed of flow is the greatest when the height of liquid above orifice is the greatest. Why?

First of all, we assume that pressures P_1 and P_2 are same and equal to atmospheric pressure P_0. Secondly, we neglect υ_1 because A1>>A2 , which means $\upsilon_1 << \upsilon_2$.

$$\upsilon_1 \ll \upsilon_2 \qquad \upsilon_1 = \upsilon_2 \frac{A_2}{A_1} \qquad \upsilon_1^2 \approx 0$$

Next, we assume that $h_2=0$, $h_1=h$ and $\upsilon_2=\upsilon$. By using these assumptions we solve Bernoulli's equation, Figure 39.

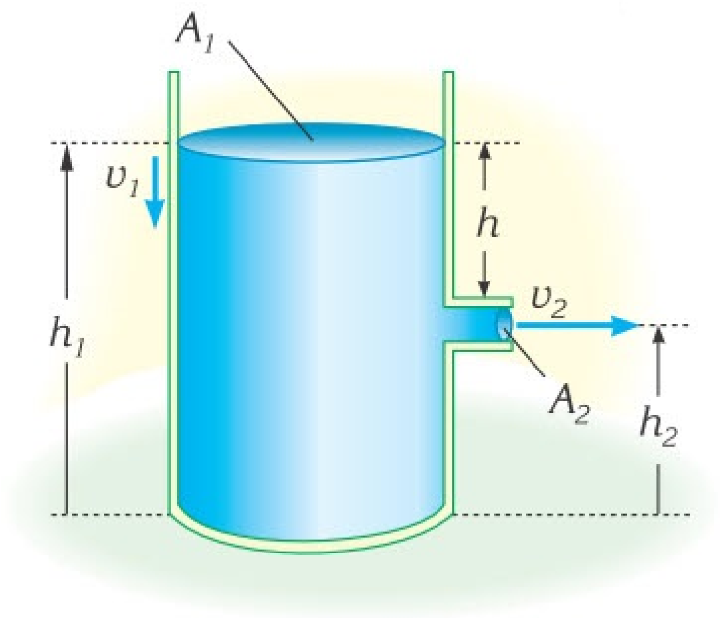
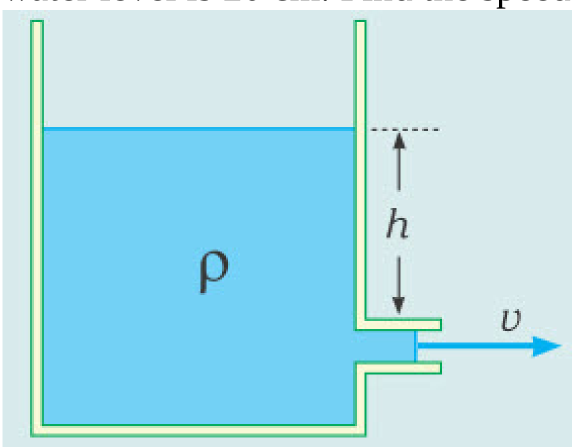


Figure 39

The expression $\upsilon=\sqrt{2gh}$ is called Torricelli's law. It is a particular case of Bernoulli's principle.

Example

Water flows through a small hole on the side of an aquarium. Height of water level is 20 cm. Find the speed with which water pours out of the hole.



Given:
$h = 20 \text{ cm} = 0.2 \text{ m}$
$g \approx 10 \text{ m/s}^2$
$v = ?$

Formulas:
$\vec{v} = \sqrt{2gh}$

Calculations:
$v = \sqrt{2 \cdot 10 \cdot 0.2}$ $v = \sqrt{4}$ $v = 2 \text{ m/s}$

Activity

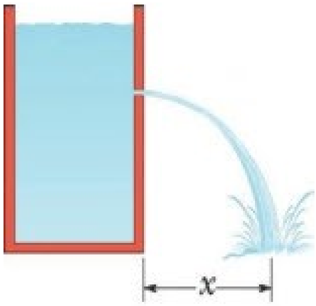
Equipment:
2 litre plastic bottle, nail, water, plastic container, tape.

Procedure:
- make three holes in the side of the bottle
- holes should be about 5 cm apart
- cover the holes with tape
- fill the bottle with water
- pull the tape off

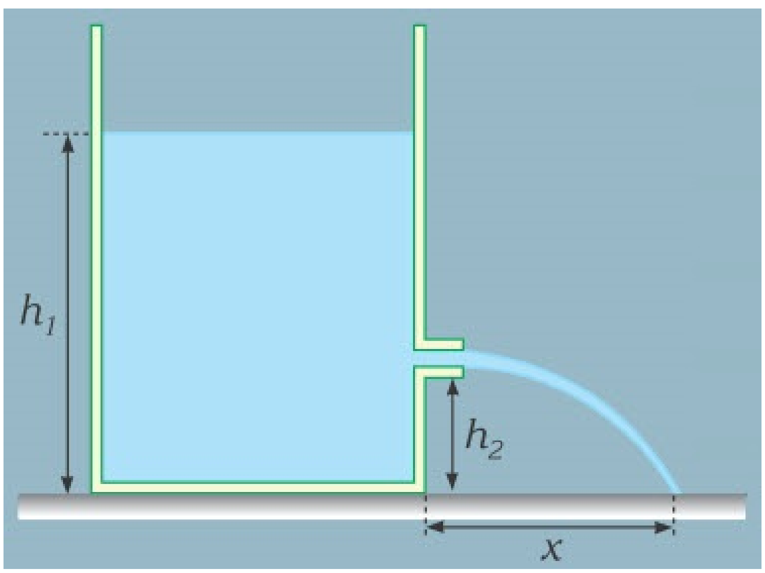
Questions:
- Which stream goes the farthest? Why?
- What does happen when level of water decreases? Why?

Literacy

1. Small crack opens in water tank at height of 0.1 metre from bottom. Water tank is filled with water to 1 metre height. At what distance from the water tank will stream hit the ground?



2. Water flows out of a small opening on the side of a container at a height h_2=5 cm from the floor, as shown in the figure. At what horizontal distance from the container does the water jet fall on the floor, when the water level in the container is h_1 =50 cm, measured from the floor?



Research time

Make non-Newtonian fluid from starch. Observe and compare its behaviour with regular fluid.

5.3 Flow of viscous fluid. Stokes' law. Archimedes' Force

You will

- apply Stokes' law for solving experimental and analytical problems

Question

Why some fluids flow slowly (like honey) and some fluids flow quickly (like water)?

Viscosity

Viscosity is the capacity of liquid to resist the movement.

Viscosity of a liquid decreases with increasing temperature. As temperature increases, the average speed of the molecules in a liquid increases and the contact time with particles decreases. Thus, as temperature increases, the average intermolecular forces decrease.

The viscosity of gases increases as temperature increases and is approximately proportional to the square root of temperature. This is due to the increase in the frequency of intermolecular collisions at higher temperatures. The more these molecules collide with one another, the more disorganised their motion becomes.

Since viscosity is so dependent on temperature, it should never be stated without it, Table 2.

fluid	T(°C)	η (mPa·s)
air	15	0.0179
blood	37	3-4
helium	0	0.0186
honey	20	10000
ketchup	20	50000
mercury	15	1.55
milk	25	3
oxygen	0	0.0181
water	0	1.79
water	20	1.00
water	40	0.65
water	100	0.28

Table 2

Stokes' Law

Consider the spherical object falling in viscous fluid. The object reaches terminal velocity almost immediately when it begins its journey. In order for something to reach terminal velocity when falling down under gravity's pull, there must be an equal force acting upon it. That force is provided by the viscous fluid.

This relationship is given by Stokes' law, which states that

$$\mathbf{F_S=6\pi r\eta \upsilon}$$

where F_S is viscous force acting on falling object, r is the radius of the spherical object, η is the viscosity of the fluid, and υ is the object's velocity. Unit of measurement of viscosity is Pascal.second.

This equation tells us that the larger the object, the larger the force that acts on it when it is moving through a fluid at terminal velocity.

Archimedes' Force (Upthrust)

Any object submerged in the fluid experiences Archimedes' force (upthrust force). Its direction is upward. Formula of upthrust is

$$F_A=\rho Vg$$

where ρ is density (kg/m^3), V is volume of displaced fluid (m^3) and g is gravitational acceleration.

Research time

Gather two or three fluids (syrup, motor oil, honey, olive oil, etc.) and a thick, tall clear glass or vase. Drop the marble into the centre of the fluid and record time of fall (after letting it drop a little to reach its terminal speed). Compare your values for the terminal speed and see if they are inversely proportional to the viscosities (find them in internet). Does it make a difference if the marble is dropped near the side of the glass?

Example

Suppose an aluminium ball (density 2700 kg/m^3, diameter 5 mm) is dropped in Mariana Trench. Mariana Trench is the deepest part of ocean (11034 metres). How long does it take for the ball to fall down on the ocean floor? Density of seawater is 1025 kg/m^3, viscosity of seawater is 0.0015 Pa·s.

Given:

$\rho = 2700\ kg/m^3$

$d = 5\ mm$

$r = \frac{d}{2} = 2.5\ mm = 0.0025\ m$

$s = 11034\ m$

$\rho_w = 1025\ kg/m^3$

$\eta = 0.0015\ Pa \cdot s$

Formulas:

$V = \frac{4}{3}\pi r^3$

$m = \rho V$

$F_A = \rho_w V g$

$mg = F_A + F_s$

$F_S = 6\pi r \eta \upsilon$

$s = \upsilon t$

Calculations:

$$V = \frac{4}{3}\pi r^3 = \frac{4}{3} \cdot 3.14 \cdot 0.0025^3$$

$$V = 6.54 \cdot 10^{-8}\ m^3$$

$$mg = F_A + F_s$$

$$\rho V g = \rho_w V g + 6\pi r \eta \upsilon$$

$$\upsilon = \frac{\rho V g - \rho_w V g}{6\pi r \eta} = \frac{(\rho - \rho_w) V g}{6\pi r \eta}$$

$$\upsilon = \frac{(2700 - 1025) \cdot 6.54 \cdot 10^{-8} \cdot 10}{6 \cdot 3.14 \cdot 0.0025 \cdot 0.0015}$$

$$\upsilon = 15.5\ m/s$$

$$t = \frac{s}{\upsilon} = \frac{11034}{15.5} = 711.2\ s$$

Literacy

1. What is definition of viscosity?
2. Why some liquids are more viscous than other liquids?
3. Determine drag force that acts on helium balloon of 30 cm diameter when it moves at terminal speed. Density and viscosity of air are 1.29 kg/m^3 and $0.018 \cdot 10^{-3}$ Pa·sec. Density of helium is 0.18 kg/m^3. Also calculate terminal speed of helium balloon.

4. Plankton (micro-organism living in ocean) dies and starts to fall to the ocean floor 1.5 km deep. Calculate terminal velocity and time needed for plankton to fall on the ocean floor. Assume plankton to be a sphere with 10 μm diameter and 1500 kg/m^3 density. Density and viscosity of ocean water are 1025 kg/m^3 and 0.0015 Pa·s.

5. When oil is produced water mixes with oil. Then we put this mixture in the huge tank and wait for water to settle down. Water droplets have diameter of 50 μm, density of water is 1000 kg/m^3. Density and viscosity of oil are 800 kg/m^3 and $5 \cdot 10^{-3}$ Pa·sec. Determine time of segregation of water and oil if height of the tank is 5 metre.

6. Determine drag force acting on a water droplet of 1 μm diameter if air current is moving upwards at 5 m/s. Viscosity of air is $0.018 \cdot 10^{-3}$ Pa·sec.

Does this water droplet move upwards or downwards? How do clouds move upwards or downwards?

Activity

Find or make "Marsh funnel". Take different fluids, for example, water, salty water, vegetable oil, honey, motor oil, syrup, milk, ketchup, etc. Measure their viscosities by Marsh funnel. Find the most viscous and the least viscous fluid.

Important note

Viscosity is the degree of internal friction in the fluid.

Career

Mud engineers use Marsh funnel for measuring viscosity by measuring the time it takes a known volume of liquid to flow from a cone through a short tube.

Is it true?

Bitumen is the most viscous fluid .

Physics in life

Geese fly in a V formation to help each other overcome air resistance (viscosity).

LAB WORK #5

Title:

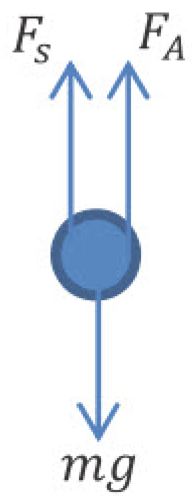
Relationship between velocity and radius of sphere moving in viscous fluid

You will

- determine factors that affect outcome of experiment, propose ways of improving experiment.

Theory:

When a spherical object is moving in a viscous fluid there are three forces acting on it: mg ,F_A, F_S.



$$F_s = 6\pi r\eta v$$

$$F_A = \rho_{liq} V g$$

For simplicity let's assume acceleration is zero.

a=0

Now let's write Newton's second law for y-axis.

$$\vec{F} = m\vec{a}$$

$$-mg + 6\pi r\eta v + \rho_{liq}Vg = 0$$

$$\rho = \frac{m}{V}$$

$$-\rho Vg + 6\pi r\eta v + \rho_{liq}Vg = 0$$

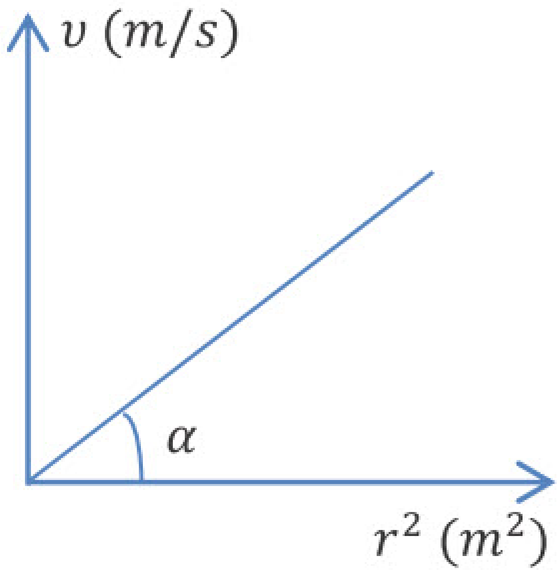
$$6\pi r\eta v = (\rho - \rho_{liq})Vg$$

$$V = \frac{4}{3}\pi r^3$$

$$6\pi r\eta v = (\rho - \rho_{liq})\frac{4}{3}\pi r^3 g$$

$$v = \frac{2(\rho - \rho_{liq})gr^2}{9\eta}$$

By using this formula we can plot υ and r^2 graph. Graph should show straight line.



Slope of this graph is

$$\tan\alpha = \frac{2(\rho - \rho_{liq})g}{9\eta}$$

That means we will calculate slope from the graph and use it to calculate viscosity of the liquid.

$$\eta = \frac{2(\rho - \rho_{liq})g}{9\tan\alpha}$$

Equipment:

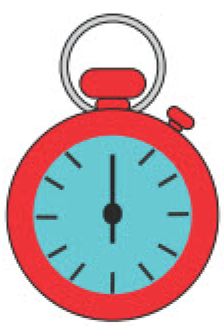
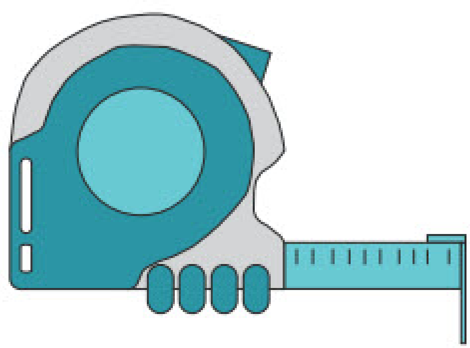
1. Safety glasses

2. Gloves

3. Marbles or ball bearings of different sizes

4. Tall graduated cylinder filled with lqiuid

5. Stopwatch and measuring tape

Procedure:

1. Take five marbles or ball bearings of different sizes. If you take glass marbles then ρ_{glass}=2600 kg/m^3, if you take steel ball bearings then ρ_{steel}=7200 kg/m^3.
2. Fill tall graduated cylinder with water. Use ρ_{liquid}=7200 kg/m^3.
3. Measure radii r of the spherical objects and record them in the table.

4. Measure distance s that the spherical objects will fall and record it in the table.
5. Drop spherical objects in liquid and measure times of travel t and record them in the table.
6. By using formula

$$\upsilon = \frac{s}{t}$$

calculate velocity υ of each spherical object.
7. Use values of υ and r^2 in the table to draw graph.
8. Use graph to calculate tanα.
9. By using tanα formula calculate viscosity of liquid η.

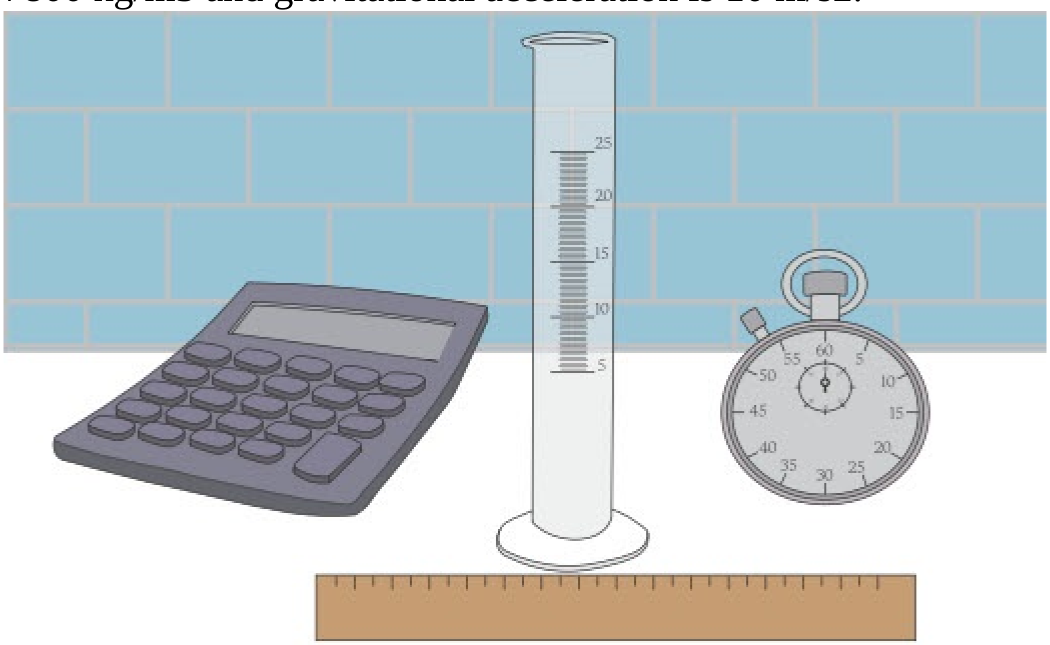
№	$r\ (m)$	$t\ (s)$	$s\ (m)$	$\upsilon\ (m/s)$	$r^2\ (m^2)$
1					
2					
3					
4					
5					

Conclusion:

1. What is relationship between velocity of the object and its radius? Which marbles fall faster: big marbles or small marbles? Why?
2. Compare experimental viscosity of liquid that you have found and viscosity of liquid given in the books or the web. Which one is greater? Why?
3. Propose ways of improving experiment. How can you reduce systematic errors and random errors?

CHECK YOURSELF

“Marble viscosity” experiment was performed. In this experiment there were two different liquids and steel marble of 5 mm diameter. Liquids were put in tall measuring cylinders so that liquid column was 50 cm high. Then marble was dropped into each liquid. Time of fall of marble in the first liquid was 57.14 sec, in the second liquid time of fall was 281.25 sec. Second liquid is about 5 times more viscous than first liquid. Also, first liquid is more dense than second liquid by 100 kg/m3. Density of steel is 7800 kg/m3 and gravitational acceleration is 10 m/s2.



1. What is velocity of the marble in the first liquid?

A) $8.75 \cdot 10^{-3}$ m/s

B) $7.75 \cdot 10^{-3}$ m/s

C) $6.75 \cdot 10^{-3}$ m/s

D) $5.75 \cdot 10^{-3}$ m/s

E) $4.75 \cdot 10^{-3}$ m/s

2. What is velocity of the marble in the second liquid?

A) $1.78 \cdot 10^{-3}$ m/s
B) $2.78 \cdot 10^{-3}$ m/s
C) $3.78 \cdot 10^{-3}$ m/s
D) $4.78 \cdot 10^{-3}$ m/s
E) $5.78 \cdot 10^{-3}$ m/s

3. What is volume of the steel marble?
A) $3.54 \cdot 10^{-8}$ m3
B) $4.54 \cdot 10^{-8}$ m3
C) $5.54 \cdot 10^{-8}$ m3
D) $6.54 \cdot 10^{-8}$ m3
E) $7.54 \cdot 10^{-8}$ m3

4. What is mass of the steel marble?
A) $5.1 \cdot 10^{-5}$ kg
B) $5.1 \cdot 10^{-4}$ kg
C) $5.1 \cdot 10^{-3}$ kg
D) $5.1 \cdot 10^{-2}$ kg
E) $5.1 \cdot 10^{-1}$ kg

5. What is weight of the steel marble?
A) $5.1 \cdot 10^{-5}$ N
B) $5.1 \cdot 10^{-4}$ N
C) $5.1 \cdot 10^{-3}$ N
D) $5.1 \cdot 10^{-2}$ N
E) $5.1 \cdot 10^{-1}$ N

6. What is density of the first liquid?
A) 1300 kg/m^3
B) 1400 kg/m^3
C) 1500 kg/m^3
D) 1600 kg/m^3
E) 1700 kg/m^3

7. What is density of the second liquid?
A) 1300 kg/m^3
B) 1400 kg/m^3
C) 1500 kg/m^3
D) 1600 kg/m^3
E) 1700 kg/m^3

8. What is viscosity of the first liquid?
A) 10 Pa·s
B) 20 Pa·s
C) 30 Pa·s
D) 40 Pa·s
E) 50 Pa·s

9. What is viscosity of the second liquid?
A) 50 Pa·s
B) 100 Pa·s
C) 150 Pa·s
D) 200 Pa·s
E) 250 Pa·s

10. What is upthrust force of the first liquid on the steel marble?

A) 7.8×10^{-4} N
B) 8.8×10^{-4} N
C) 9.8×10^{-4} N
D) 10.8×10^{-4} N
E) 11.8×10^{-4} N
11. What is upthrust force of the second liquid on the steel marble?
A) $9.16\cdot10^{-4}$ N
B) $8.16\cdot10^{-4}$ N
C) $7.16\cdot10^{-4}$ N
D) $6.16\cdot10^{-4}$ N
E) $5.16\cdot10^{-4}$ N

12. What is Stokes' drag of the first liquid on the steel marble?
A) $3.12\cdot10^{-3}$ N
B) $4.12\cdot10^{-3}$ N
C) $5.12\cdot10^{-3}$ N
D) $6.12\cdot10^{-3}$ N
E) $7.12\cdot10^{-3}$ N

13. What is Stokes' drag of the second liquid on the steel marble?
A) $4.19\cdot10^{-3}$ N
B) $3.19\cdot10^{-3}$ N
C) $2.19\cdot10^{-3}$ N
D) $1.19\cdot10^{-3}$ N
E) $5.19\cdot10^{-3}$ N

14. What is greater, weight of marble or upthrust force of the first liquid?
A) weight

B) upthrust force
C) they are equal
D) it is impossible to determine
E) there is no right answer

15. What is greater, weight of marble or upthrust force of the second liquid?
A) weight
B) upthrust force
C) they are equal
D) it is impossible to determine
E) there is no right answer

16. What is greater, weight of marble or Stokes' drag of the first liquid?
A) weight
B) Stokes' drag
C) they are equal
D) it is impossible to determine
E) there is no right answer

17. What is greater, weight of marble or Stokes' drag of the second liquid?
A) weight
B) Stokes' drag
C) they are equal
D) it is impossible to determine
E) there is no right answer

18. What is acceleration of marble in the first liquid?
A) $1 \cdot 10^{-3}$ m/s2
B) $2 \cdot 10^{-3}$ m/s2
C) $3 \cdot 10^{-3}$ m/s2
D) $4 \cdot 10^{-3}$ m/s2

E) 0

19. What is acceleration of marble in the second liquid?
A) $1 \cdot 10^{-3}$ m/s2
B) $2 \cdot 10^{-3}$ m/s2
C) $3 \cdot 10^{-3}$ m/s2
D) $4 \cdot 10^{-3}$ m/s2
E) 0

20. How long would steel marble of 10 mm diameter fall in the first liquid?
A) 10.29 sec
B) 12.29 sec
C) 14.29 sec
D) 16.29 sec
E) 18.29 sec

21. How long would steel marble of 10 mm diameter fall in the second liquid?
A) 70.31 sec
B) 60.31 sec
C) 50.31 sec
D) 40.31 sec
E) 30.31 sec

22. What is name of the first liquid? Use tables in previous topics.
A) water
B) ketchup
C) honey
D) blood
E) milk

23. What is name of the second liquid? Use tables in previous topics.
A) water
B) ketchup
C) honey
D) blood
E) milk

24. What should be diameter of steel marble so that it falls in the first liquid in exactly 100 sec?
A) 3.78 mm
B) 2.78 mm
C) 1.78 mm
D) 0.78 mm
E) 4.78 mm

25. What should be diameter of steel marble so that it falls in the second liquid in exactly 100 sec?
A) 9.39 mm
B) 10.39 mm
C) 6.39 mm
D) 7.39 mm
E) 8.39 mm

Fluid mechanics

1. Water flows through a pipe of varying cylindrical cross-section. The speed of the water is 4 m/s when the pipe radius is 3 cm. What is the speed of water through a cross-section of 6 cm radius?

2. The speed of an incompressible fluid increases as the cross-sectional area of the pipe through which it is flowing decreases. By what factor does the diameter of the pipe decrease for an increase in flow speed by a factor of 4?

3. Water comes out of a tap at a speed of 1 m/s. The cross-sectional area of the water exit is 2 cm2. How many kilograms of water is wasted when the tap is accidentally left on for 1 hour?

4. Explain why the water stream from a kitchen tap gets narrower as water flows downward.


NITROGEN
ARGON
PROPANE
HELIUM
OXYGEN
HYDROGEN
ACETYLENE

CHAPTER 6: GASES

6.1 Molecular-kinetic theory

You will

- describe relationship between temperature and average kinetic energy of translational motion of molecules.

Question

Are speeds of molecules of vapour, water and ice same or different?

There are three basic assumptions in molecular - kinetic theory

- All matter consists of small particles
- The particles are in ceaseless irregular motion
- The particles interact with each other

Careful observation gives us hints about the molecular nature of matter. Diffusion in liquids and gases for example, is best explained in terms of molecular motion.
A drop of ink allowed to fall into water is distributed throughout the whole volume of water in a short time, even if the water is not externally stirred,

Figure 40. A similar phenomenon can be observed when perfume is sprayed in one corner of a room.

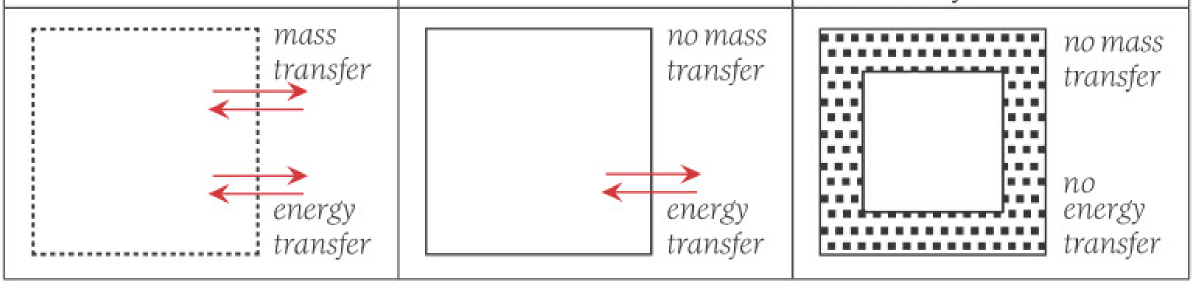
Figure 40

Thermodynamic system

Thermodynamic system is a definite macroscopic region or space in the universe, in which one or more thermodynamic processes take place. Everything external to a thermodynamic system is called surroundings. System and surroundings are separated by a definite border called boundary. Thermodynamic systems can be classified into three types: open system, closed system, isolated system, shown on Figure 41.

Figure 41

Open system	Closed system	Isolated system
An open system is a thermodynamic system which allows both mass and energy to flow in and out of it, across its boundary.	A closed system allows only energy to pass in and out of it. It does not allow mass transfer across its boundary.	An isolated system does not interact with its surroundings. It does not allow both mass and energy transfer across its boundary



State of a system

Any characteristic of a system is a system property. The state of a system is described by set of properties. To describe a state, the properties that completely describe the exact condition of a system must be chosen.

There are two types of thermodynamic parameters:

Macroscopic parameters (describe whole thermodynamic system) - temperature, volume, pressure, mass, etc

Microscopic parameters (describe single molecule's motion) - mass of molecule, its velocity, impulse, kinetic energy, etc

An equilibrium state is an internal state of a thermodynamic system(s) when no net macroscopic flows of matter or energy happen, either within a system or between systems. When a gas sample is in equilibrium, microscopic parameters change in time. However, macroscopic parameters remain constant.

When a gas sample is in equilibrium, there are definite values of P and T. In other words, pressure or temperature of a gas have well defined values only when the gas sample is in equilibrium state.

Activity

Open "Phet States of Matter". Observe what happens when you give heat to gas molecules. How do their motion change? What can be done to slow down the gas molecules?

Research time

What happens at zero Kelvin (-237.15 degrees of Celsius)? How does the particles behave?

Literacy

1. How does temperature change if average kinetic energy of molecules doubles?
2. How does temperature change if root mean square speed of molecules doubles?
3. Root mean square speed of molecules of gas is 500 m/s at 7.8oC. Use periodic table of elements to determine type of gas.
4. Average kinetic energy of molecules of gas is 1.035·10-20 Joule. What is temperature of gas in degrees of Celsius?
5. Plot temperature-velocity graph for molecules of helium gas. Use table below.

RMS speed (m/s)	0	100	200	300	400	500	600	700	800	900	1000
Temperature (Kelvin)											

6. Plot temperature-energy graph for molecules of neon gas. Use table below.

Average Kinetic Energy (10^{-21} Joule)	0	2	4	6	8	10	12	14	16	18	20
Temperature (Kelvin)											

Important note

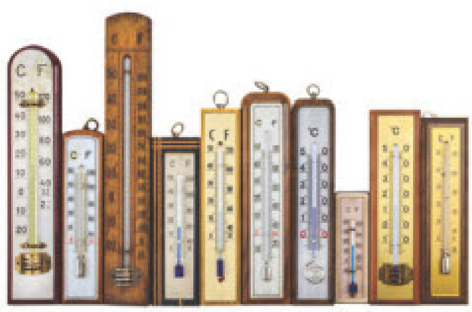
Two objects are in thermal contact if energy can be exchanged between them. Two objects are in thermal equilibrium if they are in thermal contact and there is no net exchange of energy.

6.2 Temperature as a measure of average kinetic energy of motion of particles

You will

- describe relationship between temperature and average kinetic energy of chaotic translational motion of molecules.

Question



Who did invent the first thermometer? How did people live without thermometers?

Temperature

Temperature is commonly associated with how hot or cold an object feels when we touch it. Thermometers are used to measure temperature according to scales of measurement, which use predefined reference points to help compare quantities. The three most common temperature scales are the Fahrenheit, Celsius and Kelvin scales.

The Kelvin scale is the temperature scale that is commonly used in science. It is an absolute temperature scale defined to have 0 K at the lowest possible temperature, called absolute zero. The official temperature unit on this scale is the kelvin, which is abbreviated as K, and is not accompanied by a degree sign. The freezing and boiling points of water are 273.15 K and 373.15 K, respectively. Thus, the magnitude of temperature difference is the same in units of Kelvins and degrees Celsius. Unlike other temperature scales, the Kelvin scale is an absolute scale. It is used extensively in scientific work because a number of physical quantities, such as the volume of an ideal gas, are directly related to absolute temperature.

Molecular – kinetic theory relates temperature of a substance to the motion of molecules forming the substance. All molecules in any matter are in a continuous random state of motion called thermal motion. The temperature of a substance is related to thermal motion of its molecules. Higher temperature relates to faster moving molecules.

Molecules of a gas can have a wide range of velocities, and the speed of a molecule changes millions of times in a second, due to collisions with other molecules surrounding it. The kinetic energies of molecules of a gas are quite different. However, the average kinetic energy of molecules gives us an idea about the overall behaviour of a gas sample.

The temperature of a gas is a direct measure of the average molecular kinetic energy of the gas.

The relationship between temperature and translational molecular kinetic energy is:

(Average KE of molecules of gas) = (a constant) × (temperature)

$$E_K = \frac{3}{2}kT$$

(derivation of this formula will be provided later)

where we have used

$$k = \frac{R}{N_A} = 1.38 \cdot 10^{-23}\ \frac{J}{K}$$

for Boltzmann’s constant.

Temperatures must always be in Kelvins.

The square root of υ^2 is called the root-mean-square (rms) speed of the molecules. We can get rms by:

$$\frac{m_0 v^2}{2} = \frac{3}{2}kT \qquad v_{rms} = \sqrt{\frac{3kT}{m_0}} = \sqrt{\frac{3RT}{M}}$$

where M is the molar mass in kg/mole and R is ideal gas constant. It is equivalent to the Boltzmann constant. R is measured in J/(mol.K).

Example

Find the root-mean square velocity of oxygen molecules at room temperature, T=20ºC. Take M(0_2)=32 g/mole.

Given:

$T = 20^oC = 20 + 273 = 293\ Kelvin$

$M_{O_2} = 32\ g/mole = 0.032\ kg/mole$

$R = 8.31\ J/K \cdot mole$

Formulas:

$$v_{rms} = \sqrt{\frac{3RT}{M}}$$

Calculations:

$$v_{rms} = \sqrt{\frac{3 \cdot 8.31 \cdot 293}{0.032}} = 477.77\ m/s$$

Example

A closed vessel contains an oxygen and helium mixture at 120ºC, under 2 atm of pressure. Which gas molecules have a greater translational kinetic energy on average? Take M(0_2)=32 g/mole, M(He)=4 g/mole.

Given:

$T = 120^oC = 120 + 273 = 393\ Kelvin$

$P = 2\ atm = 2 \cdot 10^5\ Pascal$

$M_{O_2} = 32\ g/mole = 0.032\ kg/mole$

$M_{He} = 4\ g/mole = 0.004\ kg/mole$

$k = 1.38 \times 10^{-23}\ J/K$

Discussion:

Average translational kinetic energy depends only on temperature. Oxygen and helium gases have same temperature. Therefore, they have same average kinetic energies.

Formulas:

$$E_{kinetic} = \frac{1}{2} m_0 v^2 = \frac{3}{2} kT$$

Calculations:

$$E_K = \frac{m_0 v^2}{2} = \frac{3}{2} kT$$

$$E_K = \frac{3}{2} \cdot 1.38 \cdot 10^{-23} \cdot 393$$

$$E_K = 8.14 \cdot 10^{-21}\ J$$

Literacy

1. What is definition of “root-mean-square speed”?
2. What is definition of “average kinetic energy of molecules”?
3. There is mixture of nitrogen and oxygen gases. Temperature of nitrogen gas is 400 Kelvin. What is temperature of oxygen gas? Which gas has higher average kinetic energy of molecules? Which gas has higher root mean square speed? Answer these questions and fill this table.

	Temperature (Kelvin)	Average Kinetic Energy (Joule)	Root mean square speed (m/s)
Nitrogen			
Oxygen			

4. Average kinetic energy of molecules of gas is $6.21 \cdot 10^{-21}$ Joule. Root mean square speed of molecules is 1367.19 m/s. Use periodic table of elements to determine type of gas.
5. Which particles have bigger average kinetic energy, helium atoms with 1000 m/s rms speed or oxygen molecules with 500 m/s rms speed?
6. Draw velocity-temperature graph for air molecules from 0°C to 10°C. Molar mass of air is 29 g/mole. Use table below.

Temperature (Celsius)	0	1	2	3	4	5	6	7	8	9	10
RMS speed (m/s)											

Activity

Open "Phet Gas Properties". Use this simulation to determine speed of molecules at 0, 100, 200, 400, 800 Kelvin, etc.

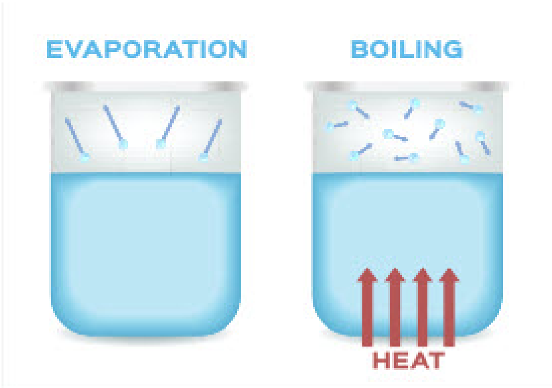
Research time

Illustrate process by which our body senses high or low temperature.

Physics in life

When we touch hot objects our body makes reflex and we pull our hand because molecules of hot metal objects hit nerves of our hands.

Physics in life



Evaporation happens because some molecules have more kinetic energy than average kinetic energy of whole liquid.

Important note

The root mean square (rms) value of a variable has a similar meaning to the average value.

$$v_{rms} = \sqrt{\frac{v_1^2 + v_2^2 + v_3^2 + \cdots + v_N^2}{N}}$$

Important note

Two objects in thermal equilibrium with each other are at the same temperature.

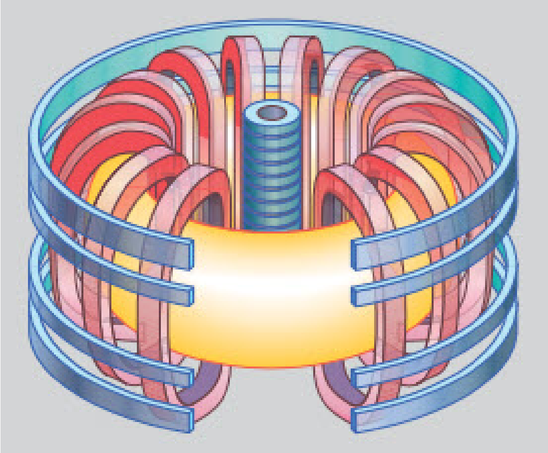
Important note

Mass of one molecule is equal to

$$m_0 = \frac{m}{N} = \frac{M}{N_A}$$

Is it true?

Temperature inside of the thermonuclear fusion reactors can reach 150 million degrees of Celsius.



Is it true?

Scientists use lasers to obtain extreme cold temperatures. They decrease kinetic energy of molecules by using laser beams.

6.3 Ideal gas. Equation of molecular-kinetic theory

You will

- describe ideal gas model.
- apply equation of molecular-kinetic theory for problem solving.

Question

Why air pressure is low at high mountain peaks?

Ideal gas

A gas is said to be 'ideal' if it has the following properties:

- All matter is made up of molecules endlessly moving around in a random fashion.
- Gas molecules obey Newton's laws of motion.
- The total volume of gas molecules is nearly zero, compared to the total volume of the gas. This means that if the gas molecules stop moving, the volume becomes zero.
- There is no force between gas molecules, except during a collision.
- Collisions between gas molecules, or between the walls of a container and gas molecules are elastic. This means the total kinetic energy does

not change.

To summarise, the particles of an ideal gas behave like billiard balls flying around in a steel-walled room.

Which gases are ideal, which gases are not? The answer is that no gas is ideal. Molecules of all gases more or less interact with each other, giving rise to intermolecular potential energies, and no gas is compressible to zero volume. However, nearly all gases can be treated as ideal gases at low densities.

The pressure of an ideal gas

The pressure p of an ideal gas is the result of the collisions of the molecules of the gas with the walls of the container, Figure 42.

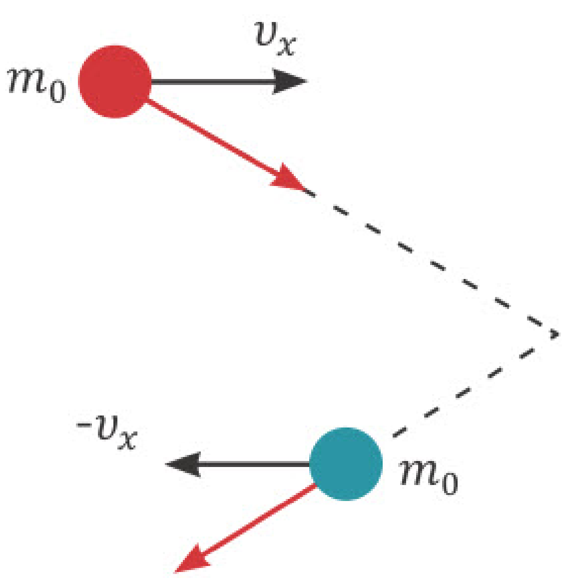


Figure 42

It can be calculated by the expression

$$p = \frac{2}{3} n \left(\frac{m_0 \bar{\upsilon}^2}{2} \right)$$

Therefore, the pressure of a gas is proportional to:

1. Molecular concentration (n)
2. The average kinetic energy of the gas molecules ($1/2 \times m_o \times \upsilon_{rms}^2$) .

Both factors increase the momentum delivered to the wall by the gas molecules in unit time.

Increasing n increases the number of impacts on the wall in unit time. Increasing the average kinetic energy, increases both the momentum transfer during one collision and the number of collisions in unit time.

Since

$$nm_0 = \frac{N}{V}\frac{m}{N} = \frac{m}{V} = \rho;$$

then

$$p = \frac{1}{3}\rho\bar{v}^2$$

Example

There is an oxygen gas in the container at 200 kPa pressure. Root mean square speed of the molecules is 400 m/s. What is the molecular concentration?

Given: $p = 200 \cdot 10^3$ Pa $\quad \bar{v} = 400$ m/s

$M = 32 \cdot 10^{-3}$ kg/mol $\quad N_A = 6.02 \cdot 10^{23}$

Formulas:

$$p = \frac{2}{3}n\left(\frac{m_0\bar{v}^2}{2}\right) \qquad n = \frac{3p}{m_0\bar{v}^2}$$

$$m_0 = \frac{M}{N_A} \qquad n = \frac{3pN_A}{M\bar{v}^2}$$

Calculations:

$$n = \frac{3 \cdot 200 \cdot 10^3 \cdot 6.02 \cdot 10^{23}}{32 \cdot 10^{-3} \cdot 400^2}$$

$$n = 7.05 \cdot 10^{25}\ \text{molecules/m}^3$$

Example

What is the density of nitrogen gas under 100 kPa pressure, if the root mean square velocity of nitrogen molecules is 480 m/s?

Given:	Formulas:	Calculations:
$p = 100\ kPa = 100000\ Pa$ $v = 480\ m/s$	$p = \frac{1}{3}\rho\bar{v}^2$	$\rho = \frac{3p}{\bar{v}^2} = \frac{3 \cdot 100000}{480^2}$ $\rho = 1.3\ kg/m^3$

Literacy

1. How does pressure of gas changes when rms speed doubles?
2. How does pressure of gas changes when temperature doubles?
3. What is pressure of gas that has 2.5×10^{25} m^{-3} concentration and 20°C temperature?
4. What is pressure of oxygen gas that has 3×10^{25} m^{-3} concentration and 300 m/s rms speed?
5. Calculate pressure of gas at 27°C at different concentrations and plot pressure-concentration graph (use logarithmic scale or semi-logarithmic scale).

Number of molecules in one cubic millimetre	1	10	1000	1000000	1000000000	1000000000000	1E+18
Pressure (Pascal)							

6. Calculate average distance between molecules of air at 27°C and standard atmospheric pressure.

Activity

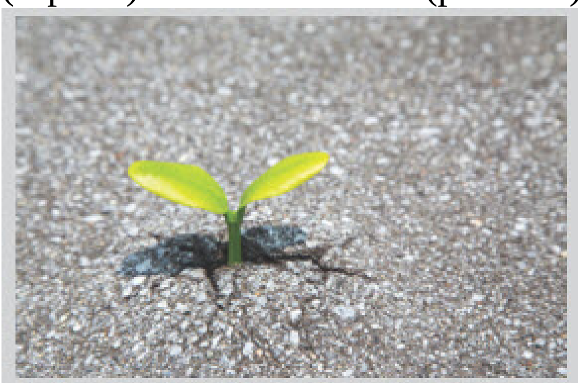
Open "Phet Gas Properties". Use criteria of ideal gas in the text to determine if simulation shows ideal gas or not ideal gas.

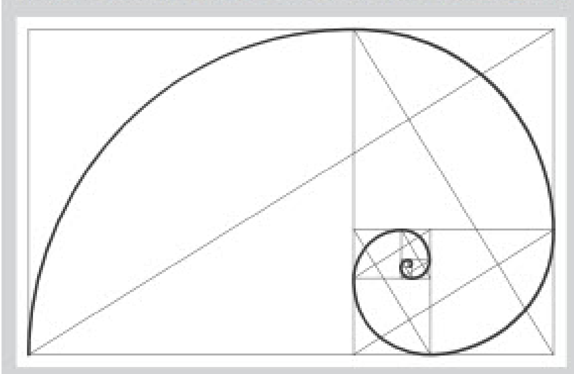
Research time

Find the υ_{rms} of O_2 molecules in your room.

New mindset

Sprout can grow through asphalt because it applies pressure of 1000 atm during growth. So this fact tells us we have to pass through difficulties (asphalt) with our stamina (pressure).



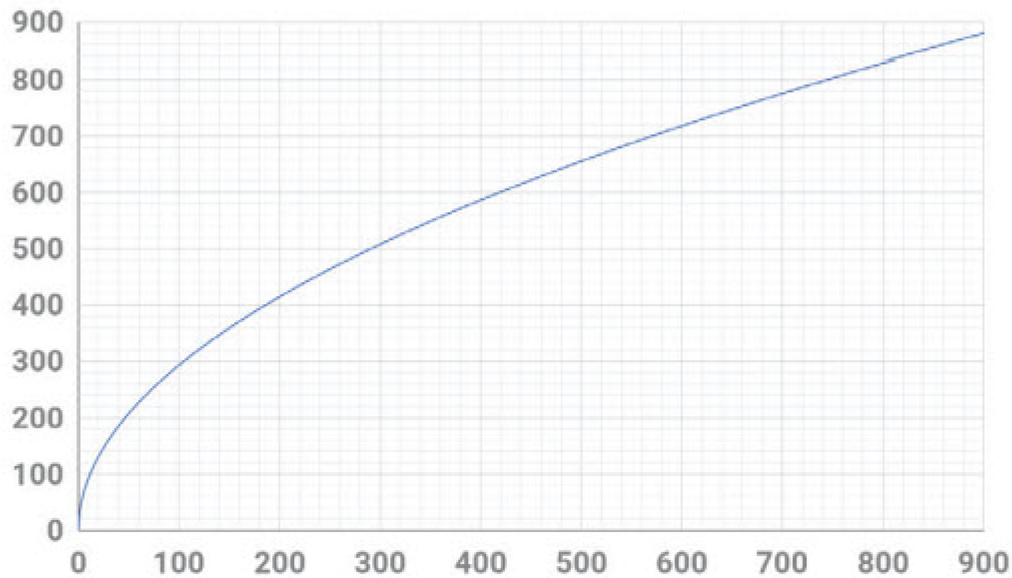


Physics in life

For fast and delicious cooking pressure cooker is used. What is its advantage?

Check yourself

There is graph that shows relationship between temperature and root mean square speed of molecules of 5 moles of unknown gas in 50 litre container.



1. What parameter is shown on the vertical axis of graph?

A) Temperature in Celsius

B) Temperature in Kelvin

C) Root mean square speed in km/h

D) Root mean square speed in m/s

E) There is no right answer

2. What parameter is shown on the horizontal axis of graph?

A) Temperature in Celsius

B) Temperature in Kelvin

C) Root mean square speed in km/h

D) Root mean square speed in m/s

E) There is no right answer

3. What is molar mass of the gas?

A) 0.039 kg/mole

B) 0.029 kg/mole

C) 0.019 kg/mole

D) 0.049 kg/mole

E) 0.059 kg/mole

4. What gas is it?

A) Oxygen

B) Air

C) Carbon dioxide

D) Nitrogen trifluoride

E) Hydroxylamine

5. What is mass of gas?

A) 45 g

B) 145 g

C) 245 g

D) 345 g

E) 445 g

6. What is mass of one molecule of gas?

A) $2.82 \cdot 10^{-26}$ kg

B) $3.82 \cdot 10^{-26}$ kg

C) $4.82 \cdot 10^{-26}$ kg

D) $5.82 \cdot 10^{-26}$ kg

E) $6.82 \cdot 10\text{-}^{26}$ kg

7. What is number of molecules of gas?

A) $1.01 \cdot 10^{24}$

B) $2.01 \cdot 10^{24}$

C) $3.01 \cdot 10^{24}$

D) $4.01 \cdot 10^{24}$

E) $5.01 \cdot 10^{24}$

8. What is concentration of gas?

A) $2.02 \cdot 10^{25}$ m^{-3}

B) $3.02 \cdot 10^{25}$ m^{-3}

C) $4.02 \cdot 10^{25}$ m^{-3}

D) $5.02 \cdot 10^{25}$ m^{-3}

E) $6.02 \cdot 10^{25}$ m^{-3}

9. What is average kinetic energy of molecules at 27°C?

A) $2.21 \cdot 10^{-21}$ Joule

B) $3.21 \cdot 10^{-21}$ Joule

C) $4.21 \cdot 10^{-21}$ Joule

D) $5.21 \cdot 10^{-21}$ Joule

E) $6.21 \cdot 10^{-21}$ Joule

10. What is internal energy of gas at 27 °C? Assume gas is monatomic.

A) 8692.1 J

B) 18692.1 J

C) 28692.1 J

D) 38692.1 J

E) 48692.1 J

11. What is pressure of gas at 27 °C?

A) 449.3 kPa

B) 349.3 kPa

C) 249.3 kPa

D) 149.3 kPa

E) 49.3 kPa

12. Maximum pressure that container can withstand is 0.5 MPa. What is temperature of gas at that pressure?

A) 228.7 °C

B) 328.7 °C

C) 428.7 °C

D) 528.7 °C

E) 628.7 °C

13. Maximum pressure that container can withstand is 0.5 MPa. What is root mean square speed of molecules of gas at that pressure?

A) 519.2 m/s

B) 619.2 m/s

C) 719.2 m/s

D) 819.2 m/s

E) 919.2 m/s

14. Maximum pressure that container can withstand is 0.5 MPa. What is density of gas at that pressure?

A) 1.9 kg/m^3

B) 2.9 kg/m^3

C) 3.9 kg/m^3

D) 4.9 kg/m^3

E) 5.9 kg/m^3

15. How does density of gas change when temperature of gas increases from 200 K to 400 K at constant pressure?

A) increases 2 times

B) decreases 2 times

C) does not change

D) increases 4 times

E) decreases 4 times

16. How does average kinetic energy of molecules change when temperature of gas increases from 200 K to 400 K?

A) increases 2 times

B) decreases 2 times

C) does not change

D) increases 4 times

E) decreases 4 times

17. How does pressure of gas change when temperature of gas increases from 200 K to 400 K at constant volume?

A) increases 2 times

B) decreases 2 times

C) does not change

D) increases 4 times

E) decreases 4 times

18. How does concentration change when temperature of gas increases from 200 K to 400 K at constant pressure?

A) increases 2 times

B) decreases 2 times

C) does not change

D) increases 4 times

E) decreases 4 times

19. How does root mean square speed of molecules change when temperature of gas increases from 200 K to 400 K?

A) increases 1.7 times

B) decreases 1.7 times

C) does not change

D) increases 1.4 times

E) decreases 1.4 times

20. How does internal energy of gas change when temperature of gas increases from 200 K to 400 K?

A) increases 2 times

B) decreases 2 times

C) does not change

D) increases 4 times

E) decreases 4 times

Root Mean Square Value

1. Five particles have velocities of 20 m/s, 30 m/s, 40 m/s, 50 m/s and 60 m/s. What is the rms speed of these particles?

2. The root-mean-square speed of molecules of helium gas is 500 m/s. What is the average kinetic energy of the gas molecules?

3. What are the assumptions of kinetic theory concerning an ideal gas?

The Pressure of an Ideal Gas

1. What is the rms speed of oxygen molecules, if the gas has a density of 1.2 kg/m^3, under 100 kPa pressure?

2. A 100 L container holds 0.1 kg (5 moles) of neon gas at 120 kPa absolute pressure. What is the rms speed of neon molecules?

3. A sample of nitrogen gas contains 10^{20} nitrogen molecules in 1 cm^3 volume. The root-mean-square speed of nitrogen molecules is 500 m/s. What is the pressure of the gas? ($M(N_2)$=28 g/mole)

4. By what factor does the pressure of a gas change when the rms speed of gas molecules is doubled, at the same concentration?

Root-Mean-Square Velocity

1. What is the average kinetic energy of oxygen molecules at 27 ºC under 1 atm pressure?

2. What is the rms speed of nitrogen molecules at 20 ºC? ($M(N_2)$=28 g/mole)

3. A 0.05 kg gas sample is kept in a 20 L container under 100 kPa pressure. What is the rms speed of the gas molecules?

4. What is the ratio of the rms speed of helium molecules to the rms speed of nitrogen molecules at the same temperature? ($M(N_2)$=28 g/mole)

CHAPTER 7: GAS LAWS

7.1 Ideal gas equation

You will

- apply ideal gas equation for problem solving.

Question

Why blue tube is attached to the tool?

The ideal gas law is the equation of state for an ideal gas, establishing the relationship between the four parameters of a gas sample. These four parameters are pressure, volume, temperature and number of moles of the gas sample. All gases behave more or less ideally at low pressures, so, when three of these four parameters are given for any gas sample, the unknown fourth parameter can be found.

Ideal gas law is an empirical physics law. It is derived from experiment and observation, rather than theory. Experiment shows that the ratio of the products

$$\frac{(Pressure) \times (Volume)}{(Number\ of\ moles) \times (Absolute\ Temperature)}$$

equals the same constant for any gas sample.

$$\frac{pV}{\nu T} = const$$

The constant in the equation is expressed as R

$$R = \frac{pV}{\nu T} = 8.31\ \frac{J}{mole \cdot \mathrm{K}}$$

In the more famous form is,

$$pV = \nu RT$$

The constant, R, can have two different units, as shown in the Table 3.

P	V	T	R
Pa	m^3	K	8.31 J/mole · K
atm	L	K	0.082 atm · L/K

Table 3

In terms of mass and molar mass of the gas sample the equation becomes

$$pV = \frac{m}{M} RT$$

To establish a relationship between the number of molecules of a gas and its pressure, use

$$pV = \frac{N}{N_A} RT \qquad pV = N \frac{R}{N_A} T$$

N is the number of molecules of the gas, N_A is Avogadro's number.

Since both R and N_A are constants, their ratio must be physical constant. It is called the 'Boltzmann' constant' and is represented as k.

$$k = \frac{R}{N_A} = 1.38 \cdot 10^{-23}\ \frac{J}{K}$$

Thus, the ideal gas law becomes

$$pV = NkT \qquad p = \frac{N}{V} kT \qquad p = nkT$$

where n - molecular concentration.

Molecular concentration is the number of molecules in unit volume. Now the ideal gas law can be expressed in terms of molecular concentration.

Written in this form, the ideal gas law indicates that the pressure of a gas depends on two factors:

- Absolute temperature
- Molecular concentration

Density of gas

Density is mass per unit volume. Using the ideal gas law,

$$pV = \frac{m}{M}RT \qquad pM = \frac{m}{V}RT \qquad pM = \rho RT \qquad \rho = \frac{pM}{RT}$$

Therefore the density of an ideal gas is directly proportional to the pressure, and inversely proportional to the absolute temperature of the gas.

Example

Calculate the mass of air in a room with dimensions V=5 m×4 m×3 m at T=27°C and 1 atm pressure. Take average molar mass of air as M_{air}=29 g/mole.

Solution:

To determine mass, find the number of moles.

$$pV = \nu RT$$

$$\nu = \frac{pV}{RT} = \frac{10^5 \cdot 60}{8.31 \cdot 300}$$

$$\nu \approx 2400\ moles$$

Since one mole is $M = 29\ g = 0.029\ kg$

$$m = \nu M$$
$$m = 2400 \cdot 0.029$$
$$m = 69.6\ kg$$

Actually air is a mixture of mainly two gases, 80% nitrogen and 20% oxygen. Their molar masses are

$$M_{N_2} = 28\ \ g/mole$$

and

$$M_{O_2} = 32\ \ g/mole$$

Example

A mass of 12 g of helium and 20 g of neon are enclosed in a container of volume 30 lt at 400 K. Find the absolute pressure inside the container. (Take M_{He} =4 g/mole, M_{Ne} =20 g/mole.)

Solution:

Inside the container is a mixture of two gases. Is the ideal gas law still applicable? The answer is yes. Ideal gas law is applicable to any gas or mixture of gases.

To use it, we require only the number of moles of a gas. The type of gas is unimportant, as long as it behaves ideally.

Therefore, to find the total pressure, substitute the total number of moles in the container.

$$\nu_{total} = \frac{m_{He}}{M_{He}} + \frac{m_{Ne}}{M_{Ne}}$$

$$\nu_{total} = \frac{12}{4} + \frac{20}{20} = 4\ moles$$

$$pV = \nu RT$$

$$p = \frac{\nu RT}{V} = \frac{4 \cdot 8.31 \cdot 400}{30 \cdot 10^{-3}}$$

$$p = 443\ 200\ Pa\ \ \approx 4.4\ atm$$

Example

What is the density of oxygen gas at 27 under 1 atm pressure? (Take M (O_2)=32 g/mole.

Solution

Density is mass per unit volume. In the question, neither mass nor volume of the gas is given. However, the density of a gas can be found if we know the temperature and pressure.

Using the ideal gas law,

$$pV = \frac{m}{M}RT \qquad \rho = \frac{pM}{RT}$$

Therefore the density of an ideal gas is directly proportional to the pressure, and inversely proportional to the absolute temperature of the gas. In our question,

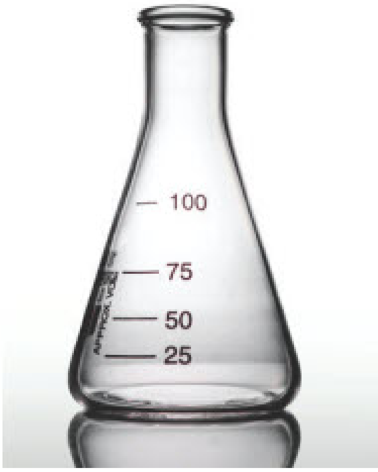
$$1\ atm \approx 10^5\ Pa,\ 27\ ^\circ\mathrm{C} \approx 300\ K$$

$$\rho = \frac{10^5 \cdot 0.032}{8.31 \cdot 300}$$

$$\rho = 1.29\ kg/m^3$$

Activity

Add 5-10 mL of water to the Erlenmeyer flask. Put air balloon on the flask. Place the balloon/flask on the hot plate and heat up the water. Write down your observations. (Do not forget safety instructions, wear goggles).

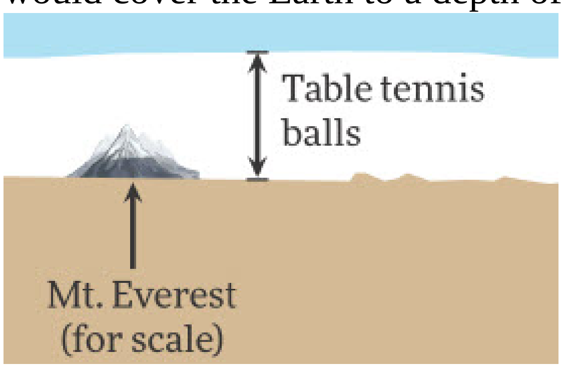


Research time

What is the pressure in human kidney ? Bigger or smaller than atmospheric pressure? Explain your answer.

New mindset

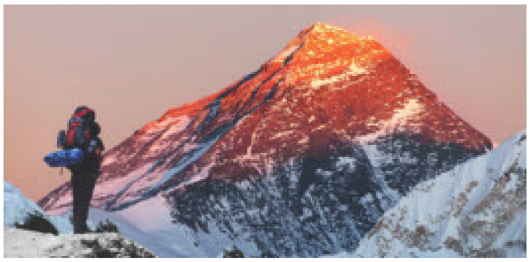
How big is a mole? On a macroscopic level, one mole of table tennis balls would cover the Earth to a depth of about 40 km.



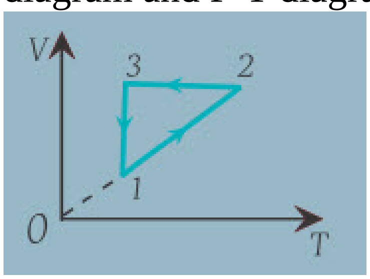
Literacy

1. What is definition of “ideal gas”?
2. How does pressure change if mole number doubles, temperature triples, and volume quadruples?
3. Calculate pressure of 1 kg of oxygen gas in vessel of 1 m^3 volume and at 27°C temperature.

4. Vessel can withstand 1568 N/cm^2 pressure before breaking. What is the minimum volume of vessel if there is 6.4 kg oxygen gas inside at 20oC temperature?
5. Atmospheric pressure on Mount Everest summit (8848 metre) is 33.7 kPa. Calculate density of air at this height at 0°C. How many times is it smaller than density at sea level (1.29 kg/m^3)? Can you breathe at Mount Everest summit?



6. There is gas cycle shown in V-T diagram. Draw same cycle in P-V diagram and P-T diagram.



7.2 Isothermal process

You will

- analyse relationship between pressure and volume during isothermal process.

Question

Why do bubbles become bigger when they rise?

Gas laws are relationships between the macroscopic parameters of a gas (pressure, volume and temperature).

Law of Boyle and Mariotte

Changing the volume and pressure of a gas sample at a constant temperature is called an isothermal process. ‘Isothermal’ means occurring at ‘constant temperature’. When a fixed amount of gas is compressed, decreasing its volume, its pressure increases, Figure 43. This law was formulated by Robert Boyle, an Irish natural philosopher, chemist, physicist and inventor. This law is also known as the Law of Boyle and Mariotte.

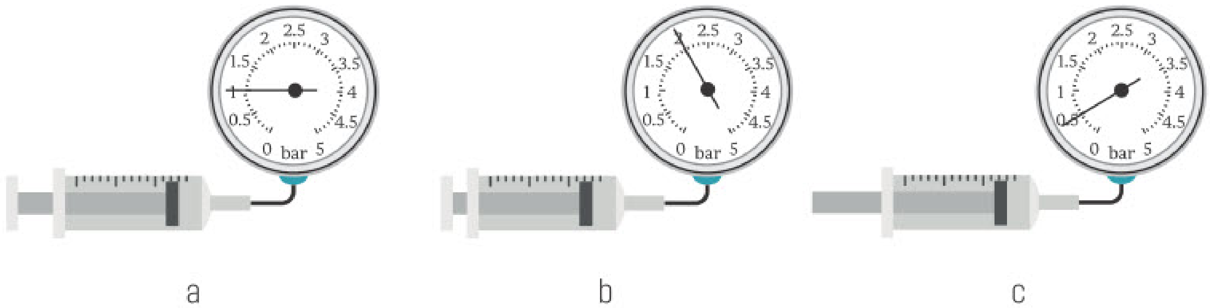


Figure 43

As seen in the Figure 44, the PV product is constant at constant temperature.

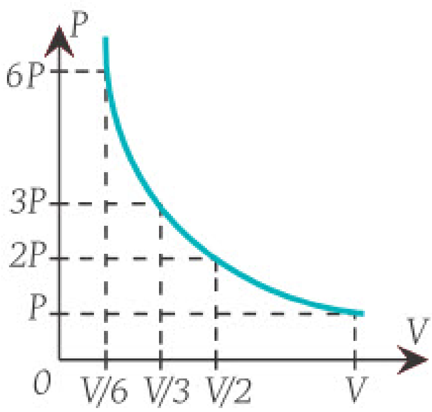


Figure 44

The curve plotted in the P-V graph is called an isotherm, which has hyperbolic form. Along the curve at all points, temperature is constant. If the same experiment is performed at a different constant temperature, a similar curve on the P–V graph can be obtained, Figure 45.

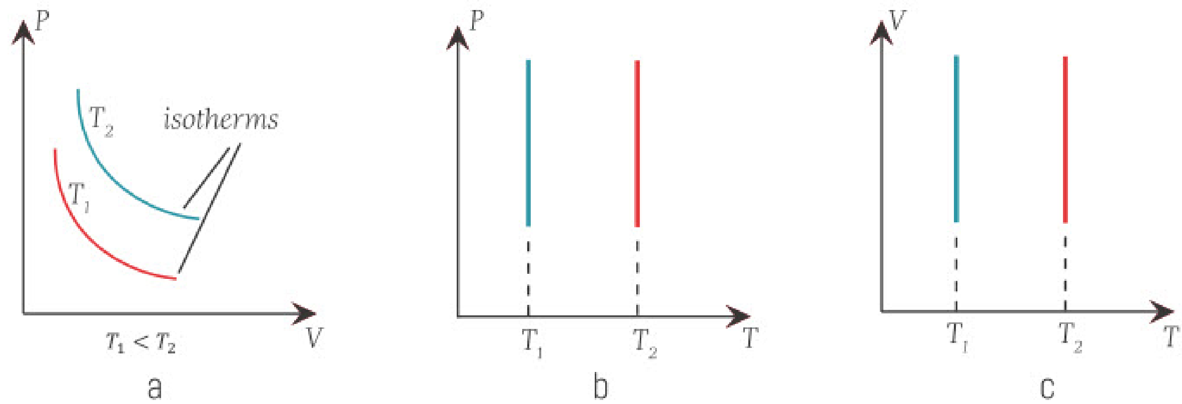


Figure 45

Throughout an isothermal process, the product of the pressure and the volume is constant, and the pressure is inversely proportional to the volume.

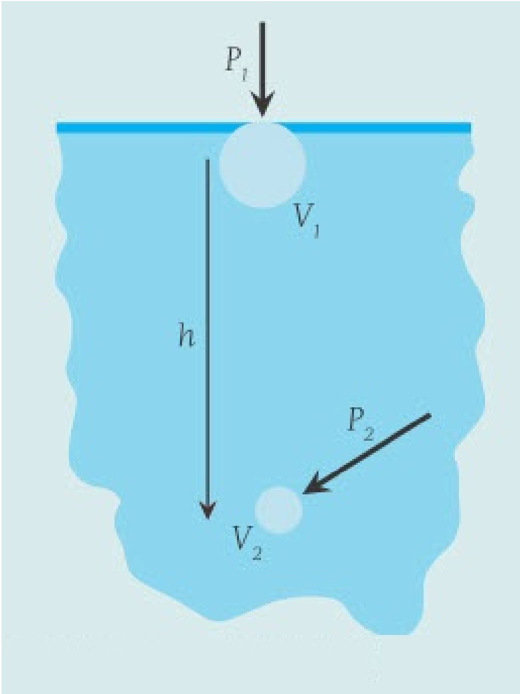
$$pV = const$$

$$p_1V_1 = p_2V_2$$

Any unit for P and V can be used, as long as it is used on both sides.

Example

The volume of an air bubble becomes four times greater as it rises from the bottom to the top of a lake. What is the depth of the lake if its temperature is constant? Atmospheric pressure is measured to be 100 kPa and the density of water is 1000 kg/m^3.



Given:

$p_1 = 100\ kPa = 100000\ Pa$

$V_1 = 4V$

$V_2 = V$

$p_2 = ?$

Formulas:

$p_1V_1 = p_2V_2 \qquad p_2 = p_1 + \rho gh$

Calculations:

$p_1V_1 = p_2V_2$

$p_2 = \frac{p_1V_1}{V_2} = \frac{100000 \cdot 4V}{V}$

$p_2 = 400000\ Pa$

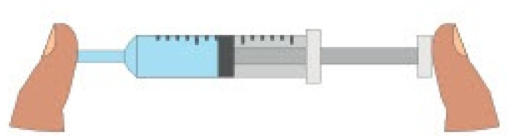
$p_2 = p_1 + \rho gh$

$h = \frac{p_2 - p_1}{\rho g} = \frac{400000 - 100000}{1000 \cdot 10}$

$h = 30\ m$

Activity

Take a syringe without needle and compress as in the figure. Can you squeeze it to zero volume? Is it possible? What can you say about the pressure-volume relationship in this case?

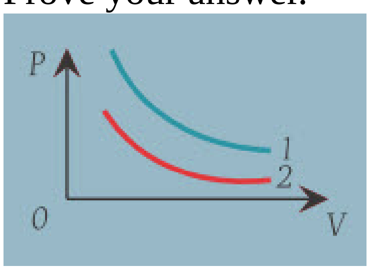


Research time

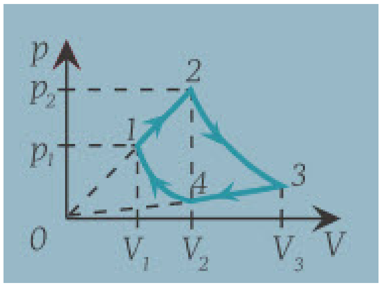
A bubble's volume increased 3 times as it rises from depth of the sea. What will happen to the pressure inside the bubble? Find initial depth of the bubble.

Literacy

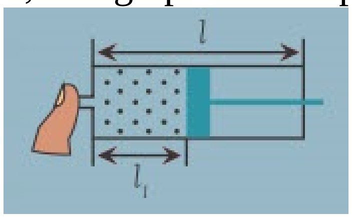
1. What is definition of "isothermal process"?
2. How can you achieve "isothermal process"?
3. Which isothermal process shown on the figure has higher temperature? Prove your answer.



4. Gas was isothermally compressed from 8 litres to 6 litres so that pressure changed by $4 \cdot 10^3$ Pascals. Calculate initial and final pressures. Draw P-V, V-T, P-T graphs of this process.
5. There is P-V graph of cyclic process done on the 1 mole of gas. Parts 2-3 and 1-4 are isotherms. Draw this cyclic process on T-V diagram. Calculate V_3 if V_1=3 litre and V_2=V_4=6 litre.



6. Calculate force applied by the finger on the opening of bicycle pump of 4 mm diameter when piston is moved as shown on the figure. Length of pump is l=42 cm, length l_1 is 2 cm. Compression is isothermal. Also, draw P-V, V-T, P-T graphs of this process.



Is it true?

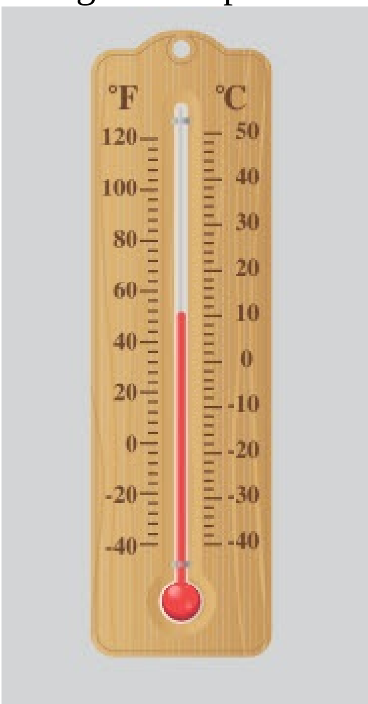
In physical terms, cold is not a "thing"—it is simply the absence of heat.

Important note

1 bar = 10^5 Pa

Physics in life

In a typical thermometer like this one, the alcohol, with a red dye, expands more rapidly than the glass containing it. When the thermometer’s temperature increases, the liquid from the bulb is forced into the narrow tube, producing a large change in the length of the column for a small change in temperature.

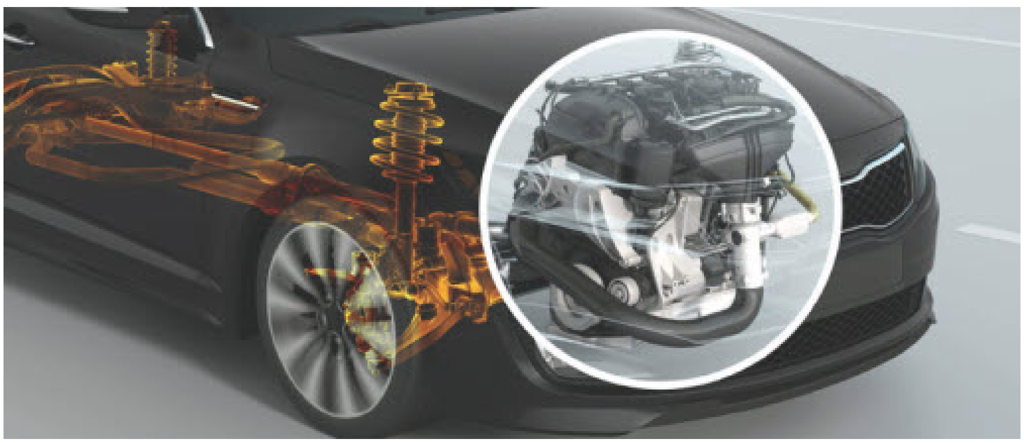


7.3 Isobaric process

You will

- analyse relationship between volume and temperature during isobaric process.

Question



What parameter is constant in internal combustion engine (ICE): pressure, volume, temperature? Why?

Changing the volume and temperature of a gas sample, at constant pressure is called an isobaric process. ‘Isobaric’ means occurring at ‘constant pressure’.

Keeping the pressure of a gas constant is relatively easy. As long as the external pressure on the gas sample is constant, and the gas is in equilibrium with the surroundings, the pressure of the gas is constant. Consider the cylinder - piston system. If the piston is stationary, or moving with constant velocity, the net force on it is zero. Therefore, the pressure of the gas inside, must be equal to the pressure applied upon the gas by the piston.

Suppose an ideal gas sample, confined in a cylinder-piston system, is heated. As a result, an increase in volume is observed, Figure 46a. Conversely, if the gas is cooled, the piston moves downward, Figure 46b.

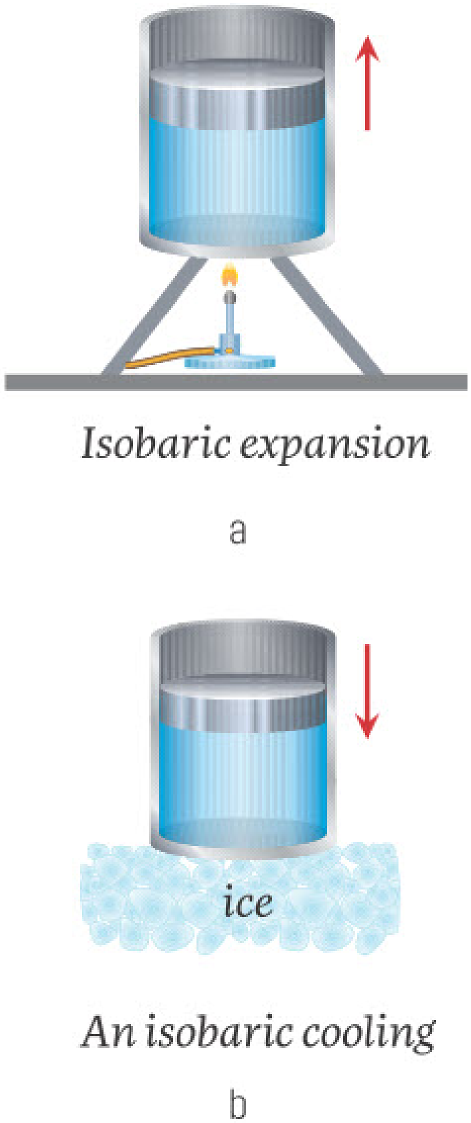


Figure 46

Plotting a constant pressure V-T (volume versus temperature) graph on the Kelvin scale indicates a proportional relationship.

A straight line, starting from zero on the V - T (volume versus temperature) graph, indicates constant pressure, Figure 47.

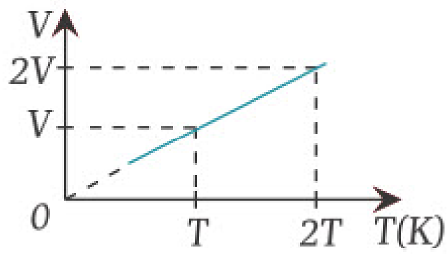


Figure 47

Constant pressure lines on graphs are called isobars, Figure 48.

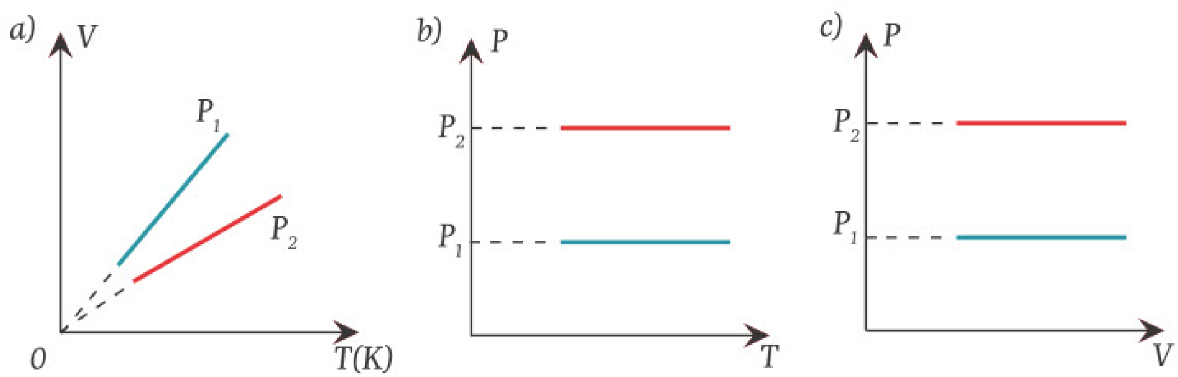


Figure 48

Throughout an isobaric process, the ratio of the volume and the temperature is constant, and the volume is directly proportional to the temperature.

Two points must be treated with caution during problem solving:

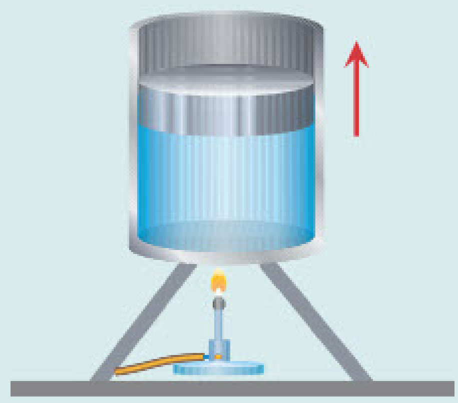
- Kelvin temperature scale must be used.
- Any unit for V can be used, as long as it is used on both sides.

$$\frac{V}{T} = const$$

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Example

The volume of a gas increases by 20% when its temperature is increased by 55°C, at constant pressure. What is the initial temperature of the gas?


Isobaric expansion

Given:

$V_1 = V$

$V_2 = 120\% \cdot V = 1.2V$

$T_1 = ?$

$T_2 = T_1 + 55$

Formulas:

$$\frac{V_1}{T_1} = \frac{V_2}{T_2}$$

Calculations:

$$\frac{V}{T_1} = \frac{1.2V}{T_1 + 55}$$

$$T_1 + 55 = 1.2 \cdot T_1$$

$$55 = 0.2 \cdot T_1$$

$$T_1 = 275\ K$$

Research time

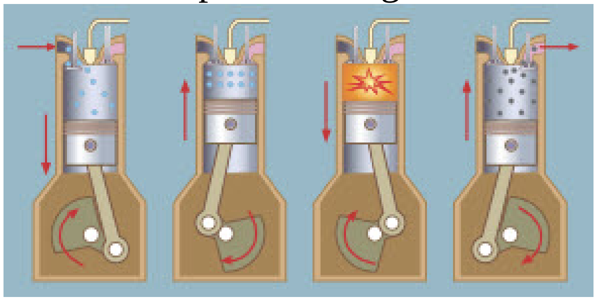
Discuss where isobaric process is used. What are the advantages and disadvantages of this process?

Literacy

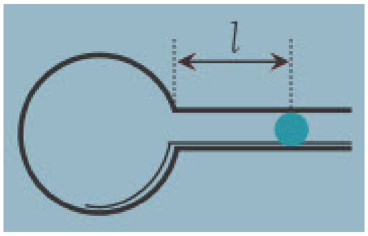
1. What is definition of "isobaric process"?
2. How can you achieve isobaric process?
3. Gas is cooled isobarically from 323 Kelvin to 273 Kelvin. Initial volume of gas is 10 litres. Calculate final volume of gas.
4. Fill the table for cyclic process shown on the P-V graph and draw V-T and P-T graphs. P is 10^5 Pascals, V is 0.1 m^3, number of moles is 1 mole.

	Pressure (Pascal)	Volume (m^3)	Temperature (Kelvin)
Point 1			
Point 2			
Point 3			

5. Volume of gas in the cylinder of diesel engine increases 2.2 times as result of combustion of fuel at constant pressure. Calculate change of temperature if initial temperature of gas is known to be 1400°C.



6. On the figure you can see gas thermometer. When temperature of gas increases volume of gas increases and drop of mercury moves in tube. Cross-sectional area of tube is 0.1 cm^2. At 273 Kelvin drop of mercury is 30 cm from the sphere, and at 278 Kelvin drop of mercury is 50 cm from the sphere. Assume pressure to be constant and calculate volume and radius of the sphere. Also, fill in the table and draw l-T graph.



Temperature of gas (Kelvin)	273	278	283	288	293	298	303	308	313
Distance of mercury drop from sphere (cm)	30	50							

Activity

Open "Phet Gas Properties". Choose constant pressure process. Then heat or cool gas. Write down your observations.

Important note

In a real experiment, after some point the experiment cannot continue, since a real gas turns into a liquid below a certain temperature. In addition, a real gas would not produce a perfect straight line in V-T graph and will behave less ideally as its density increases.

Physics in life

When you leave your football ball on balcony (or outside) in winter, you will observe that it has lost its shape even if it has not lost air inside. Why?

7.4 Isochoric process

You will

- analyse relationship between pressure and temperature during isovolumetric process.

Question

Does the volume of Earth's atmosphere change? Why yes? Why no?

Changing the pressure and temperature of a gas sample at constant volume is called an isovolumetric process (or isochoric). ‘Isovolumetric’ means occurring at ‘constant volume’.

When an ideal gas is heated in a closed container, the pressure of the gas increases with increasing temperature, Figure 49.

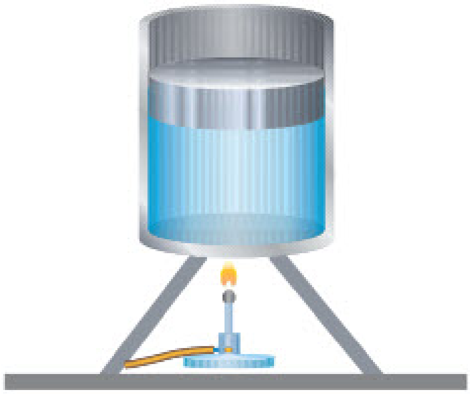

Iso-volumetric heating

Figure 49

On the Kelvin scale the P - T ratio stays constant as volume is varied. A straight line starting from zero on the P - T graph indicates an isovolumetric process, Figure 50.

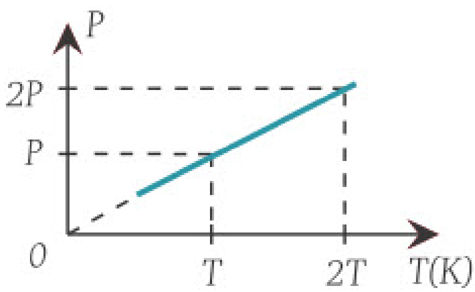


Figure 50

A real gas would liquefy at very low temperatures. The graphs below have been extrapolated after the point at which the real gas liquifies, assuming that the pressure of an ideal gas would continue to decrease in the same manner, Figure 51.

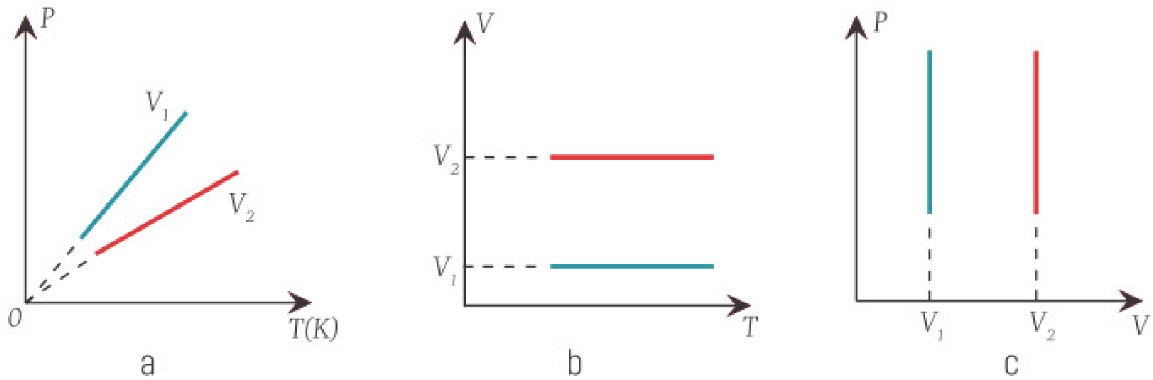


Figure 51

From a molecular point of view, the pressure of a gas is caused by the motion of its molecules. Since molecular motion stops at absolute zero (0 Kelvin), it is natural to expect pressure to be zero at this temperature. Higher temperatures mean faster moving particles. As average speed increases, molecules strike the walls of the container more forcefully, thus increasing the pressure.

Throughout an isovolumetric process, the ratio of the pressure and the temperature is constant, and the pressure is directly proportional to the temperature.

$$\frac{p}{T} = const$$

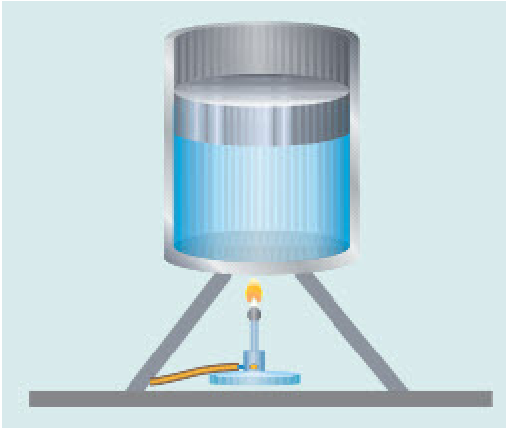
$$\frac{p_1}{T_1} = \frac{p_2}{T_2}$$

Two points must be treated with caution during problem solving:

- Kelvin temperature scale must be used.
- Any unit for P can be used, as long as it is used on both sides.

Example

Absolute pressure in a sealed container is 100 kPa at 27°C. What is the pressure in the same container at 127°C?



Given:

$p_1 = 100\ kPa = 100000\ Pa$

$T_1 = 27^oC = 27 + 273 = 300\ Kelvin$

$T_2 = 127^oC = 127 + 273 = 400\ Kelvin$

$p_2 = ?$

Formulas:

$$\frac{p_1}{T_1} = \frac{p_2}{T_2}$$

Calculations:

$$p_2 = \frac{p_1 T_2}{T_1} = \frac{100000 \cdot 400}{300}$$

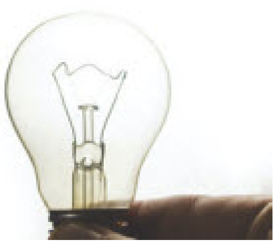
$$p_2 = 133333.3\ Pa$$

Research time

Inflate a balloon a little and draw a happy face (without ears) on the surface of a balloon. Hold two plastic cups firmly on both sides of the balloon like the ears of the face. Inflate the balloon further while they keep the cups on the sides. Release the cups, they should stick to the balloon by themselves forming the ears of the happy face! Why does the cups stick to the balloon?

Literacy

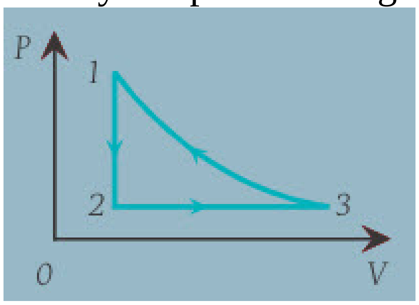
1. What is definition of “isovolumetric process”?
2. How can you achieve isovolumetric process?
3. When incandescent light bulb is switched off, pressure inside is 80 kPa at 7°C. Calculate temperature of light bulb if pressure increases up to 100 kPa when incandescent light bulb is switched on.



4. How does pressure inside of car tire change when temperature increases by 30 Kelvin? Initial temperature and pressure are 270 Kelvin and 360 kPa. Assume volume of tire to be constant.

5. What is initial temperature of gas in closed container if pressure increases 1.5 times when temperature of gas increases by 140 Kelvin?

6. There is P-V graph of cyclic process, done on one mole of gas that has molar mass of 29 g/mole. Fill the table and draw this cyclic process on density-temperature diagram.



	Pressure (Pascal)	Volume (m^3)	Temperature (Kelvin)	Density (kg/m^3)
Point 1	$3 \cdot 10^5$	0.02		
Point 2	$1 \cdot 10^5$			
Point 3				

Activity

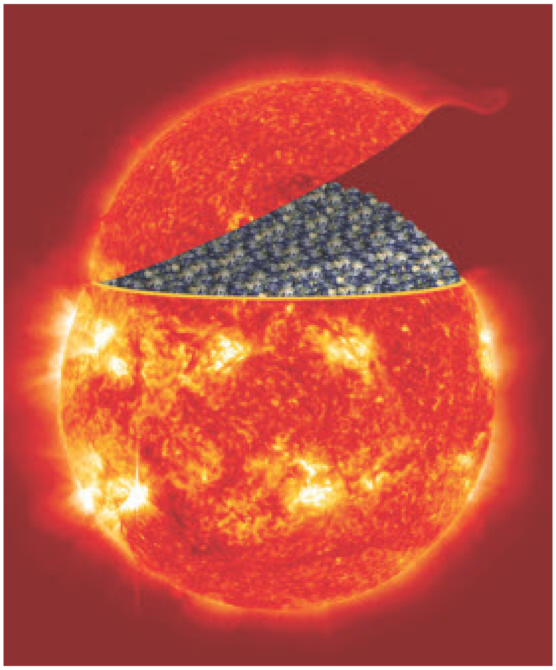
Open "Phet Gas Properties". Choose constant volume process. Then heat or cool gas. Write down your observations.

Physics in life

Rapid expansion of gas tank (explosion) is due to high pressure.

Is it true?

It would take 1 300 000 Earths to fill up the volume of the Sun.



7.5 Dalton's law

You will

- apply gas laws for solving analytical and graphical problems.

Question

When you spray an air freshener in the room, does the pressure change? How?

Partial pressure and Dalton's Law

Assume the gases in our mixtures can be approximated as ideal gases and the molecules have no intermolecular attractions, which means they act independently of other gas molecules. Based on these assumptions, we can calculate the contribution of different gases in a mixture to the total pressure. The pressure exerted by a specific gas in a mixture is its partial pressure. The partial pressure of a gas can be calculated using the ideal gas law. Dalton's law of partial pressures states that the total pressure of a mixture of gases is the sum of the partial pressures of its components:

$$p_{total} = p_{gas1} + p_{gas2} + p_{gas3} + \cdots$$

where the partial pressure of each gas is the pressure that the gas would exert if it was the only gas in the container, Figure 52.

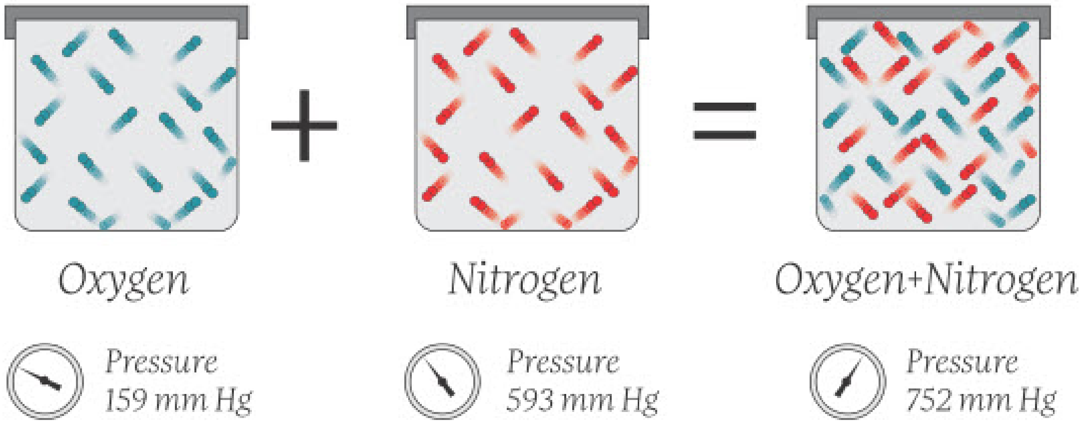


Figure 52

Consider two different gases in a closed vessel. The volume for both gases and total volume are same. To calculate the pressure applied by each gas

$$p_1 V = \nu_1 RT$$

$$p_2 V = \nu_2 RT$$

Adding the equations gives

$$p_{total} V = \nu_{total} RT$$

Therefore, the partial pressure of gas 1 is given by

$$p_1 = \frac{\nu_1}{\nu_{total}} p_{total}$$

Activity

Open "Phet Gas Properties". Make mixture of two gases, record their total pressure. Then remove one gas and determine partial pressures of gases. Calculate number of moles by using partial pressures. Verify your answers by looking at number of molecules.

Example

A 31.1625 litre sealed vessel holds 4 grams of helium and 4 grams of oxygen at 27 °C. What are partial pressures of oxygen and helium? What is the total pressure of gas mixture? (M(He)=4 g/mole, M(O_2) =32 g/mole)

Given:

$V = 31.1625\ litre = 0.0311625\ m^3$

$m_{He} = 4\ g = 0.004\ kg$

$m_{O_2} = 4\ g = 0.004\ kg$

$T = 27^oC = 27 + 273 = 300\ K$

$M_{He} = 4\ g/mole = 0.004\ kg/mole$

$M_{O_2} = 32\ g/mole = 0.032\ kg/mole$

$p_{He} = ?$

$p_{O_2} = ?$

$p_{total} = ?$

Formulas:

$$\nu = \frac{m}{M}$$

$$pV = \nu RT$$

$$p_{total} = p_{He} + p_{O_2}$$

Calculations:

$$\nu = \frac{m}{M}$$

$$\nu_{He} = \frac{0.004}{0.004} = 1\ mole$$

$$\nu_{O_2} = \frac{0.004}{0.032} = 0.125\ mole$$

$$pV = \nu RT$$

$$p_{He} = \frac{\nu_{He} RT}{V} = \frac{1 \cdot 8.31 \cdot 300}{0.0311625} = 80000\ Pa$$

$$p_{O_2} = \frac{\nu_{O_2} RT}{V} = \frac{0.125 \cdot 8.31 \cdot 300}{0.0311625} = 10000\ Pa$$

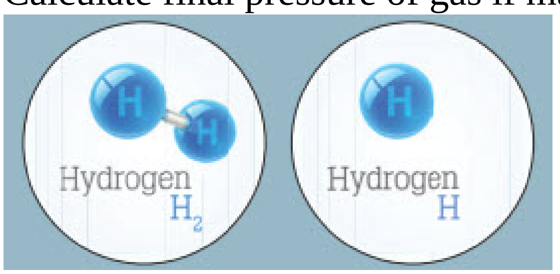
$$p_{total} = p_{He} + p_{O_2}$$

$$p_{total} = 80000 + 10000 = 90000\ Pa$$

Literacy

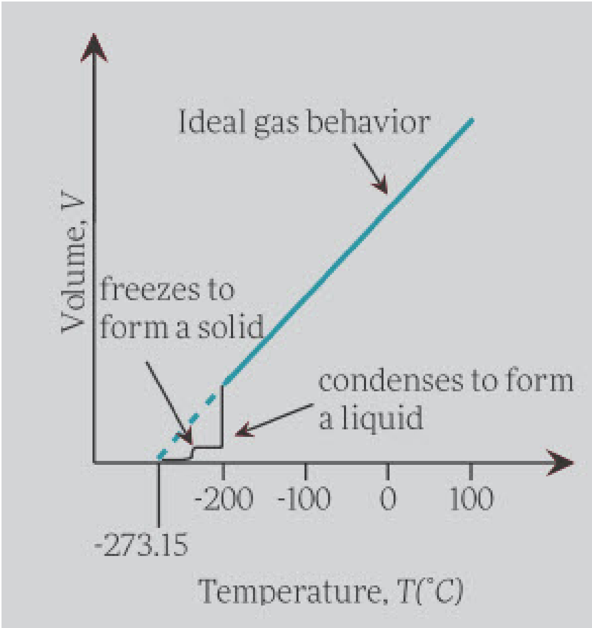
1. What is definition of “Dalton’s law”?
2. Tell three examples of use of gas mixtures.
3. There are oxygen and nitrogen gases in 4 litre vessel at 0°C. Calculate pressure of mixture if masses of gases are same and equal to 1 gram.
4. There are three vessels of 3 litre, 7 litre and 5 litre volume which are filled with oxygen (at 2 atm pressure), nitrogen (at 3 atm pressure) and carbon dioxide (at 0.6 atm pressure) at same temperature. Then vessels are connected and mixture of gases form. Calculate pressure of mixture. Temperature remains constant.
5. One breath of human is about 0.5 litre of air. How many molecules of oxygen are there in one breath if oxygen is 20% of air?

6. There is hydrogen gas at 200 Kelvin and 400 Pascals. Then gas is heated up to 10000 Kelvin. At this temperature molecules dissociate into atoms. Calculate final pressure of gas if mass and volume remain constant.



Physics in life

The linear (straight line) part of the graph represents ideal gas behaviour — volume and temperature are directly and positively related and the line extrapolates to zero volume at –273.15ºC, or absolute zero. When the gas becomes a liquid, however, the volume actually decreases precipitously at the liquefaction point. The volume decreases slightly once the substance is solid, but it never becomes zero.



Important note

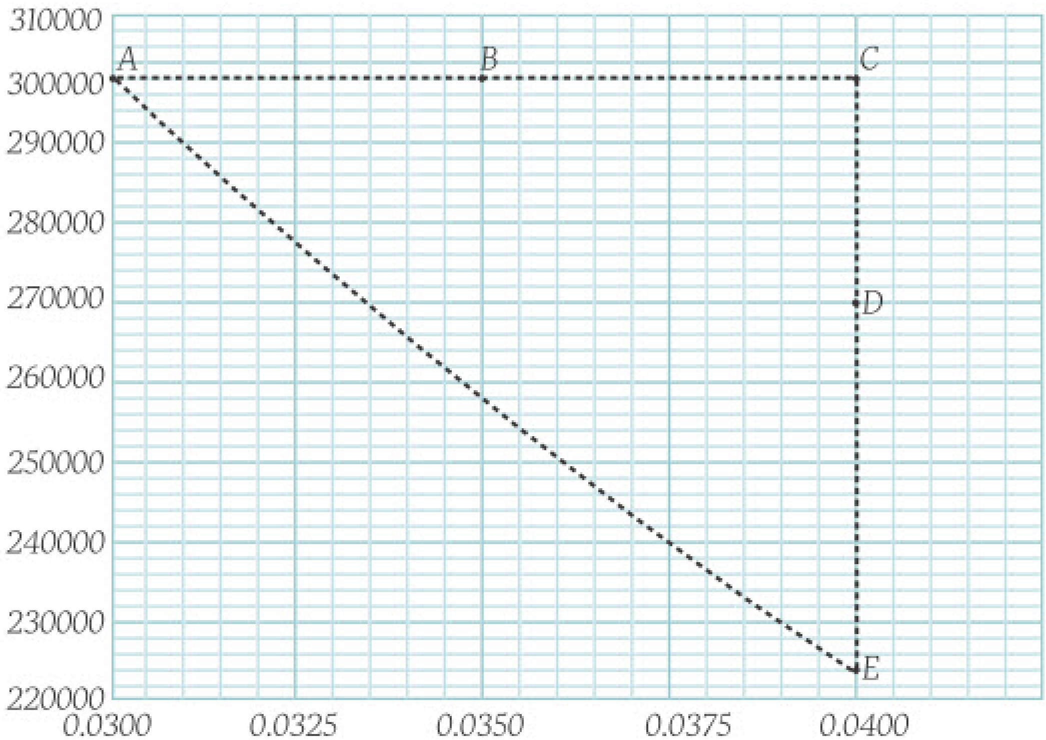
Hg is symbol of mercury in periodic table. mm-Hg is unit of pressure.
760 mm-Hg=1 atm
760 mm-Hg=101325 Pascal

Research time

What mixture of gases is used in internal combustion engine (ICE) of cars?
What mixture of gases is used in rocket engines?

Check yourself

There is graph that shows cyclic process ABCDEA done on 3 moles of ideal gas. Cyclic process consists of isothermal, isochoric (isovolumetric), and isobaric processes. Use graph to answer questions 1-20.



1. What parameter is shown by vertical axis?

A) Temperature in Celsius

B) Temperature in Kelvin

C) Volume in m^3

D) Pressure in Pascal

E) There is no right answer

2. What parameter is shown by horizontal axis?

A) Temperature in Celsius

B) Temperature in Kelvin

C) Volume in m3

D) Pressure in Pascal

E) There is no right answer

3. What type of process is AC?

A) Isothermal

B) Isobaric

C) Isochoric

D) Isenthalpic

E) There is no right answer

4. What type of process is CE?

A) Isothermal

B) Isobaric

C) Isochoric

D) Isenthalpic

E) There is no right answer

5. What type of process is EA?

A) Isothermal

B) Isobaric

C) Isochoric

D) Isenthalpic

E) There is no right answer

6. Which point (or points) on the graph has the highest pressure?

A) A

B) B

C) C

D) D

E) E

7. Which point (or points) on the graph has the lowest pressure?

A) A

B) B

C) C

D) D

E) E

8. Which point (or points) on the graph has the highest volume?

A) A

B) B

C) C

D) D

E) E

9. Which point (or points) on the graph has the lowest volume?

A) A

B) B

C) C

D) D

E) E

10. Which point (or points) on the graph has the highest temperature?

A) A

B) B

C) C

D) D

E) E

11. Which point (or points) on the graph has the lowest temperature?

A) A

B) B

C) C

D) D

E) E

12. In which interval does gas expand?

A) AC

B) CE

C) EA

D) DE

E) There is no right answer

13. In which interval does gas contract?

A) AC

B) CE

C) EA

D) DE

E) There is no right answer

14. In which interval does gas heat up?

A) AC

B) CE

C) EA

D) DE

E) There is no right answer

15. In which interval does gas cool down?

A) AC

B) CE

C) EA

D) AB

E) There is no right answer

16. What is temperature at point A?

A) 361 °C

B) 88 K

C) 500 K

D) 88 °C

E) 400 K

17. What is temperature at point B?

A) 421.18 K

B) 248.18 °C

C) 148.18 K

D) 361 K

E) There is no right answer

18. What is temperature at point C?

A) 281.35 K

B) 381.35 K

C) 481.35 K

D) 581.35 K

E) 681.35 K

19. What is temperature at point D?

A) 160.21 °C

B) 260.21 °C

C) 360.21 °C

D) 60.21 °C

E) 360.21 K

20. What is temperature at point E?

A) 160.21 °C

B) 260.21 °C

C) 360.21 °C

D) 60.21 °C

E) There is no right answer

The Gas Laws

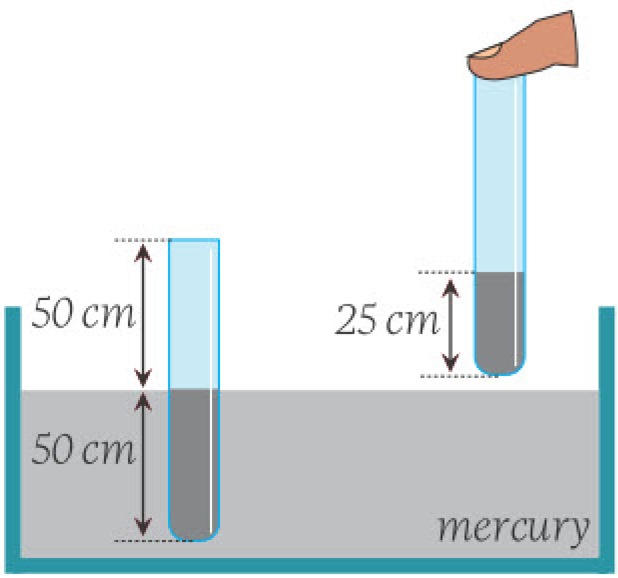
1. A gas is trapped in a vertical cylinder by a piston of mass 60 kg and area of 300 cm^2. The open air pressure is 100 kPa. What is the pressure of the gas inside the cylinder?

2. A gas sample occupies a volume of 60 L, under 100 kPa pressure. What is the volume of the same gas sample under 250 kPa pressure, at the same temperature?

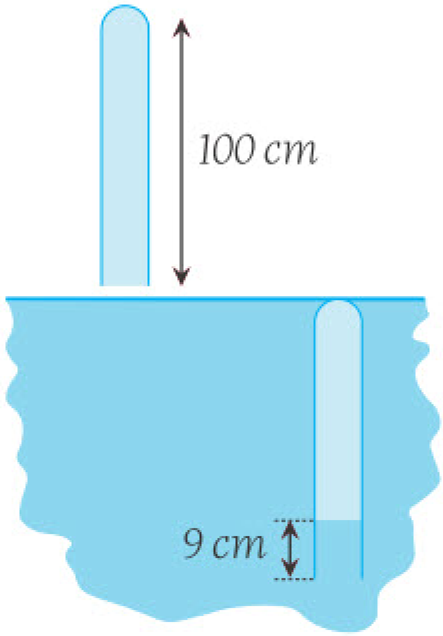
3. The volume of a gas sample decreases from 5 L to 3 L, when it is compressed isothermally. What is the final pressure of the gas, if its initial pressure is 120 kPa?

4.A glass tube open at both ends is dipped in mercury vertically up to half its length, as shown in the figure. The total length of the tube is 100 cm. The upper hole is then covered and the tube is vertically raised, slowly, out of the mercury bath, so that it gives rise to an isothermal process. A column of mercury of 25 cm length is observed to remain in the tube. What is the atmospheric pressure? (Hint: Use

cm-Hg as the unit of pressure.)



5. A 1 m glass tube, closed at one end, is immersed in water completely. Find the open air pressure if the water rises 9 cm in the tube. Assume that the temperature remains constant.



6. The volume of an ideal gas sample triples, as its temperature increases by 300 K at constant pressure. What was the initial temperature of the gas?

7. The temperature of a gas sample is increased by 100 K isobarically. The volume of the gas increases by 20% during the process. What was the initial temperature of the gas?

8. The temperature of a sample of gas increases from 27°C to 327°C, at constant pressure. Find the ratio of its final density to its initial density.

9. Absolute pressure in a sealed container is 100 kPa at 27°C. What is the pressure in the same container at 127°C?

10. The pressure of a gas increases by 20 % when its temperature is increased by 55°C, at constant volume. What was the initial temperature of the gas?

The Ideal Gas Law

1. What is the absolute pressure of 50 g neon gas kept in a 10 L vessel at 300 K? ($M(N_2)$=20 g/mole)

2. What volume does 0.016 kg oxygen gas occupy at 57 ºC, under 100 kPa pressure?($M(O_2)$=32 g/mole)

3. What is the mass of air in an 80 m3 room at 20ºC and 1 atm of pressure? Take the molar mass of air to be M=29 g/mole

4. 30 g of neon and 10 g of helium are enclosed in a container of volume 20 lt. If the temperature is 300 K, what is the pressure inside the container in units of kPa? (Take M_{He}=4 g/mole, M_{Ne}=20 g/mole)

5. The temperature of air in a 120 m^3 room increases from 27°C to 32°C. What mass of air leaves the room? (Take Mair=0.029 kg/mole, P_o=100 kPa)

6. An air bubble has a volume of 1 cm^3 at a depth of 10 m, under the surface of the water, in a lake whose temperature is 7°C. What is the

volume of the bubble near the surface, where the temperature is 17°C? Take atmospheric pressure to be 1 atm.

7. A gas sample is enclosed in a vessel at 400 Kelvin, under 200 kPa pressure. What will the pressure of the gas be if 40% of the gas is taken out, and the temperature is decreased to 300 K?

8. One mole of air is confined in a cylinder by a movable piston having a mass of 10 kg and an area of 10–3 m2. Atmospheric pressure is 100 kPa. The cylinder absorbs heat, such that its temperature increases by 20°C. What is the displacement of the piston?

Expressing the Ideal Gas Law in Terms of Number of Molecules

($k=1.38\cdot10^{-23}$J/K)

1. What is the pressure of an ideal gas of concentration $2.5\cdot10^{19}$ molecules/cm^3 at 300 K?

2. Estimate the total number of air molecules in your classroom under standard atmospheric pressure at 20ºC.

3. The pressure of a gas in a sealed balloon is 10 kPa at 200 K. What is the concentration of gas atoms in the balloon?

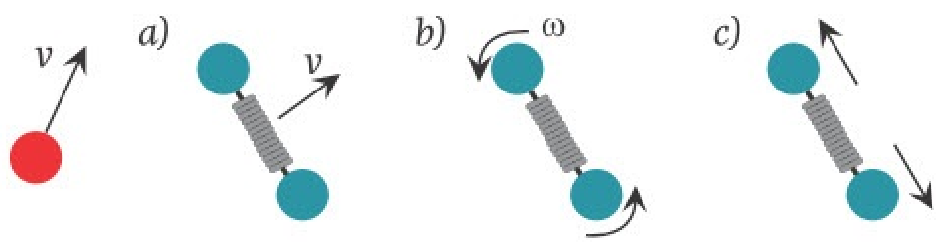
CHAPTER 8: THERMODYNAMICS

8.1 Internal energy of ideal gas

You will

- apply formulas of internal energy of monatomic and diatomic gases for problem solving.

Question



On the figure you can see models of atom (violet) and diatomic molecule (yellow). Which particle has more energy if their temperatures are same? Why?

Internal energy

Let us first assume, that our ideal gas is a monatomic gas (each molecule contain 1 atom), such as helium, neon, or argon. In thermodynamics, the total energy of a system is called its internal energy and is denoted by ‘U’. The internal energy is the sum of the translational kinetic energies of the molecules. The average translational kinetic energy of a single atom depends only on the gas temperature and is given by E_K=3/2 kt. A sample of such a gas contains N atoms ($N=\nu N_A$). The internal energy U of the sample is

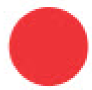
$$U = N \cdot \left(\frac{3}{2}kT\right) = \nu N_A \cdot \left(\frac{3}{2}\frac{R}{N_A}T\right) = \frac{3}{2}\nu RT$$

The internal energy U of an ideal gas is a function of the gas temperature only, it does not depend on any other variable.

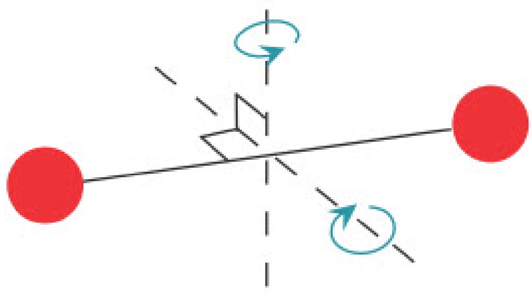
For more complicated diatomic and polyatomic gases, internal energy includes both rotational and translational kinetic energy.

To keep account of the various ways in which energy can be stored in a gas, James Clerk Maxwell introduced the theorem of the equipartition of energy: Every type of molecule has a certain number i of degrees of freedom, which are independent ways in which the molecule can store energy.

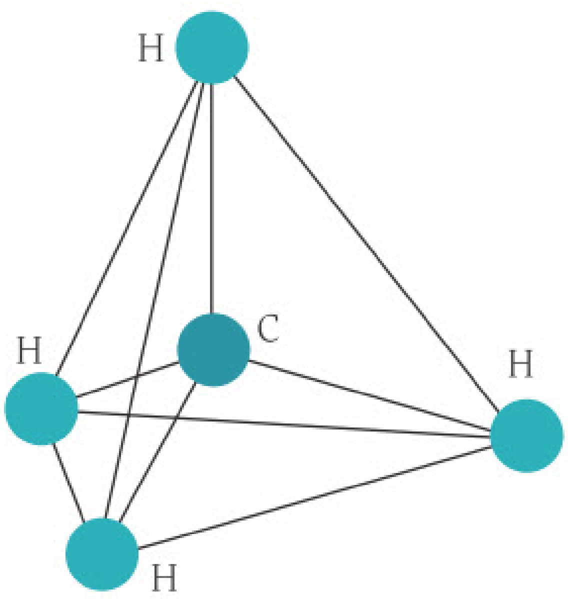
Let us apply the theorem to the translational and rotational motions of the molecules. For the translational motion, molecules will, in general, have velocity components along x, y, z axes. Thus, gas molecules of all types have three degrees of translational freedom (three ways to move in translation), Figure 53a.



(a) He



(b) O_2



(c) CH_4

Figure 53

For the rotational motion, imagine the origin of our xyz coordinate system at the centre of each molecule. A diatomic molecule can rotate like a top only about axes perpendicular to the line connecting the atoms and not about that line itself. Therefore, a diatomic molecule can have only two degrees of rotational freedom, Figure 53b. In a polyatomic gas, each molecule should rotate with an angular velocity component along each of the three axes, so each gas should have three degrees of rotational freedom, Figure 53c.

Molecule	Degrees of freedom		
	Translational	Rotational	Total (i)
Monoatomic	3	0	3
Diatomic	3	2	5
Polyatomic	3	3	6

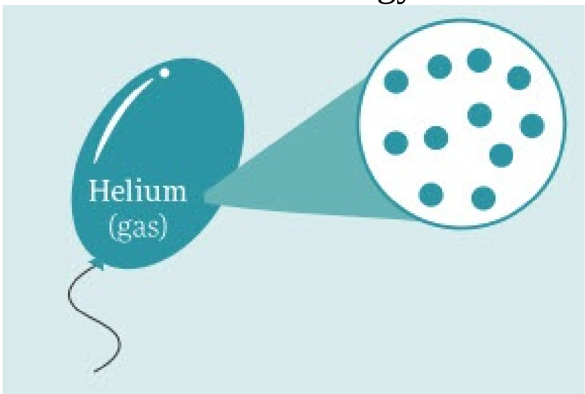
In conclusion, the general formula of internal energy iswhere i is degree of freedom.

$$U = \frac{i}{2}\nu RT$$

where i is degree of freedom.

Example

Determine internal energy of 5 moles of helium gas at 350 Kelvin.



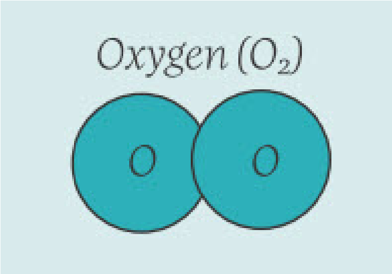
Given:
$\nu = 5\ mole$
i=3 (degree of freedom of monatomic gas He)
T=350 $Kelvin$
R=8.31 $J/K \cdot mole$
U= ? $Joule$

Formulas:
$$U = \frac{i}{2}\nu RT$$

Calculations:
$$U = \frac{i}{2}\nu RT$$
$$U = \frac{3}{2} \cdot 5 \cdot 8.31 \cdot 350 = 21813.75\ J$$

Example

Determine internal energy of 3 moles of oxygen gas at 300 Kelvin.



Given:
$\nu = 3\ mole$
$i = 5$ degree of freedom of diatomic gas O_2
$T = 300\ Kelvin$
$R = 8.31\ J/K \cdot mole$
$U = ?\ Joule$

Formulas:
$$U = \frac{i}{2}\nu RT$$

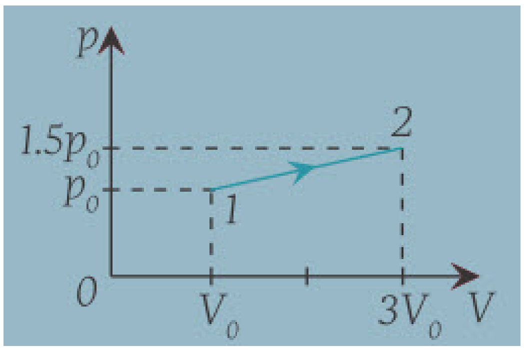
Calculations:
$$U = \frac{i}{2}\nu RT$$
$$U = \frac{5}{2} \cdot 3 \cdot 8.31 \cdot 300 = 18697.5\ J$$

Activity

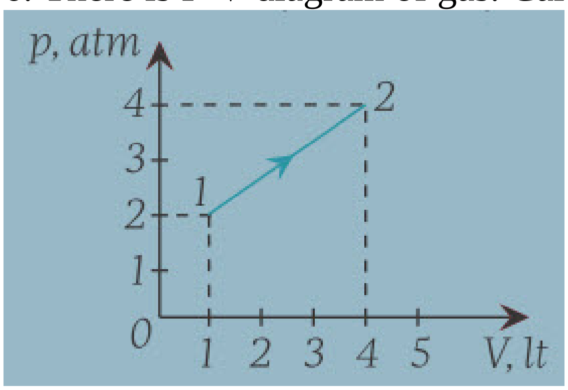
Make a few squats. Does the speed of blood circulation change? What about your body temperature? What can you say about your internal energy?

Literacy

1. What is definition of “internal energy of gas”?
2. What is difference between monatomic, diatomic, and polyatomic gases? Give examples for each type of gas.
3. Internal energy of 10 moles of monatomic gas is 74.79 kJ. Calculate temperature of gas.
4. Monatomic ideal gas is in 10 litre vessel at 10^5 Pascal pressure. Calculate internal energy of gas.
5. There is P-V diagram of diatomic gas. Calculate change of internal energy of gas if p_0=0.1 MPa and V_0=2 litre.



6. There is P-V diagram of gas. Calculate work done by gas.



Important note

1 atm=101325 Pascal
1 litre=0.001 m^3

Research time

What other ways of increasing temperature are present (except by heating)?

Is it true?

Mice tremble to increase internal energy of own body.

8.2 Thermodynamic work. First law of thermodynamics

You will

- apply first law of thermodynamics to isoprocesses and adiabatic process.

Question

Here you can see control panel of refrigerator. What type of iso-process does refrigerator use? Does refrigerator have thermostat inside?

Work

In thermodynamic systems, work is defined in terms of pressure and volume change. Pressure is a measure of how much force is applied over a given area ($P = F/A$). Change in volume is equal to area multiplied by displacement ($\Delta V = A \cdot x$), Figure 54. These expressions can be substituted into the definition of work introduced in mechanics ($W = F \cdot x$) to derive a new definition for the work done on or by a gas, as follows:

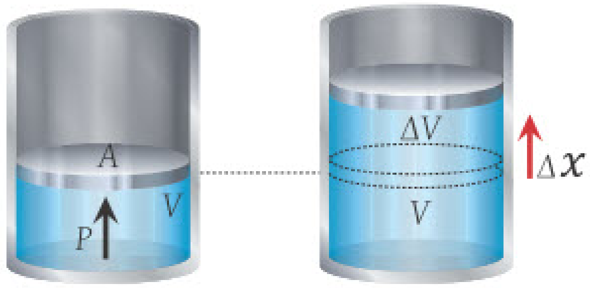


Figure 54

$$W = Fx = \left(\frac{F}{A}\right) \cdot (Ax)$$

$$W = p\Delta V$$

Note this definition assumes that P is constant. Also, for isobaric process since pV=νRT , we can derive

$$W = \nu R\Delta T$$

If the gas expands, ΔV is positive, and the work done by the gas on the piston is positive. If the gas is compressed, ΔV is negative, and the work done by the gas on the piston is negative. (In other words, the piston does work on the gas.) When the gas volume remains constant, there is no displacement and no work is done on the system or by the system.

Increase in volume	$\Delta V>0$	$W_{by\ gas}>0$
Decrease in volume	$\Delta V<0$	$W_{by\ gas}<0$
Constant volume	$\Delta V=0$	$W_{by\ gas}=0$

Although the pressure can change during a process, work is done only if the volume changes. A situation in which pressure increases and volume remains constant is comparable to one in which a force does not displace a mass even as the force is increased. Work is not done in either situation.

The area under the graph in a PV diagram is equal in magnitude to the work done on the gas, Figure 55a.

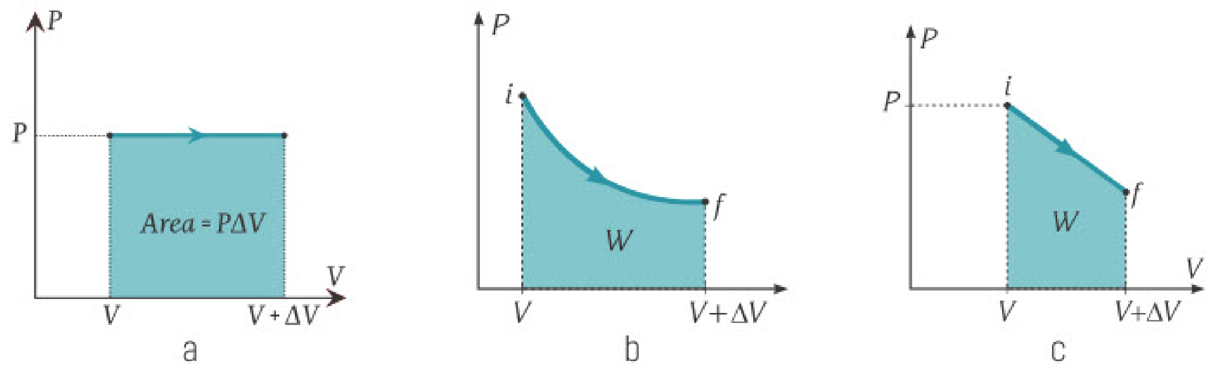


Figure 55

This is true in general, whether the process proceeds at constant pressure or not. Just draw the PV diagram of the process, find the area under the graph (and above the horizontal axis), and that area will be the equal to the magnitude of the work done on the gas, Figure 55b and 55c.

If the arrow on the graph points toward larger volumes, the work done on the gas is positive. If the arrow on the graph points toward smaller volumes, the work done on the gas is negative.

First Law of Thermodynamics

The first law of thermodynamics is another energy conservation law that relates change in internal energy ΔU to energy transfers due to heat Q and work W. The change in the internal energy is the difference between the final internal energy value Uf and the initial internal energy value Ui. That is, $\Delta U = U_f - U_i$. Formula of the first law of thermodynamics is

$$\Delta U = Q - W \qquad \text{or} \qquad Q = W + \Delta U$$

Change of internal energy, heat and work have same unit - Joule. Sign conventions of these quantities are given in the table below.

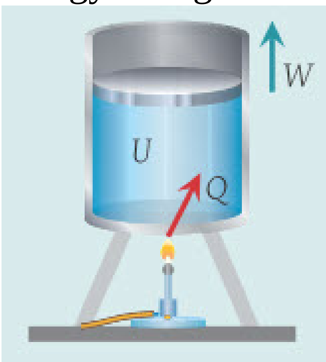
Q	positive	Heat is added(absorbed) to system
	negative	Heat flows out (released) from system
W	positive	Work done by gas, increasing the volume
	negative	Work done on gas, decreasing the volume
ΔU	positive	Internal energy, temperature increases
	negative	Internal energy, temperature decreases

First law of thermodynamics in isoprocesses:

Process	Condition		First law of thermodynamics
isobaric	*P-const*		$Q=W+\Delta U$
isovolumetric	*V-const*	$W=0$	$Q=\Delta U$
isothermal	*T-const*	$\Delta U=0$	$Q=W$
isolated	$Q=W=0$	$\Delta U=0$	
adiabatic	$Q=0$		$W=-\Delta U$

Example

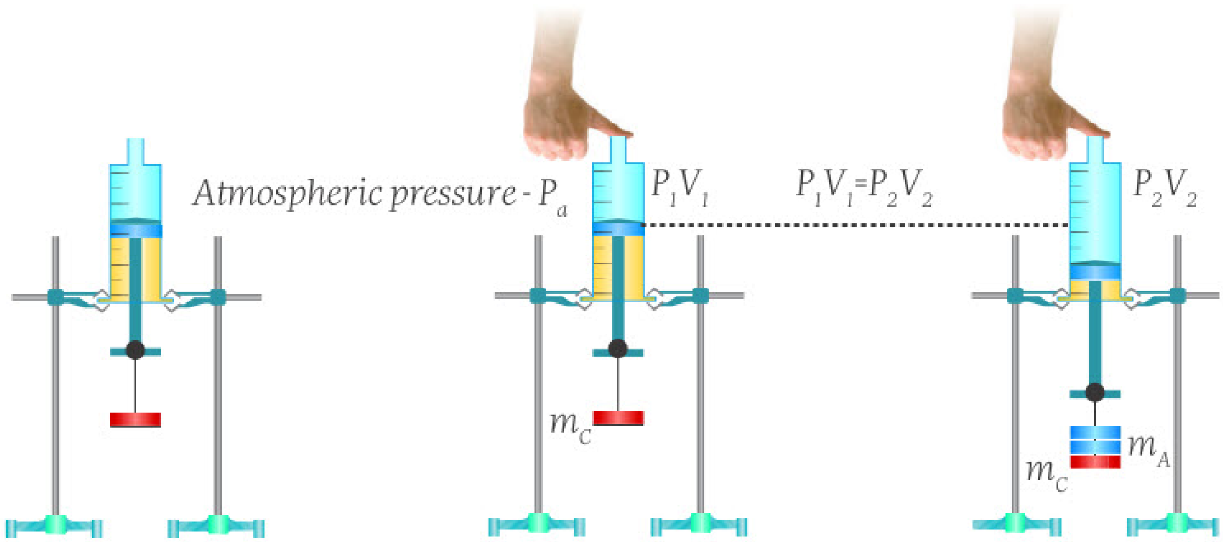
A system does 300 J of work as it absorbs 800 J heat. What is the internal energy change of the system?



Given:	Formulas:	Calculations:
$W = 300\,Joule$	$Q = W + \Delta U$	$\Delta U = Q - W$
$Q = 800\,Joule$		$\Delta U = 800 - 300$
$\Delta U = ?$		$\Delta U = 500\,J$

Activity

Find the pressure of atmosphere by using Boyle Mariotte gas law (isothermal process) and basic pressure formula.

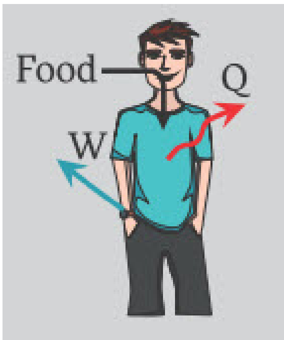


Important note

Work of gas in a closed container equals zero since volume of gas remains constant.

Physics in life

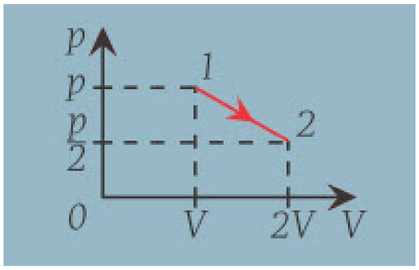
How can first law of thermodynamics be related to human's metabolism?



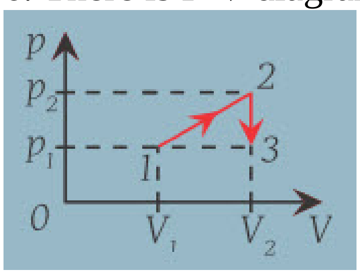
Literacy

1. What is definition of "work"? In which isoprocess work is zero?
2. What is definition of the "first law of thermodynamics"? Write the formulas of the application of the first law of thermodynamics to isothermal, isobaric, isovolumetric, and adiabatic processes.

3. Gas absorbs $5 \cdot 10^5$ Joules of heat and does $2 \cdot 10^5$ Joules of work. What is change of internal energy of gas?
4. Monatomic ideal gas of 2 kmole is transferred from one state to another. These states have same temperature of 27°C. Calculate initial and final internal energies of gas, change of internal energy and work done by gas if heat absorbed by gas is 10 kJ.
5. There is P-V diagram of gas. Calculate amount of heat absorbed by gas, change of internal energy and work done by gas. $p = 2 \cdot 10^5$ Pascal and V=3 litre.



6. There is P-V diagram of one mole of gas.



Calculate heat absorbed by gas.

$V_1 = 0.2$ m^3, $V_2 = 0.1$ m^3,

$p_1 = 3 \cdot 10^6$ Pascal,

$p_2 = 5 \cdot 10^6$ Pascal.

8.3 Adiabatic process. Poisson's equation for adiabatic process

You will

- apply first law of thermodynamics to isoprocesses and adiabatic process.

Question

Why do clouds form in the sky? What is the role of adiabatic cooling in cloud formation?

Adiabatic process

In an adiabatic process, no energy enters or leaves the system by heat. Such a system is insulated, thermally isolated from its environment. In general, however, the system isn't mechanically isolated, so it can still do work.

For adiabatic processes Q = 0, so the first law becomes

$$\Delta U = -W$$

The work done during an adiabatic process can be calculated by finding the change in the internal energy. Alternately, the work can be computed from a PV diagram. On a P-V diagram the process occurs along a line called an adiabat, Figure 56.

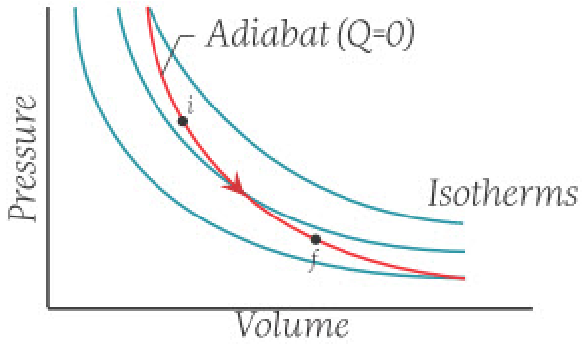


Figure 56

Poisson's equation for adiabatic process.

For an ideal gas undergoing an adiabatic process, it can be shown that

$$pV^{\gamma} = const$$

where

$$\gamma = \frac{C_p}{C_V}$$

is called the adiabatic index of the gas, Table 4. Adiabatic index is ratio of the molar specific heat of the gas at constant pressure C_p and molar specific heat of the gas at constant volume C_V. General formula of molar specific heat is

$$C = \frac{Q}{\nu \Delta T}$$

Molecule	Molar specific heats		Adiabatic index
	C_p	C_V	$\gamma = C_p/C_V$
monatomic	5/2 R	3/2 R	5/3
diatomic	7/2 R	5/2 R	7/5
polyatomic	4R	3R	4/3

Table 4

For isovolumetric process	For isobaric process
$Q = \Delta U$	$Q = W + \Delta U$
$\nu C_V \Delta T = \frac{i}{2}\nu R\Delta T$	$\nu C_p \Delta T = \nu R\Delta T + \frac{i}{2}\nu R\Delta T$
$C_V = \frac{i}{2}R$	$\nu C_p \Delta T = \frac{i+2}{2}\nu R\Delta T$
	$C_p = \frac{i+2}{2}R$
	$C_p = C_V + R$

To write an equation for an adiabatic process in terms of T and V, we use the ideal gas equation (pV=νRT) to eliminate p.

$$pV^{\gamma} = const$$

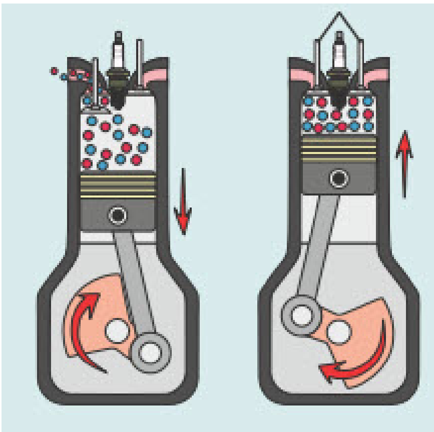
$$\frac{\nu RT}{V} \cdot V^{\gamma} = const$$

Because ν and R are constants, we can rewrite this in the alternative form

$$TV^{(\gamma-1)} = const$$

Example

During compression stroke of gasoline engine volume of air in cylinder changes from 1 litre to 0.1 litre. Initial pressure and temperature are 100 kPa and 300 Kelvin
respectively. Determine final pressure and temperature. Assume process is adiabatic.



Given:

$V_1 = 1\ litre = 0.001\ m^3$

$V_2 = 0.1\ litre = 0.0001\ m^3$

$p_1 = 100\ kPa = 100000\ Pa$

$T_1 = 300\ Kelvin$

Formulas:

$$\gamma = \frac{i+2}{i}$$

$$p_1V_1^\gamma = p_2V_2^\gamma$$

$$pV = \nu RT$$

i=5 (air is mainly oxygen O_2 and nitrogen N_2, so we assume air is diatomic gas)

Calculations:

$$\gamma = \frac{i+2}{i} = \frac{5+2}{5} = 1.4$$

$$p_1V_1^\gamma = p_2V_2^\gamma$$

$$p_2 = \frac{p_1V_1^\gamma}{V_2^\gamma} = \frac{100000 \cdot 0.001^{1.4}}{0.0001^{1.4}}$$

$$p_2 = 2.51 \cdot 10^6\ Pa$$

$$p_1V_1 = \nu RT_1$$

$$\nu = \frac{p_1V_1}{RT_1} = \frac{100000 \cdot 0.001}{8.31 \cdot 300}$$

$$\nu = 0.04\ mole$$

$$p_2V_2 = \nu RT_2$$

$$T_2 = \frac{p_2V_2}{\nu R} = \frac{2.51 \cdot 10^6 \cdot 0.0001}{0.04 \cdot 8.31}$$

$$T_2 = 755.1\ K$$

Literacy

1. What is definition of “adiabatic index”? What is formula of “adiabatic index”?
2. What is formula of Poisson's equation for adiabatic process? When do we use it?
3. Monatomic gas of 10 moles is adiabatically expanded so that temperature changes from 400 Kelvin to 300 Kelvin. Calculate work done by gas, change of internal energy of gas, initial pressure of gas, final pressure and final volume of gas if initial volume of gas is 0.1 m^3. Plot P-V, V-T and P-T graphs of this process. Use table shown below.

P_1 (Pascal)	V_1 (m^3)	T_1 (Kelvin)	P_2 (Pascal)	V_2 (m^3)	T_2 (Kelvin)
	0.1	400			300

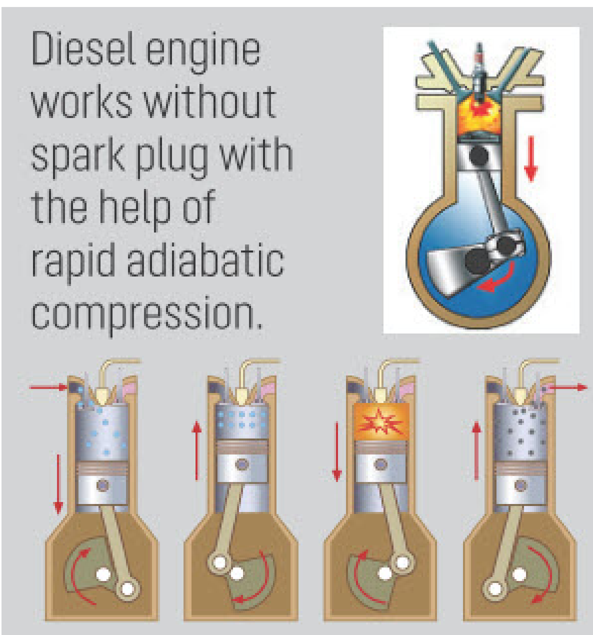
4. Diatomic gas of 5 moles is adiabatically expanded from 0.2 m^3 to 0.5 m^3.

Calculate work done by gas, change of internal energy of gas, initial temperature of gas, final temperature and final pressure of gas if initial pressure of gas is 200 kPa. Plot P-V, V-T and P-T graphs of this process. Use table shown below.

P_1 (Pascal)	V_1 (m^3)	T_1 (Kelvin)	P_2 (Pascal)	V_2 (m^3)	T_2 (Kelvin)
200000	0.2			0.5	

5. One mole of oxygen gas at 290 Kelvin is compressed adiabatically so its pressure increases tenfold. Calculate final temperature of gas and work done on the gas.
6. Gas is adiabatically compressed from 200 litres to 122 litres so that pressure increases from 100 kPa to 200 kPa. What type of gas is it, monatomic, diatomic, polyatomic? Calculate initial and final temperatures if number of moles is 6 moles. Plot P-V, V-T and P-T graphs of this process.

Physics in life



Is it true?

On contrary to adiabatic heating there is adiabatic cooling.

Physics in life

To be exact, there exists one perfectly adiabatic system - the universe. The universe cannot exchange heat with surroundings because for the universe, surroundings do not exist.

Activity

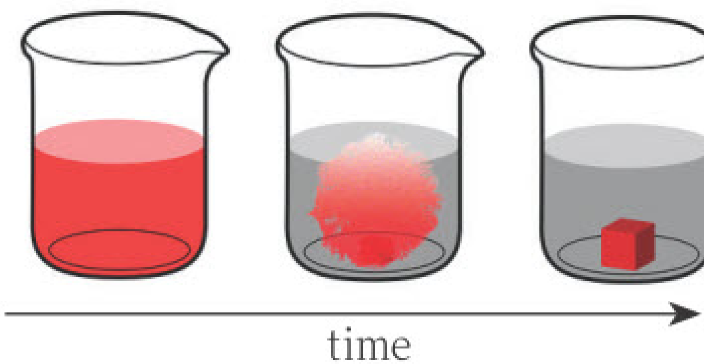
Fire syringe (or fire piston) makes fire by adiabatic heating. Make an experiment with fire syringe. If you don't have it then watch video from internet.

8.4 Second law of thermodynamics. Efficiency

You will

- describe Carnot cycle for ideal heat engine.

Question



Is it possible that sugar cube dissolved in water, becomes cube again as shown in the figure? Explain your answer. What law is it?

Reversible and irreversible processes

The process in which the system and surroundings can be restored to the initial state from the final state without producing any changes in the thermodynamics properties of the universe is called a reversible process. There are two important conditions for the reversible process to occur.

1) The process should occur in very small time

2) All of the initial and final state of the system should be in equilibrium with each other.

In actual practice the reversible process never occurs, thus it is an ideal or hypothetical process.

The irreversible process is also called the natural process because all the processes occurring in nature are irreversible processes. The natural process occurs due to the difference between the two states of the system. Heat flow between two bodies occurs due to the temperature difference between the two bodies. Water flows from high level to low level, current moves from high potential to low potential, etc.

Heat transfer occurs spontaneously from higher-to lower-temperature bodies but never spontaneously in the reverse. In other words, heat by itself cannot transfer from cold body to hot one.

Entropy

In thermodynamics, a system tends to go from a state with an ordered set of energies to one in which there is less order. The measure of a system's disorder is called the entropy of the system.

Let Q be the energy absorbed or expelled during a reversible, constant temperature T process between two equilibrium states. Then the change in entropy ΔS during any constant temperature process connecting the two equilibrium states is defined as

$$\Delta S = \frac{Q}{T}$$

SI unit: Joules/Kelvin (J/K)

The greater the entropy of a system is, the greater the system's disorder. The total entropy of a system either increases or remains constant in any process; it never decreases. Once a system has reached a state of the greatest disorder, it will tend to remain in that state and have maximum entropy, Figure 57.

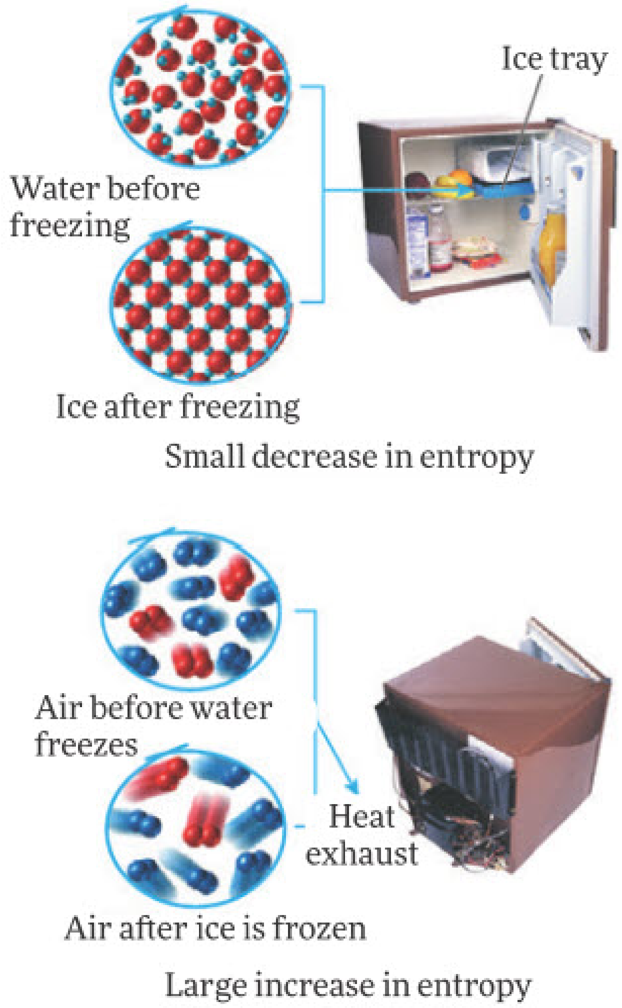


Figure 57

All naturally occurring processes increase disorder. The entropy of the universe increases in all natural processes.

Note that entropy can decrease for parts of systems. The water's entropy decreases as it becomes ice, but the entropy of the air in the room is increased by a greater amount as energy is transferred by heat from the refrigerator, Figure 57. The result is that the total entropy of the refrigerator and the room together has increased.

Second law of thermodynamics. Efficiency

A heat engine is a device that uses heat to do mechanical work. Net work done by heat engine is equal the difference between the energy transferred as heat from a high-temperature substance to the engine (Q_h) and the energy transferred as heat from the engine to a lower-temperature substance (Q_c).

$$W_{net} = Q_{hot} - Q_{cold}$$

According to the second law of thermodynamics, a heat engine cannot transfer all energy as heat to do work. Some energy must always be transferred as heat to the system's surroundings ($Q_c > 0$).

Efficiency is a measure of the useful energy taken out of a process relative to the total energy put into the process. For a heat engine, the efficiency is the ratio of work done by the engine to the energy added to the system as heat during one cycle. Formulas of efficiency are

$$\eta = \frac{W}{Q_{hot}} \qquad \eta = \frac{Q_{hot} - Q_{cold}}{Q_{hot}}$$

Carnot cycle

Carnot cycle has the maximum possible efficiency between two given heat reservoirs with definite temperatures. Carnot cycle consists of two adiabatic and two isothermal processes.

The efficiency of a real heat engine operating between given temperatures (T_h) and (T_c) is always lower than the efficiency of a Carnot engine operating between the same temperatures. This is because a real engine does not work on a Carnot cycle, and additional factors like friction and heat losses decrease the efficiency.

The efficiency of a Carnot engine, absorbing heat from a hot reservoir at T_h and releasing heat to a cold reservoir at T_c is given by

$$\eta = 1 - \frac{T_{cold}}{T_{hot}}$$

Example

A Carnot heat engine receives heat from a high temperature heat source at 700°C and releases heat to a low temperature heat sink (cold reservoir) at 27°C.

a) What is the efficiency of this engine?

b) What is the mechanical work output of the engine in one cycle, if it receives 400 kJ of heat from the hot reservoir in one cycle.

Given:

$T_{hot} = 700°C = 973\ K$

$T_{cold} = 27°C = 300\ K$

$Q_{hot} = 400000\ J$

$\eta = ?$

$W = ?$

Formulas:

$$\eta = 1 - \frac{T_{cold}}{T_{hot}}$$

$$\eta = \frac{W}{Q_{hot}}$$

Calculations:

$$\eta = 1 - \frac{T_{cold}}{T_{hot}}$$

$$\eta = 1 - \frac{300}{973} = 0.6917 = 69.17\%$$

$$\eta = \frac{W}{Q_{hot}}$$

$$W = \eta Q_{hot} = 0.6917 \cdot 400000$$

$$W = 276680\ J = 276.68\ kJ$$

Activity

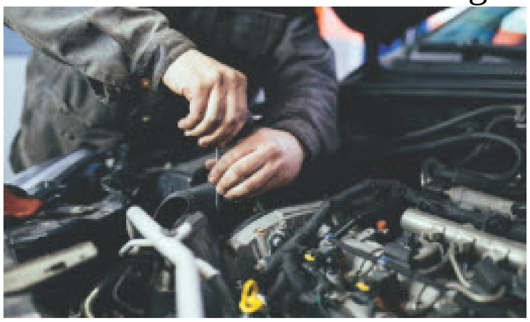
Put an ice cube on a plate. After it completely melts down, is it possible for water to become ice cube again without any external interaction? Explain your answer.

Research time

Is there any absolutely reversible process in nature?

Career

Auto mechanics use knowledge of thermodynamics to repair engines.



Important note

When calculating the efficiency of the Carnot cycle, do not forget to convert temperature values into Kelvin.

Physics in life

These cooling towers are necessary for power stations.
Why do we need these cooling towers?

Literacy

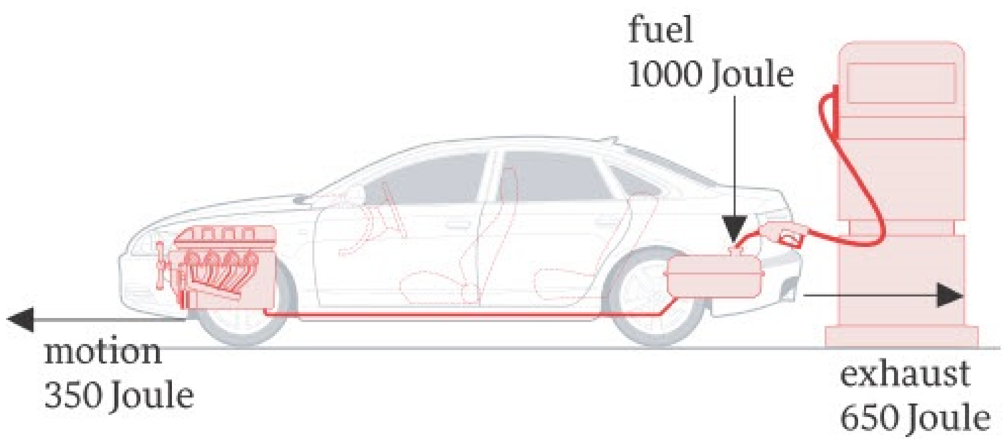
1. What is definition of “entropy”?
2. What is definition of “Carnot cycle”?
3. What is the maximum efficiency of heat engine if the temperature of hot reservoir is 227°C and temperature of cold reservoir is 27°C?
4. Efficiency of Carnot cycle is 25%. How many times should you increase temperature of hot reservoir so that efficiency doubles? Temperature of cold reservoir remains constant.
5. Temperature of hot reservoir of ideal heat engine is 117°C and temperature of cold reservoir is 27°C. Amount of heat received from hot reservoir in one second is 60 kJ. Calculate efficiency of heat engine, heat given to cold reservoir in one second, and power of heat engine.
6. Efficiency of Carnot engine is 80%, heat given to cold reservoir is 2 Joules. Calculate work done by gas during isothermal expansion.

8.5 Problem solving

You will

- apply first law of thermodynamics to isoprocesses and adiabatic process.

Question



What is efficiency of this car? How can you increase efficiency of the car? How can you decrease exhaust of the car?

Example

A steam power plant burns 50 tons of coal every hour. The useful power output of the plant is 130 MW. What is the efficiency of this plant? Take q_{coal} =30 MJ/kg.

Given:

$m = 50000\ kg$

$t = 3600\ s$

$P = 130 \cdot 10^6\ W$

$q_{coal} = 30 \cdot 10^6\ J/kg$

$\eta = ?$

Formulas:

$Q_{hot} = mq_{coal}$

$W = Pt$

$$\eta = \frac{W}{Q_{hot}}$$

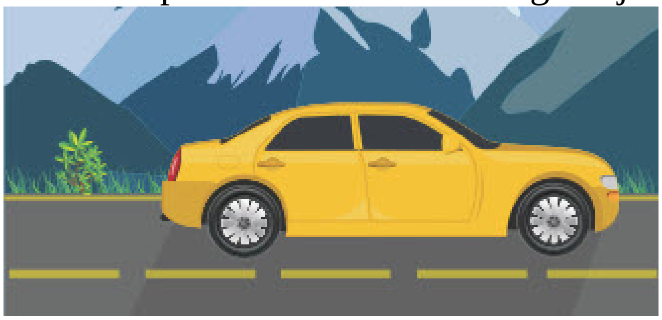
Calculations:

$$\eta = \frac{Pt}{mq_{coal}} \qquad \eta = \frac{130 \cdot 10^6 \cdot 3600}{50000 \cdot 30 \cdot 10^6}$$

$$\eta = 0.312 = 31.2\%$$

Example

An automobile's motor develops 32 kW power while it travels 40 km at a constant speed of 80 km/h. During the journey it consumes 4 kg diesel fuel.



Find the percent efficiency of the motor, if the heat of combustion of the fuel is 42 MJ/kg.

Given:
$P = 32000\ W$
$s = 40000\ m$
$v = 22.22\ m/s$
$m = 4\ kg$
$q_{diesel} = 42 \cdot 10^6\ J/kg$
$\eta = ?$

Formulas:
$s = vt$
$W = Pt$
$Q_{hot} = mq_{diesel}$
$\eta = \frac{W}{Q_{hot}}$

Calculations:

$$\eta = \frac{Ps}{mq_{diesel}v}$$

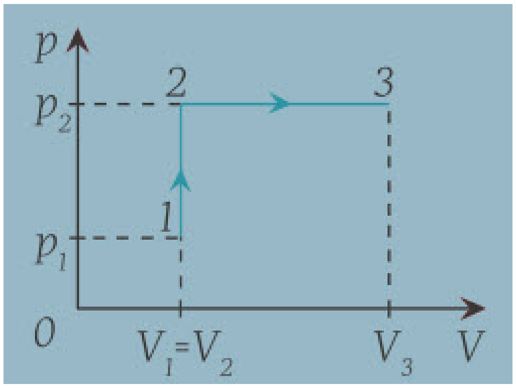
$$\eta = \frac{32000 \cdot 40000}{4 \cdot 42 \cdot 10^6 \cdot 22.22}$$

$$\eta = 0.3429 = 34.29\%$$

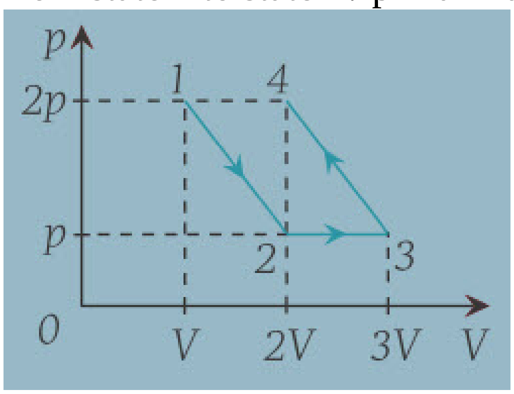
Literacy

1. What is definition of “thermodynamic work”? When work is negative and when it is positive?
2. What is definition of “heat”? When heat is negative and when it is positive?
3. There is P-V diagram of gas. Calculate work done by gas when it goes from state 1 to state 3. Use table shown below.

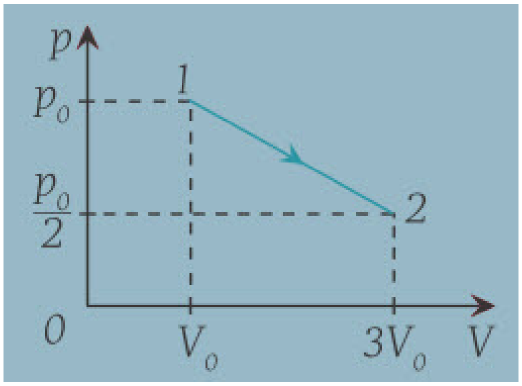
	Pressure (Pascal)	Volume (m^3)	Temperature (Kelvin)
State 1	10^5	0.01	300
State 2			320
State 3			350



4. There is P-V diagram of gas. What is the work done by gas when it goes from state 1 to state 4? $p=10^5$ Pascal and V=0.01 litre.



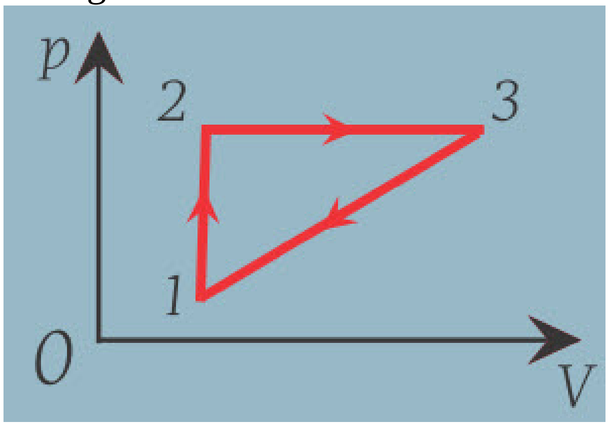
5. There is P-V diagram of monatomic ideal gas. Calculate change of internal energy of gas if p_0=0.2 MPa and V_0=1 litre.



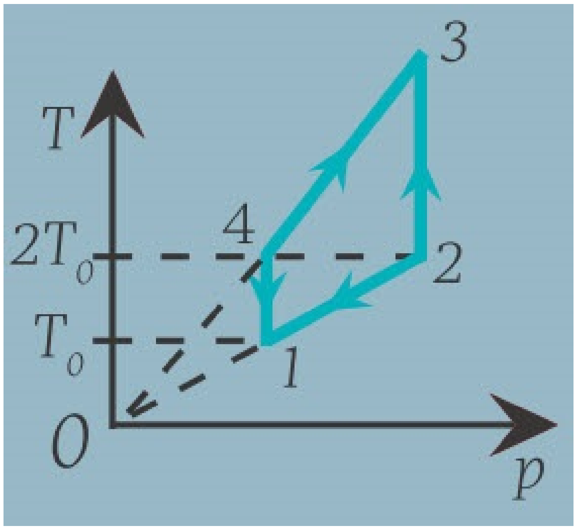
6. Internal energy of monatomic ideal gas is 300 Joules. Gas is in the 2 litre vessel at 27°C. Calculate concentration of gas molecules.

Literacy

1. What is difference between reversible and irreversible processes?
2. In which cases does entropy decrease? Give examples and explain them by using the second law of thermodynamics.
3. There is P-V diagram of cyclic process done on a gas. Work done by gas in the cyclic process is nine times smaller than the heat released by gas during transition 3-1. Calculate efficiency of cyclic process?



4. There is T-P diagram of cyclic process. Use it to plot P-V diagram and calculate efficiency of cyclic process done on monatomic ideal gas.



5. Heat released to cold reservoir by heat engine is 25 J. Calculate work done by heat engine if efficiency is known to be 15%.
6. Three fourths of heat absorbed from hot reservoir by Carnot engine is released to cold reservoir. Calculate temperature of cold reservoir if hot reservoir is at 400 K.

Activity

Draw a 10 cm ×10 cm box. Divide into 4 boxes. Into the first, write the word “Entropy”. Into the second, write your own definition. Into the third, draw a picture that resembles the word. Into the fourth, write a translation in your native language.

Word: Entropy	Your own definition:
Picture:	Translation:

Research time

What is perpetuum mobile? Is it real?

Activity

What Big Bang theory is about? Can it be explained by laws of thermodynamics?

Research time

Freon fluids are used in refrigerators and air conditioners. Why?

Physics in life

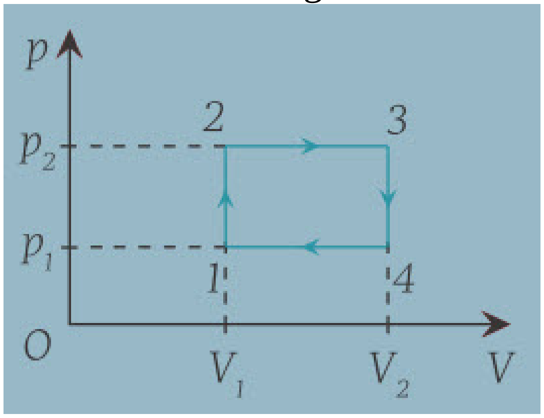
Growers spray water on the plants in orchards so that the water freezes and heat is released to the growing oranges on the trees.

Literacy

1. What is definition of “efficiency”?
2. What is definition of the “second law of thermodynamics”?
3. How many times should you increase volume of 4 moles of ideal gas so that its entropy increases by 23 Joule/Kelvin? Use formula

$$\Delta S = \nu \cdot R \cdot \ln\frac{V_2}{V_1}$$

4. Ideal heat engine absorbs 150 kJ and releases 100 kJ in 0.5 hours. Calculate power of heat engine.
5. Efficiency of heat engine is 12% and its power is 2 kW. What is heat absorbed from hot reservoir in one hour?
6. There is P-V diagram of monatomic ideal gas.



Calculate efficiency of cycle shown on the graph.

$p_1=3\cdot10^6$ Pascal,

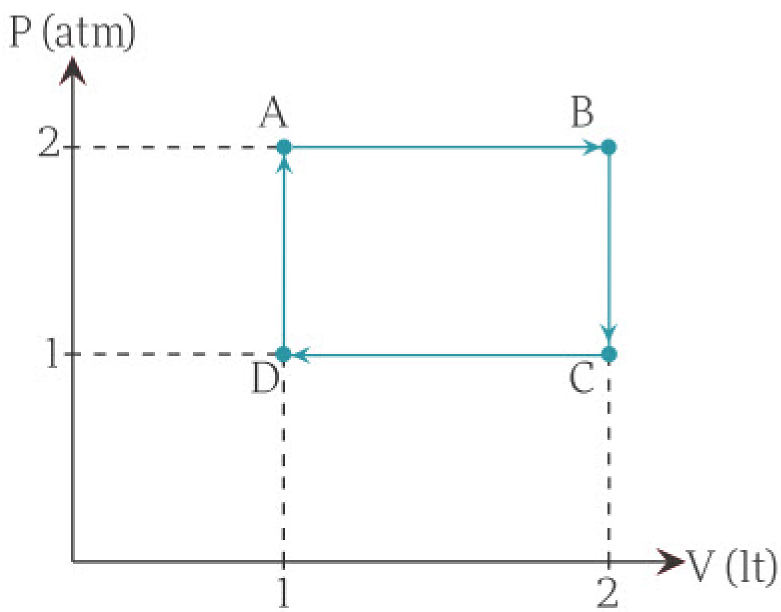
$p_2=7\cdot10^6$ Pascal,

$V_1=2\cdot10^{-3}$ m^3, $V_2=5\cdot10^{-3}$ m^3.

CHECK YOURSELF

There is 1 mole of oxygen gas O_2 in a closed container that undergoes process ABCDA shown on the P-V graph. Use graph to answer questions 1-25.

$R = 8.31$ J/mol·K, $M_{Oxygen} = 0.032$ kg/mole, $N_A = 6\cdot10^{23}$ mol^{-1}



1. What type of process is AB?
A) Isochoric
B) Isobaric
C) Adiabatic
D) Isothermal
E) Isenthalpic

2. What type of process is BC?
A) Isochoric
B) Isobaric
C) Adiabatic

D) Isothermal
E) Isenthalpic

3. What is work in cyclic process ABCDA?
A) 0
B) 200 J
C) -100 J
D) -200 J
E) 100 J

4. What is work in process BC?
A) 0
B) 200 J
C) 400 J
D) 300 J
E) 100 J

5. What is work in process CD?
A) 0
B) 200 J
C) -100 J
D) -200 J
E) 100 J

6. What is the ratio of the temperatures in points A and B?
A) 1
B) 2
C) 3
D) 4
E) 5

7. What is the ratio of the temperatures in points C and D?
A) 1

B) 2
C) 3
D) 4
E) 5

8. How much has the temperature changed in process ABCDA?
A) by 100 K
B) by 200 K
C) by 300 K
D) by 400 K
E) by 0

9. What is the ratio of the temperatures in points A and C?
A) 1
B) 2
C) 3
D) 4
E) 5

10. What is the ratio of the temperatures in points B and D?
A) 1
B) 2
C) 3
D) 4
E) 5

11. What is the ratio of the average kinetic energies of molecules in points D and C?
A) 1
B) 2
C) 3
D) 4
E) 5

12. What is density of gas in point B if cyclic process is quasi-static (infinitely slow)?

A) $2 \cdot 10^3$ g/cm^3

B) $16 \cdot 10^3$ g/m^3

C) 16 g/m^3

D) $2 \cdot 10^3$ kg/m^3

E) 16 kg/cm^3

13. What is the ratio of the root mean square speed of molecules in points B and D?

A) 2
B) 3
C) 4
D) 5
E) 6

14. What is root mean square speed of molecules in point A?

A) 107 m/s
B) 117 m/s
C) 127 m/s
D) 137 m/s
E) 147 m/s

15. What is heat capacity of gas in process AB?

A) 20.775 J/K
B) 23.085 J/K
C) 25.085 J/K
D) 27.085 J/K
E) 29.085 J/K

16. What is number of molecules in the system?

A) 10^{22}

B) $3 \cdot 10^{22}$

C) $6 \cdot 10^{22}$

D) $6 \cdot 10^{23}$

E) $3 \cdot 10^{23}$

17. What is change of the internal energy in the process CD?

A) 250 J

B) 350 J

C) 150 J

D) 450 J

E) 0 J

18. How does internal energy change in the process CD?

A) Does not change

B) Decrease

C) Increase

D) No right answer

E) It is impossible to determine

19. How much heat is released to surroundings in the process BC?

A) 200 J

B) 300 J

C) 400 J

D) 500 J

E) 0 J

20. How much heat is released to surroundings in the process CD?
A) 250 J
B) 350 J
C) 150 J
D) 450 J
E) 0 J

21. How much heat is given to system in the process ABCDA?
A) 650 J
B) 100 J
C) 850 J
D) 950 J
E) 0 J

22. How much heat is released to surroundings in the process ABCDA?
A) 650 J
B) 100 J
C) 850 J
D) 950 J
E) 0 J
23. What is efficiency of the cyclic process ABCDA?
A) 30%
B) 25%
C) 20%
D) 15%
E) 10%

24. How many molecules are there in 1 cm^3 in the point B?
A) $3 \cdot 10^{20}$
B) $3 \cdot 10^{22}$
C) $6 \cdot 10^{22}$
D) $6 \cdot 10^{23}$

E) $3 \cdot 10^{23}$

25. Which points do have the largest concentration of molecules?
A) C and D
B) A and B
C) B and C
D) A and D
E) Concentration is same in all points

Internal Energy of a Gas

1. What is the difference between the internal energy of a gas sample and the internal energy of a solid object?

2. Why can't we change the internal energy of a gas sample without changing its temperature?

3. On which macroscopic parameters does the internal energy of an ideal gas depend?

Transferring Energy to a System

1. Does the energy of a system increase or decrease when the surroundings do work on the system?

2. What is the relationship between work done by a system and work done on a system?

3. Does a gas sample do positive or negative work as its volume increases against external forces

The First Law of Thermodynamics

1. What happens to heat given to a system according to the first law of thermodynamics?

2. A gas sample does 320 J of work, as it absorbs 700 J heat from the surroundings. What is the internal energy change of the gas?

3. The internal energy of a gas sample increases by 280 J when it does 185 J of work. What amount of heat is absorbed by the gas?

4. 800 J of work is done on a gas sample as it releases 150 J of heat. What is the internal energy change of the gas?

5. The internal energy of a system increases by 100 J, when it absorbs 400 J heat. What is the work done by the system on the surroundings?

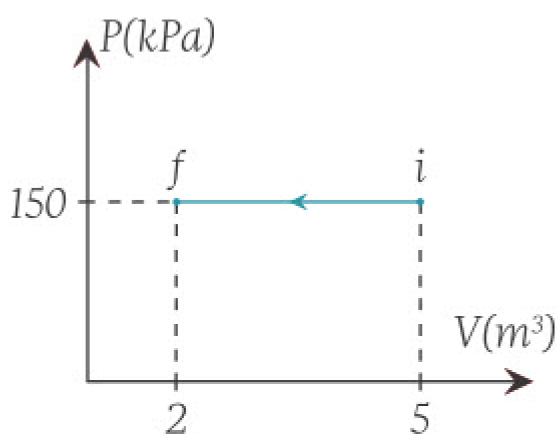
6. A gas in a closed container absorbs 450 J heat. What is the internal energy change of the gas?

Work in a Thermodynamic Process

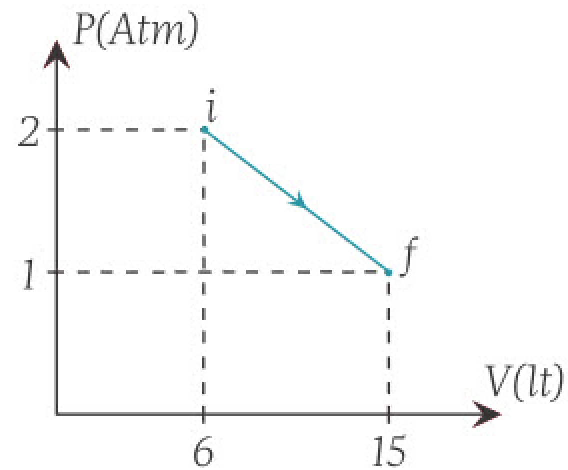
1. A gas sample slowly expands from 2 L to 5 L against constant standard atmospheric pressure. What is the work done by the gas?

2. A gas expands slowly against a constant pressure of 200 kPa, doing 100 J work during the expansion. What is the volume change of the gas?

3. A gas sample in a cylinder-piston system is slowly compressed from state (i) to state (f) as, in the PV graph shown in the figure. What is the work done by the gas during compression?

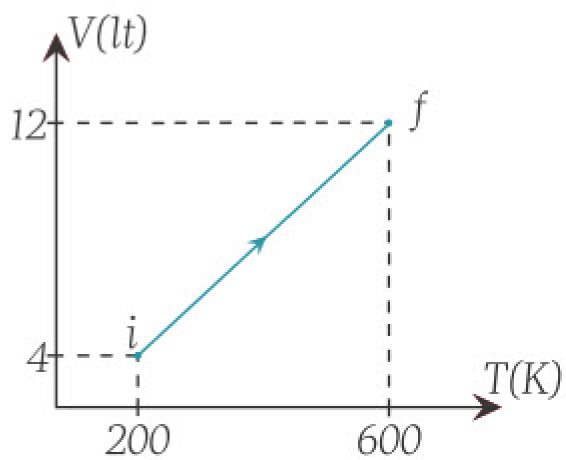


4. A gas expands as shown in the P-V graph. What is the work done by the gas during expansion?



5. A gas sample, initially having a volume of 2 L, slowly expands against a constant 100 kPa pressure. During the expansion the gas absorbs 2100 J of heat and its temperature increases from 300 K to 1200 K. What is the internal energy change of the gas?

6. 2 moles of an ideal gas expands from (i) to (f), as shown in the figure. What is the change in the internal energy of the gas, if 16620 J heat flows into the gas during the expansion.



7. 250 J of heat is transferred to a gas sample in a cylinder-piston system initially at 27 °C. The movable piston keeps the pressure constant at 1 atm.

The initial volume of the gas is 3 L. What is the change in the internal energy of the gas, if the final temperature becomes 127 ºC?

Thermal Processes

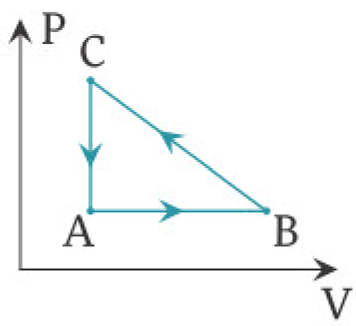
1. The volume of a gas in a cylinder-piston system is decreased to half its initial value, due to a sudden compression. Does the pressure increase to twice its original value?

2. One mole of an ideal gas is adiabatically compressed from 3 L to 2 L. During the compression 300 J of work is done on the gas. What is the change in the internal energy of the gas?

3. One mole of an ideal gas expands adiabatically, doing 20 J work on the surroundings during the expansion. What is the change in the internal energy of the gas, if the initial volume is 0.015 m^3?

4. An ideal gas sample isothermally expands from 0.3 L to 0.8 L. What is the change in the internal energy of the gas during the process, if its initial temperature is 300 K?

5. A gas sample confined to a cylinder by a movable piston undergoes the process described in the V-T graph shown. Transfer the same process to a P-V graph



Heat Engines

1. A heat engine produces 3000 J of heat during the combustion of fuel and releases 2000 J of heat from its exhaust. What is the efficiency of this engine?

2. A heat engine of $\eta=0.3$, loses 5000 J heat during one cycle. What is the work done by the engine in one cycle?

3. A steam power plant burns 50 tons of coal every hour. The useful power output of the plant is 130 MW (megawatts $=10^6$ watts). What is the efficiency of this plant?

(Take $q_{coal}= 30$ MJ/kg)

4. A 500 MW (megawatt) steam power plant has an efficiency of 0.45.
a) What is the useful energy produced by the plant per day?
b) How much heat energy is released to the surroundings per day?

The Second Law of Thermodynamics

1. Could a heat engine have a 100% efficiency, if friction, heat losses to the surroundings, etc. were eliminated?

2. a) What maximum efficiency can a steam engine have if it absorbs hot steam at 800ºC and exhausts it at 120ºC?
   b) Explain why this engine can never reach this theoretical efficiency value?

3. What is the efficiency of a Carnot engine which operates between the temperatures T_h=1200 K and T_c=300 K?

4. A Carnot engine operates between a hot reservoir at 327 ºC and a cold reservoir at 27ºC. How much work does the engine do if it absorbs 800 J heat from the hot reservoir?

5. An ideal heat engine produces 400 J of mechanical work for each 900 J of energy it absorbs from the hot reservoir. What is the absolute temperature of the hot reservoir, if the temperature of the cold reservoir is 350K?

CHAPTER 9: PROPERTIES OF LIQUIDS AND SOLIDS

9.1 Saturated and unsaturated vapour. Humidity of air.

You will

- determine relative humidity of air with hygrometer and psychrometer.

Question

Why -10 degrees of Celsius feels different in Astana and Almaty?

Saturated and unsaturated vapour

Consider a closed container filled with ‘dry’ air containing no water vapour in it. When water is placed in the container water starts to evaporate, the concentration of water molecules in the air increases. There is a maximum limit of water vapour that air can hold at a particular temperature. When this limit is reached, the air is said to be saturated. When the air does not contain the maximum amount of water vapour it is said to be unsaturated for that temperature.

Humidity of air

Humidity is the amount of water vapour in the air. It can be measured as absolute humidity (the amount of water vapour in a unit volume of air), or as relative humidity. Relative humidity (φ) is defined as the proportion of the partial pressure of water vapour in the air to the vapour pressure of water at that temperature.

$$\varphi = \frac{p_{H_2O}(in\ air)}{p_V}$$

Saturation means air cannot carry any more water vapour, dew starts to form at φ= 1. Dew forms in the morning (when it is cold), or on cold surfaces (like window panes), Figure 58. Cold air cannot 'carry' water vapour in it.

Figure 58

Hygrometer

A hygrometer is instrument used to measure the humidity, Figure 59.

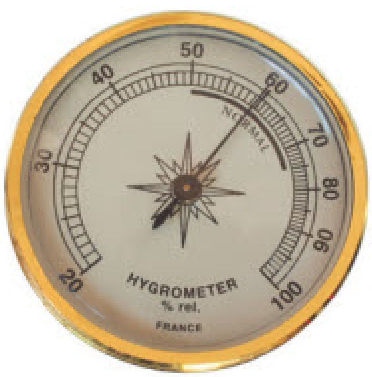


Figure 59

Humidity measurement instruments rely on measurements of some other quantity such as temperature, pressure, etc. Modern electronic devices use changes in electrical capacitance or resistance to measure humidity, Figure 60.

Figure 60

Psychrometer

A psychrometer is the most simple way of measuring humidity, Figure 61.

Figure 61

Psychrometer uses two thermometers, one with a wet bulb, one with a dry bulb. Evaporation on the wet bulb causes its temperature to drop, causing it to show a lower temperature than the dry bulb, Figure 62. Then psychrometric table is used to determine relative humidity, Table 5.

EXPERIMENTAL SET-UP

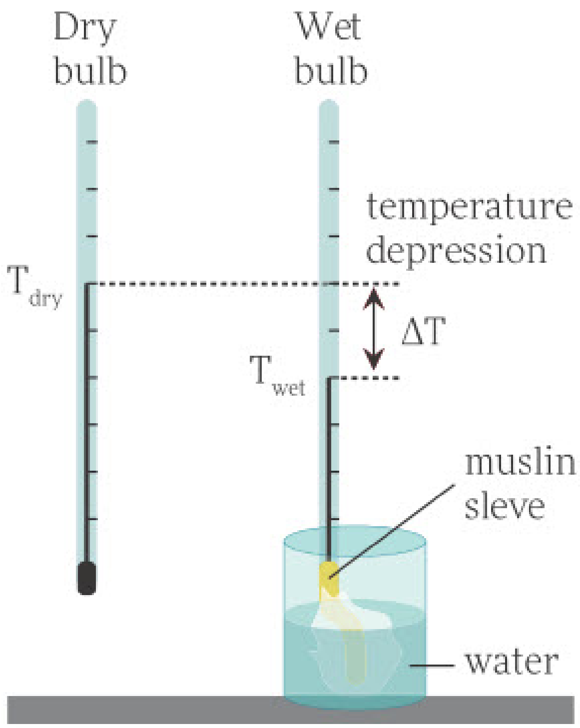


Figure 62

Relative Humidity (%)																
Dry-Bulb Temperature (°C)	Difference between Wet-Bulb and Dry-Bulb temperatures (°C)															
	0	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
-20	100	28														
-18	100	40														
-16	100	48														
-14	100	55	11													
-12	100	61	23													
-10	100	66	33													
-8	100	71	41	13												
-6	100	73	48	20												
-4	100	77	54	32	11											
-2	100	79	58	37	20	1										
0	100	81	563	45	28	11										
2	100	83	67	51	36	20	6									
4	100	85	70	56	42	27	14									
6	100	86	72	59	46	35	22	10								
8	100	87	74	62	51	39	28	17	6							
10	100	88	76	65	54	43	33	24	13	4						
12	100	88	78	67	57	48	38	28	19	10	2					
14	100	89	79	69	60	50	41	33	25	16	8	1				
16	100	90	80	71	62	54	45	37	29	21	14	7	1			
18	100	91	81	72	64	56	48	40	33	26	19	12	6			
20	100	91	82	74	66	58	51	44	36	30	23	17	11	5		
22	100	92	83	75	68	60	53	46	40	33	27	21	15	10	4	
24	100	92	84	76	69	62	55	49	42	36	30	25	20	14	9	4
26	100	92	85	77	70	64	57	51	45	39	34	28	23	18	13	9
28	100	93	86	78	71	65	59	53	47	42	36	31	26	21	17	12
30	100	93	86	79	72	66	61	55	49	44	39	34	29	25	20	16

Table 5

Example

What is the partial pressure of water vapour in air at 20°C, if the relative humidity is 40%? The vapour pressure of water at 20°C is . What is absolute humidity of air?

Given:

$T = 20^oC = 20 + 273 = 293\ Kelvin$

$\varphi = 40\% = 0.4$

$p_V = 2333\ Pa$

$M = 18\ g/mole = 0.018\ kg/mole\ (H_2O)$

$R = 8.31\ J/K \cdot mole$

$p = ?$

Formulas:

$$\varphi = \frac{p}{p_V} \cdot 100\%$$

$$\rho = \frac{m}{V} = \frac{pM}{RT}$$

Calculations:

$$\varphi = \frac{p}{p_V} \cdot 100\%$$

$$p = \frac{\varphi p_V}{100\%} = \frac{40\% \cdot 2333}{100\%}$$

$$p = 933.2\ Pa$$

$$\rho = \frac{pM}{RT} = \frac{933.2 \cdot 0.018}{8.31 \cdot 293}$$

$$\rho = 0.0069\ kg/m^3 = 6.9\ g/m^3$$

Discussion:

Absolute humidity of 6.9 g/m^3 means that 1 m^3 of air contains 6.9 gram of water vapour.

Activity

Use materials shown in Figure 5 and Table 1 to determine relative humidity of air in the classroom.

Research time

Take two glass or transparent plastic cups. Fill half (½) of a cup with hot water (be careful). Put empty cup on the top of the cup with hot water. Observe for 3-4 minutes.

a) What is happening? Why?

b) What will happen if you put ice at the top? Why?

Is it true?

The highest dew point temperature ever recorded was 95% in July 2003, in Dhahran, Saudi Arabia.

Interesting question

Why do some trees have leaves and some trees have needles? How it is related to humidity?

LIteracy

1. What is “triple point”? Give examples of triple point of different substances.
2. What is difference between absolute humidity and relative humidity?
3. There is 80 grams of water vapour in 5 m^3 of air. Calculate absolute humidity of air.
4. There is moist air in closed container that has 10^{-2} kg/m^3 absolute humidity. Volume of container is 1 m^3. How many molecules of water vapour are there in container?
5. Density of saturated mercury vapour is 0.02 kg/m^3 at 20 °C. Calculate pressure of saturated vapour of mercury.
6. Calculate absolute humidity of air if partial pressure of water vapour at 60 °C is $1.4 \cdot 10^4$ Pascal.

9.2 Phase diagrams. Triple point. Critical point. Supercritical fluid

You will

- determine relative humidity of air with hygrometer and psychrometer.

Question

Why do you sweat all the time in tropical rainforest? What is humidity in tropical rainforest?

Phase diagram

Phase diagram is a graphical representation of the physical states of a substance under different conditions of temperature and pressure, Figure 63.

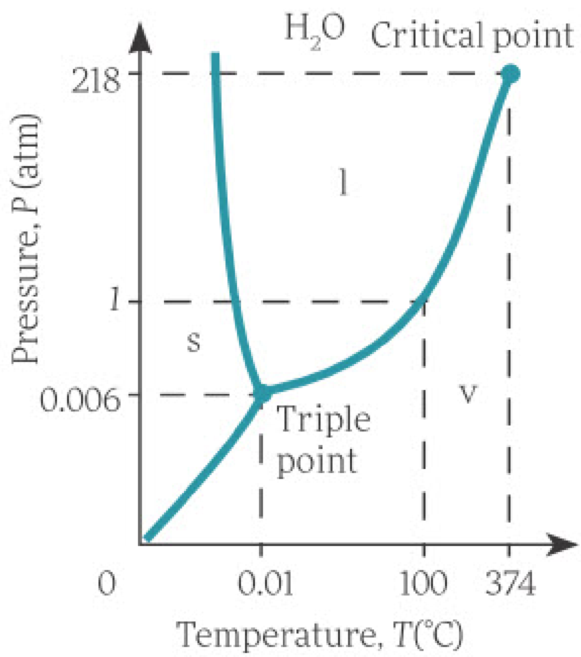


Figure 63

Using the graph, if you know the pressure and temperature you can determine the phase of substance. The lines indicate temperatures and pressures at which the phases coexist (exist together).

The curve between the solid and vapour regions gives the boiling temperature at various pressures. For example, the boiling point of water is 100°C at 1 atm. As the pressure increases, the boiling temperature also rises (374°C at 218 atm).

The curve between the solid and liquid regions gives the melting temperature at various pressures. For example, the melting point of ice is 0°C at 1 atm, Figure 63.

Critical point

The curve ends at a point called the critical point, because at higher temperatures the liquid phase does not exist at any pressure. At sufficiently high pressure above the critical point, the gas will have the density of a liquid but will not condense. Substances in this region can take on properties and behaviours of both gas and liquid. This region is known as the supercritical fluid region.

At sufficiently low pressures there is no liquid phase, but the substance can exist as either gas or solid. For water, there is no liquid phase at pressures below 0.006 atm. The phase change from solid to gas is called sublimation.

Critical pressure is the minimum pressure needed for a liquid to exist at the critical temperature.

Critical temperature is the temperature above which a liquid cannot exist.

Triple point

All three curves on the phase diagram meet at a single point, the triple point, where all three phases exist in equilibrium. For water, the triple point occurs at 273.16 K (0.01°C).

Supercritical fluid

A supercritical fluid is substance above critical point. It has properties of both liquids and gases. For example it can pass through solids like gas (air) and dissolve solids like liquid (water).

Example

Relative humidity of water vapour in air at 20°C is 40%. The vapour pressure of water at 20°C is p_V=2333 Pa. Find the mass of vapour in air in a 100 m^3 room. How much additional water can be vaporised in the same room?

Given:

$T = 20^oC = 20 + 273 = 293\ Kelvin$

$\varphi = 40\% = 0.4$

$p_V = 2333\ Pa$

$M = 18\ g/mole = 0.018\ kg/mole\ (H_2O)$

$R = 8.31\ J/K \cdot mole$

$m_1 = ?\ kg$

$\Delta m = ?\ kg$

Formulas:

$$\varphi = \frac{p}{p_V} \cdot 100\%$$

$$\rho = \frac{m}{V} = \frac{pM}{RT}$$

$$\Delta m = m_2 - m_1$$

Calculations:

$$\varphi = \frac{p}{p_V} \cdot 100\%$$

$$p = \frac{\varphi p_V}{100\%} = \frac{40\% \cdot 2333}{100\%}$$

$$p = 933.2\ Pa$$

$$\frac{m_1}{V} = \frac{pM}{RT}$$

$$m_1 = \frac{pMV}{RT} = \frac{933.2 \cdot 0.018 \cdot 100}{8.31 \cdot 293}$$

$$m_1 = 0.69\ kg = 690\ g$$

$$\frac{m_2}{V} = \frac{p_V M}{RT}$$

$$m_2 = \frac{p_V MV}{RT} = \frac{2333 \cdot 0.018 \cdot 100}{8.31 \cdot 293}$$

$$m_2 = 1.725\ kg = 1725\ g$$

$$\Delta m = 1725 - 690 = 1035\ g$$

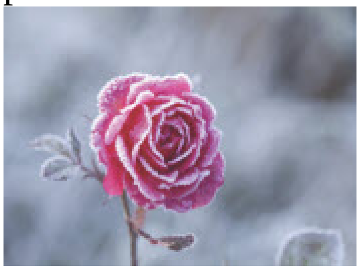
Discussion:

At 100% humidity room can contain 1725 gram of vapour. If we add more vapour after 1725 gram vapour will condense into water. At 40% humidity room contains 690 grams of vapour. That means 1035 grams of vapour can be added to air in room.

Literacy

1. What is definition of “critical point”? Give examples of substances below and above critical point.
2. What is “supercritical fluid”? Give examples of supercritical fluid and tell difference between supercritical fluid and regular liquid.
3. Partial pressure of water vapour is 1040 Pascals when relative humidity is 40%. What is the saturated vapour pressure?
4. What is the mass of water vapour in 1 m^3 during 30°C summer day that has 75% relative humidity? Saturated vapour pressure at 30°C is 4240 Pascals.
5. There is air in 30 m^3 room at 20°C and 20% relative humidity. How many grams of water should air humidifier vaporise so that relative humidity becomes 50%? Saturated vapour pressure at 20°C is 2330 Pascals.

6. Relative humidity of air in the basement of house is 100% at 10°C. You need to decrease humidity to 52.4%. How should you change temperature? Saturated vapour pressure at 10°C is 1230 Pascals.
7. Temperature of air outside is 2°C, relative humidity of air is 60%. Will be there any frost on a rose if temperature drops to -3°C? Use table of vapour pressure.



8. Temperature of air is 25°C and relative humidity is 95%. At what temperature there will be mist? Use table of vapour pressure.

Activity

When an electric heater is used in the room, it is advised to use humidifier in the room. Why?

Career

Meteorologists use concept of humidity for accurate weather forecasts.

Research time

Solar still is a device to make distilled water. Make one for yourself

Is it true?

Increases in humidity help these moths detect which flowers are high in nectar.

Is it true?

Silica gel is used in goods for absorption of humidity.

Physics in life

Low humidity causes tissue lining nasal passages to dry, crack and become more susceptible to penetration of rhinovirus cold viruses.

9.3 Surface tension. Adhesion and cohesion. Capillary action

You will

- determine surface tension of liquid by using different methods

Question

Why do water striders (gerridae) can walk on surface of water? Why can't you walk on water?

Surface tension

Consider the rectangular wire frame. One side is free to slide in both directions. The frame is dipped in water, which forms a film stretching over the structure, Figure 64a. In the absence of an external force, the film - trying to reduce the surface area - pulls the movable side back, until the surface area is nearly zero. In the figure two forces are indicated by the liquid film, since the liquid has two surfaces, Figure 64b. The surface tension is defined as the ratio of the surface-tension force to the length, L along which it acts. Greek letter (sigma) symbolises the surface tension.

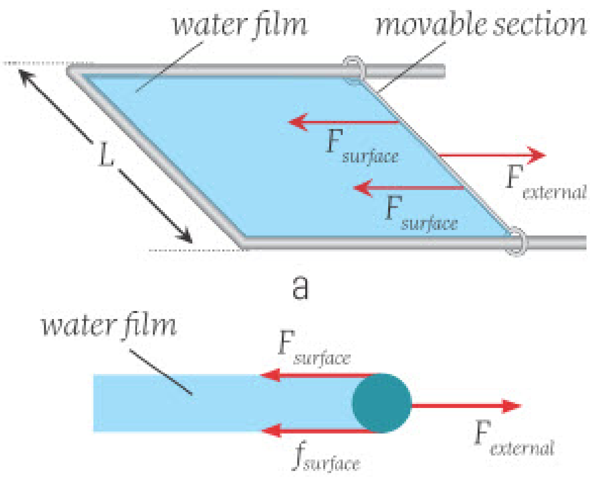


Figure 64

$$\sigma = \frac{F}{L}$$

The SI unit for surface tension is N/m.

The surface tension of liquids decreases with increasing temperature, Table 6. This is why hot water is used for washing clothes. Detergent also decreases surface tension.

Substance	Surface tension at 20^0C (N/m)
Benzene	0.029
Glycerin	0.063
Mercury	0.465
Water	0.072
Water at 100^0C	0.059

Table 6

The expression for the surface-tension force shows us that the force is independent of amount of stretching.

$$F = \sigma L$$

The work done in pulling the sliding portion from position 1 to position 2 must be stored as a kind of potential energy change, since no other known energy form appears, Figure 65.

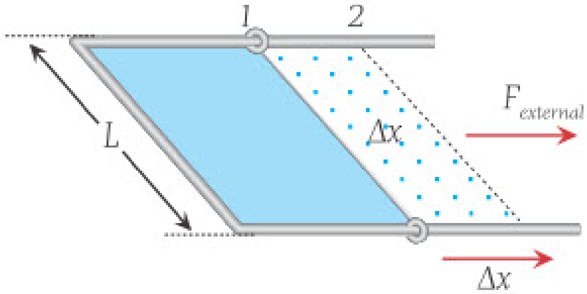


Figure 65

A surface potential energy U, can be defined. Following the discussion above, change in surface potential energy (ΔU) is;

$$W_{external} = \Delta U_{total}$$

$$F_{external} \Delta x = 2\Delta U_{total}$$

Inserting $F_{external} = 2F_{surface\ tension}$ gives

$$2F\Delta x = 2\Delta U; \qquad (\sigma L)\Delta x = \Delta U$$

However $L\Delta x$, equals the area change A;

$$\sigma \Delta A = \Delta U$$

The expression describes the change in surface potential energy. Surface potential energy can be defined as follows:

$$U_{surface} = \sigma A$$

Adhesive and cohesive forces

Forces between like-molecules (e.g. water - water) are called cohesive forces. Forces between unlike-molecules (e.g. water - glass) are called adhesive forces.

When adhesive forces are greater than cohesive forces, for a liquid, in contact with a surface, the liquid 'wets' the surface. If cohesive forces are greater, the surface is not wetted.

It is possible to compare adhesive and cohesive forces by observing the angle of contact between the liquid and the solid surface. The angle of contact is defined as the angle between the liquid and solid surfaces, facing the interior of the liquid.

- Adhesive forces > Cohesive forces ↔ f < 90° ↔ Liquid tries to climb upwards along the solid surface. Liquid-gas interface curves upwards, Figure 66a.
- Adhesive forces = Cohesive forces ↔ f = 90° ↔ Liquid stays horizontal.
- Adhesive forces < Cohesive forces ↔ f > 90° ↔ Liquid tries to shrink into a sphere. Liquid-gas interface curves downward, Figure 66b.

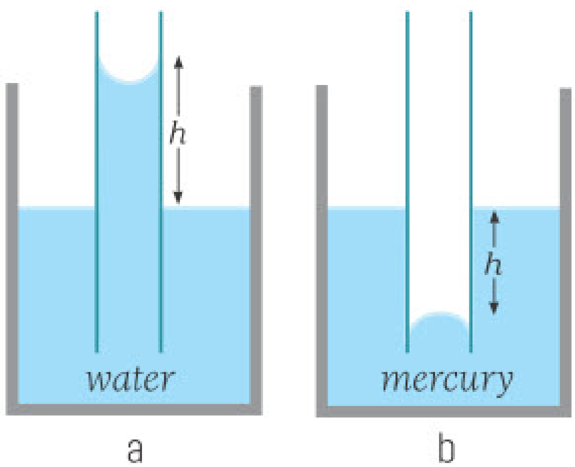


Figure 66

Capillary action

A capillary is a tube with a very small internal diameter. Capillary action is the rise or fall of a liquid in a capillary by amount h, Figure 67.

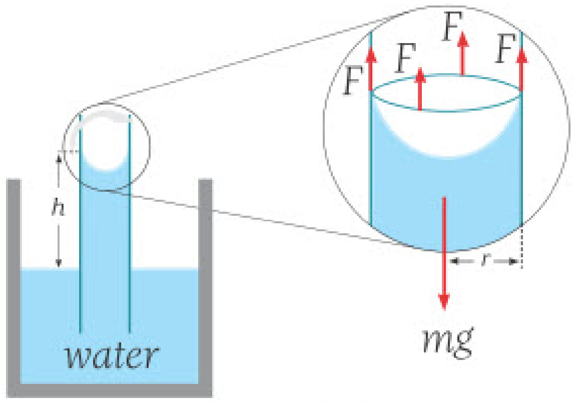


Figure 67

Absorption of water by a paper towel is an example of capillary action. Paper pulls water into the narrow channels between the fibres.

The capillary effect is more significant in thinner tubes. The weight of the water column above the water surface is supported by the vertical component of surface tension force, Figure 68. The height h is calculated by this formula, where q is angle of contact,

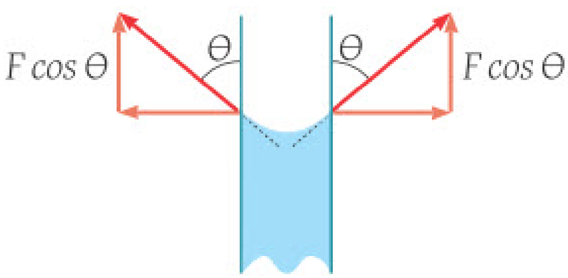


Figure 68

$$mg = \sigma L cos\theta; \quad \rho V g = \sigma L cos\theta; \quad \rho(\pi r^2 h)g = \sigma(2\pi r)cos\theta;$$

$$h = \frac{2\sigma cos\theta}{\rho g r}$$

Example

Hyperion is the name of the tallest tree in the world (115.92 m). Can capillary action transport sap to the highest point of Hyperion? Sap is fluid inside of trees (1050 kg/m^3). Sap moves through the xylem, which forms tubes with radius of $2.5 \cdot 10^{-5}$ m. Contact angle is zero, and sap's surface tension is 0.0728 N/m.

Given:

$\rho = 1050\ kg/m^3$

$r = 2.5 \times 10^{-5}\ m$

$\theta = 0^o$

$\sigma = 0.0728\ N/m$

$g = 10\ N/kg$

$h = ?\ m$

Formulas:

$$h = \frac{2\sigma}{\rho g r} cos\theta$$

Calculations:

$$h = \frac{2\sigma}{\rho g r} cos\theta$$

$$h = \frac{2 \cdot 0.0728}{1050 \cdot 10 \cdot 2.5 \cdot 10^{-5}} \cdot \cos 0°$$

$$h = 0.55\ m$$

Discussion:

As you can see 0.55 metres is much less than 115 metres. That means sap is transported by other mechanism than capillary action.

Literacy

1. What is "surface tension"? Give examples of low surface tension and high surface tension.
2. What is difference between adhesion and cohesion? What does happen when adhesion is greater than cohesion? What does happen when cohesion is greater than adhesion?
3. Paperclip has mass of 0.1 gram and length of 3.5 cm. Will it lie on the surface of water or will it sink? Prove your answer with calculations.
4. Dropper (pipet) was used to determine surface tension of liquid. Forty drops were measured to be 1.9 gram. Diameter of dropper is 2 mm. Calculate surface tension of liquid.
5. Liquid has risen to height of 11 mm in capillary tube of 0.5 mm radius. Calculate density of this liquid if surface tension is 22 mN/m.
6. What amount of energy is released when small water droplets of $2 \cdot 10^{-3}$ mm radius coalesce into one big droplet of 2 mm radius?

Activity

Put needle (or paperclip) so that it floats on surface of water. Measure length of needle and calculate its mass.

Physics in life

The mercury inside the thermometer does not stick to the wall of the tube due to the surface tension.

Research time

Fill the shallow tray (or sink) with water. Cut the one dimensional boat shape out of the cardboard. Using the dropper, place a drop of detergent into the centre opening of the boat

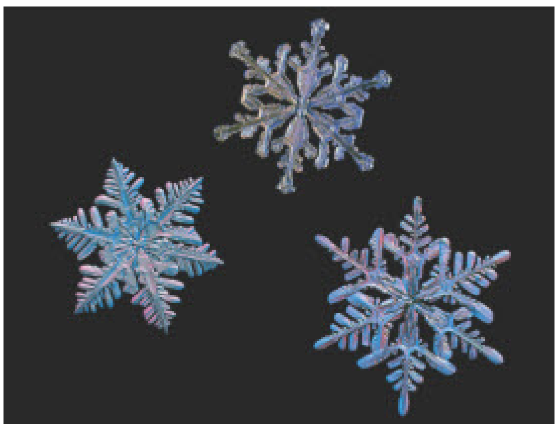
Why does the paper boat move forward only when the detergent touches the water? What pushes the paper boat forward? Is it the detergent dropped or the surface of the water? What did the detergent do to the cohesive forces between the water molecules?

9.4 Crystalline solids and amorphous solids

You will

- tell difference between crystalline and amorphous solids by using examples of different solids.

Question



Why are snowflakes symmetrical and unique although temperature and humidity of air are chaotic? How shape of snowflake is related to shape of water molecule?

Bonds between molecules of solids are stronger than liquids and gases. A molecule in a solid structure is not free to move around in the substance.

The arrangement of atoms forming the solid structure differs between substances. The atoms of crystalline solids are neatly arranged. In an amorphous solid, however, atoms are just lumped together.

Crystalline Solids

A crystalline structure is characterised by two properties:

- Regularly repeating internal structure
- External plane faces

All crystals of the same substance have the same angles between their faces. The arrangement of atoms in a regular periodic pattern, in three dimensions, is called the crystal lattice, Figure 69.

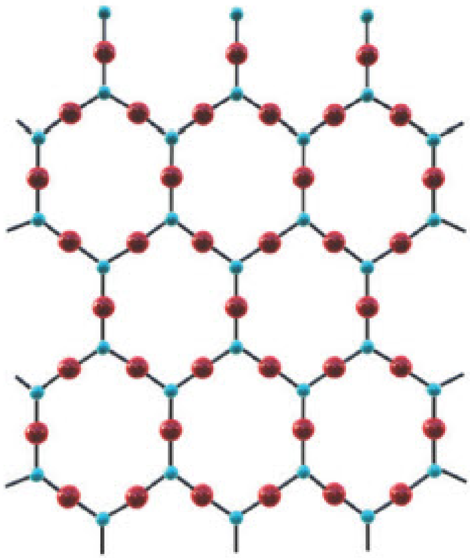


Figure 69

A group of atoms that repeats in three dimensions, in the crystal structure, is called a unit cell. Crystalline substances are classified into seven systems on the basis of the geometry of their unit cells. The cubic system is one of these seven systems, Figure 70.

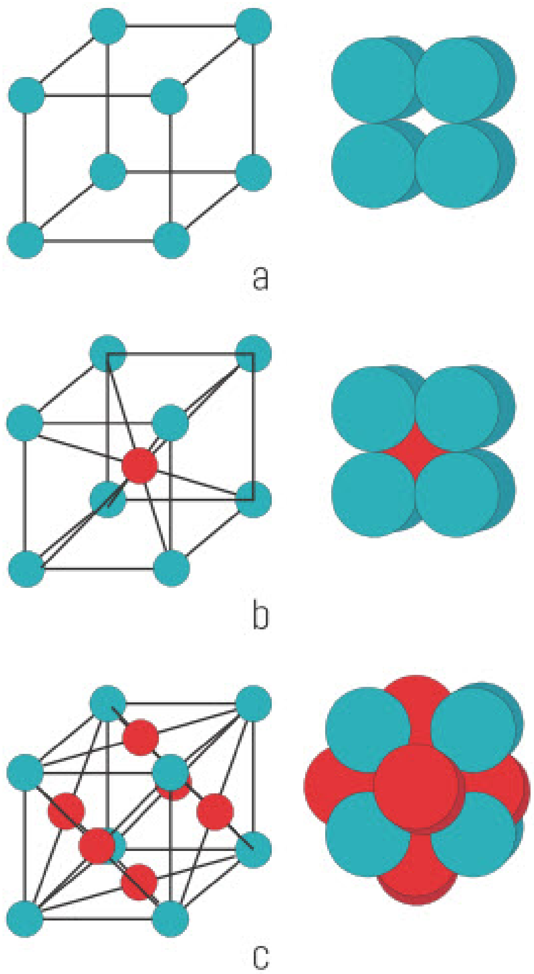


Figure 70

An element can exist in two or more distinct physical forms. The phenomenon is known as allotropy. As an example, carbon displays allotropy in graphite and diamond, which means both the substances graphite and diamond consist of carbon atoms, however, they display totally different properties.

Different arrangements of the atoms in the crystals cause allotropic forms to differ in physical properties; like colour, density, hardness, conductivity etc.

Physical properties (e.g. mechanical strength, heat and electric conduction) of crystalline solids, depend upon the direction of flow within the lattice. Such substances are called anisotropic.

Amorphous Solids

Amorphous solids do not have any order in the arrangement of their atoms, Figure 71. Only proximate atoms have some order. The recurrence of the same structure in all directions, which is characteristic of crystals, is not present in amorphous substances. Plastic, tar, resin, and glass are examples of amorphous solids. Amorphous substances are isotropic; their physical properties are independent of direction within the solid.

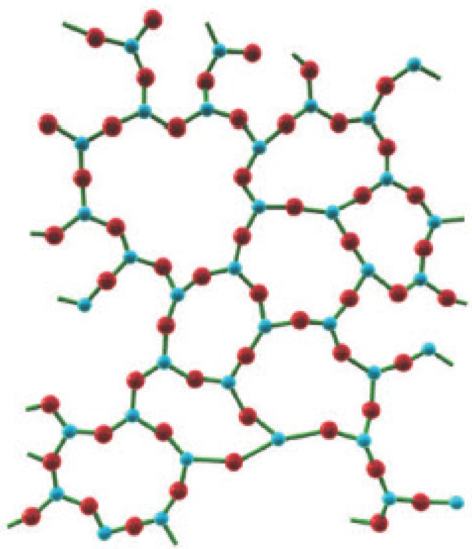


Figure 71

Frequently the same substance (such as quartz) may occur both in crystalline and amorphous forms.

The amorphous substances occupy an intermediate state between crystalline solid structures and fluids. They behave like elastic solids against sudden shocks, but flow like liquids over very long time scales.

Crystalline solids have definite melting points. Amorphous solids do not have a definite melting point. In other words, changing the shape of an amorphous substance gets easier as temperature increases. At high temperatures, an amorphous solid becomes more like a very thick (viscous) liquid. However, since the transformation takes place gradually, a single temperature cannot be identified as the melting point.

Example

At what load will a given metal wire of 2 cm diameter break, if its breaking limit of mechanical stress equals 1000 N/mm^2?

Given:

$d = 0.02\ m$

$1\ mm^2 = 0.000001\ m^2$

$\sigma = 10^9\ N/m^2$

$F = ?$

Formulas:

$A = \pi r^2 = \frac{\pi d^2}{4}$

$\sigma = \frac{F}{A}$

Calculations:

$$F = \frac{\sigma \pi d^2}{4}$$

$$F = \frac{10^9 \cdot 3.14 \cdot 0.02^2}{4}$$

$$F = 314000\ N$$

Discussion:

314000 Newton is weight of about 31.4 tons (about 30 cars).

Activity

Draw a 10 cm · 10 cm box. Divide into 4 boxes. Into the first, write the word "Amorphous". Into the second, write your own definition. Into the third, draw a picture that resembles the word. Into the fourth, write a translation in your native language.

Word: Amorphous	Your own definition:
Picture:	Translation:

Research time

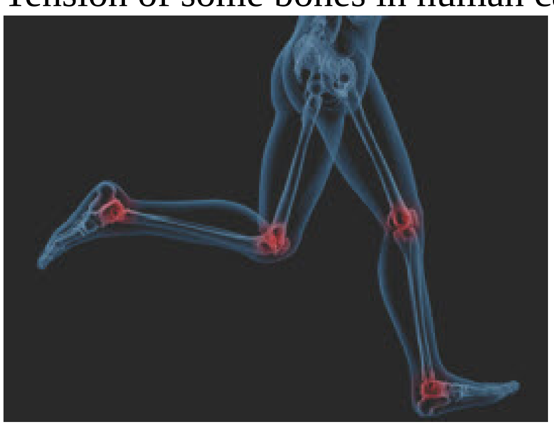
Capture several photos of snowflakes. Try to find identical snowflakes. Explain symmetry and uniqueness of snowflakes.

Literacy

1. What is difference between crystalline and amorphous solids? Give examples of crystalline and amorphous solids.
2. What is “Young’s modulus”? Give examples of materials with high Young’s modulus and materials with low Young’s modulus.
3. How many steel wires are needed to make steel cable that can lift 16 ton load? Ultimate tensile strength of steel is 500 MPa. Diameter of wire is 2 mm.
4. Steel cable of 9 mm diameter can hold stationary elevator cabin. What diameter should steel cable have so that elevator cabin can move at 8g acceleration?
5. Galvanometer has coil inside which is suspended on thin platinum thread of 4 m diameter. Calculate maximum weight of coil if ultimate tensile strength is 30 N/mm^2.
6. Steel wire of 1 mm diameter is stretched horizontally between two posts 2 metre away from each other. Load of 0.25 kg is attached to the middle of wire (point O). How many centimetres does point O move?

Is it true?

Tension of some bones in human can reach a value of 16 billion Pascals.

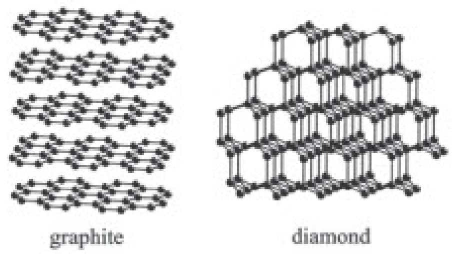


Research time

Sugar is crystalline solid. Melt it down (be careful and do it under the supervision of adults). Does the sugar remain as crystalline? Explain your answer and explain process of making of caramel.

Physics in life

Diamond and graphite (coal) are same element - carbon. Difference is in internal structure.



Physics in life

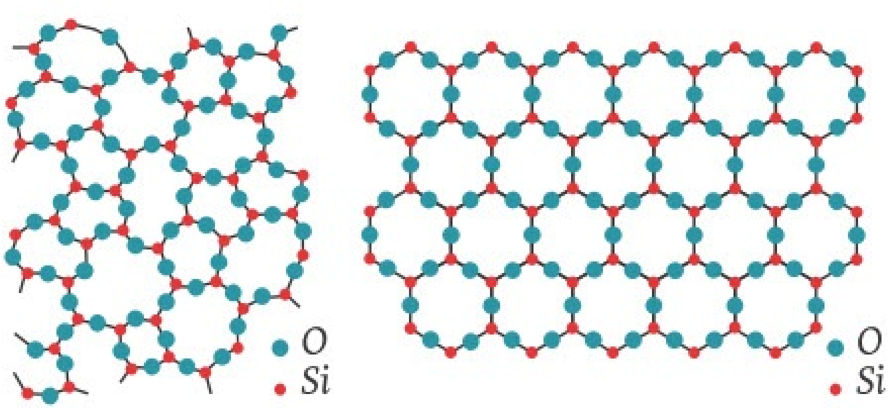
Steel cables are used in cranes for lifting heavy objects.

9.5 Mechanical properties of solids

You will

- determine Young's modulus during elastic deformation.

Question



Here you can see molecular structures of quartz and glass. They are both composed of oxygen and silicon atoms. Which one is quartz and which one is glass? What is difference between quartz and glass?

Mechanical properties of solids

Consider a metal bar of length L and cross sectional area A, Figure 72.

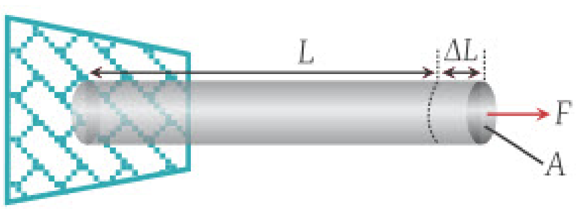


Figure 72

The bar is fixed at one end and a force F is applied at the other end, compressing or stretching the bar. Under the action of a force, length changes by ΔL.

Strain is the fractional change in length.

$$Strain = \frac{Change\ in\ length}{Initial\ length} \qquad \varepsilon = \frac{\Delta L}{L}$$

Mechanical stress is the (perpendicular) force to cross-sectional area ratio:

$$Stress = \frac{Force}{Area} \qquad \sigma = \frac{F}{A}$$

Mechanical stress is dimensionally equivalent to pressure. The unit of stress is N/m^2=Pa.

The type of mechanical stress elongating the substance is called the tensile stress. Increasing the tensile stress on a substance increases its length.

In the elastic region of the curve (between points A and C), the material returns to its initial length when the stress is removed, like resin rope, Figure 73.

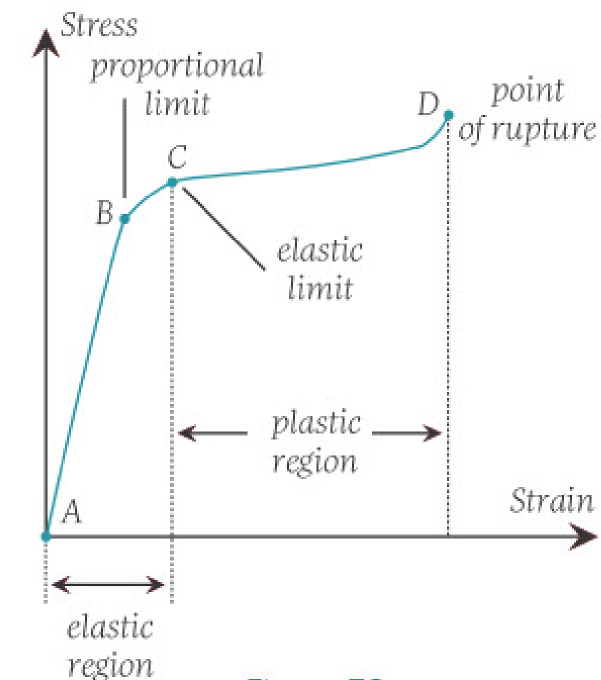


Figure 73

If the elastic limit (point C) is exceeded, the substance becomes permanently deformed (between C and D); it does not assume its initial shape, even after the stress is removed, like plasticine, Figure 73. Such a deformation is called plastic deformation.

If mechanical stress is further increased, the material breaks at point D.

As seen from the curve, strain is proportional to mechanical stress for small strain values, from A to B, Figure 73. Therefore, for sufficiently small strain:

$$\frac{Tensile\ Stress}{Tensile\ Strain} = constant$$

The constant in the formula is called Young's modulus, and is denoted by E.

$$\sigma = E\varepsilon \qquad \frac{F}{A} = E\frac{\Delta L}{L}$$

Young's modulus depends only on the substance, not on the geometry or size. Therefore, it is a characteristic property for a solid, Table 7.

Material	Young's modulus (10^9 N/m^2)
Aluminum	70
Brass	90
Brick	15
Concrete	20
Glass	70
Gold	80
Granite	45
Human Hair	10
Hardwood	15
Iron, cast	100
Lead	16
Marble	60
Nylon	5
Polystyrene	3
Silk	6
Steel	210

Table 7

Hooke's law can be written for a given object using Young's modulus.

$$F = \frac{EA}{L}\Delta L$$

Since for a given substance Young's modulus, cross sectional area and original length are constants,

$$Force = Constant \cdot Elongation$$

$$F = kx$$

where

$$k = \frac{EA}{L}$$

Safety factor

Safety factor is a ratio of maximum strength to intended load.

$$Safety\ Factor = \frac{Yield\ Stress}{Working\ Stress}$$

For example, rope that mountain climber uses can hold 5000 Newton. If the weight of climber is 1000 Newton then safety factor is equal to 5.

Buildings use safety factor of 2. Pressure vessels use SF=4, automobiles use SF=3, aircrafts use SF=2.

Safety factor should not be very high. For example, aircraft with SF=5 would be too heavy to fly.

Example

What force is needed to increase the length of a steel wire by 4 mm? The initial length of the wire is 2 m and its cross sectional area is 0.5 mm^2. Young's modulus of steel is $20 \cdot 10^{10}$ Pascals.

Given:

$\Delta L = 0.004\ m$

$L = 2\ m$

$A = 5 \cdot 10^{-7}\ m^2$

$E = 20 \cdot 10^{10}\ Pa$

$F = ?$

Formulas:

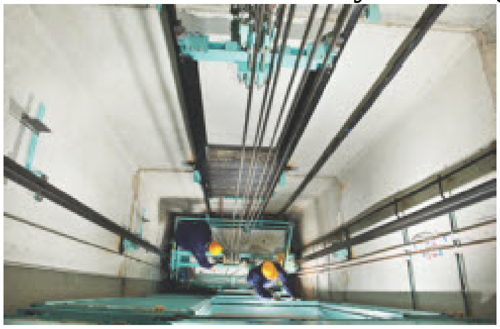
$$F = \frac{EA}{L} \Delta L$$

Calculations:

$$F = \frac{20 \cdot 10^{10} \cdot 5 \cdot 10^{-7}}{2} \cdot 0.004 \qquad F = 200\ N$$

Literacy

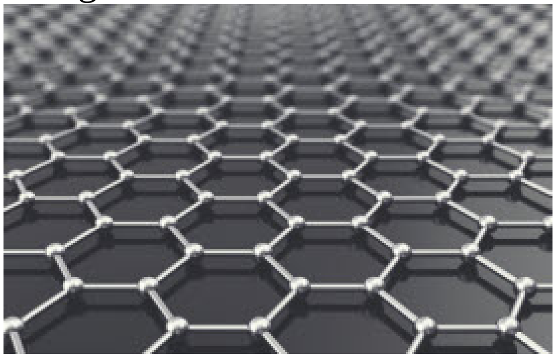
1. What is “hardened steel”? What is difference between hardened steel and unhardened steel? Why do we make hardened steel?
2. What is “amorphous metal” (metallic glass)? What is difference between amorphous metal and crystalline metal? Where are amorphous metals used? How can you produce amorphous metal?
3. What load is suspended on 10 metre long aluminium wire of 3 mm diameter if it elongates by 5 mm?
4. Design steel cable for elevator cabin of 200 kg mass that carries 8 persons that have average mass of 70 kg. Acceleration of elevator cabin is 5 m/s^2. Elevator is in 20-storey building and each storey is about 3 metre.



5. Load of 250 kg is suspended on 5 m and 20 mm^2 wire that has Young’s modulus of 90 GPa. What is deformation of wire?
6. What is spring constant of 30 cm steel wire that has 1 mm diameter?

Is it true?

Graphene consists of just only single layer of carbon atoms arranged in a hexagonal lattice.



Activity

Take resin tape and measure its length and cross-sectional area. Attach load to it and measure change in length. Calculate Young's modulus and compare it with the values in Table 1.

Research time

Search web for instruction of making salt crystals. Make salt crystals. Be careful and do it under the supervision of adults.

Career

Eye surgeons use diamond knives for performing delicate operations.

Physics in life

Amorphous silica SiO_2 is likely the best material for converting sunlight into electricity (photovoltaic).

LAB WORK #6

Title:

Applications of Gas Laws

You will

- find the pressure of atmosphere by using gas law Boyle Mariotte (Isothermal process) and basic pressure formula

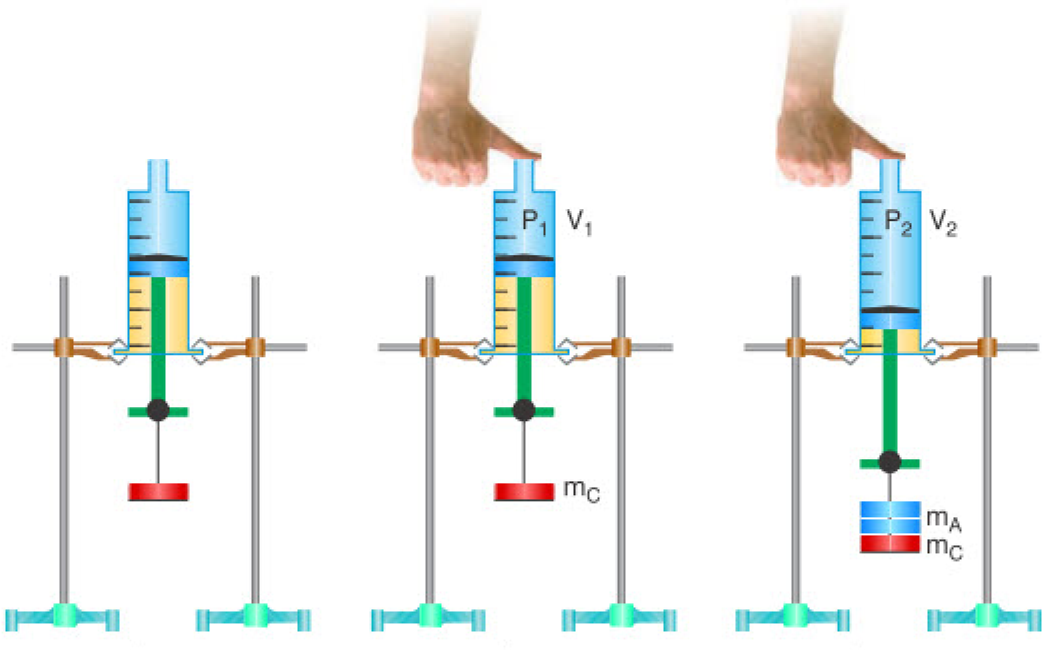
Theory:

In this experiment, you will find the pressure of atmosphere by using Boyle-Mariotte gas law (isothermal process) and basic formula of pressure.

Firstly we eliminate the friction force by using the force produces by critical mass. Mass necessary to move the piston freely down is called the critical mass . Next we close the syringe with finger and measure the volume . Then we add additional mass to change the volume and measure new volume . We need to keep the end of syringe with closed.

In order to have more accurate experiment try to include the volume in the beginning part of the syringe .

Do not apply too much force to syringe. Be careful with your finger. Do not overload your finger.



Formula of Boyle-Mariotte gas law for isothermal process is

$$p_1V_1 = p_2V_2$$

where p_1 is initial pressure (atmospheric pressure).

Pressure will decrease by amount F/A

$$p_2 = p_1 - \frac{F}{A}$$

where F is the force provided by additional mass.

$$F = m_A g$$

Area of piston of the syringe can be calculated by formula

$$A = \pi r^2$$

By using all the formulas above we can derive expression for .

$$\frac{p_1 V_1}{V_2} = p_1 - \frac{F}{A}$$

$$\frac{F}{A} = p_1 \left(1 - \frac{V_1}{V_2}\right)$$

$$p_1 = \frac{F}{A}\left(\frac{V_2}{V_2 - V_1}\right)$$

$$p_1 = \frac{m_A g}{\pi r^2}\left(\frac{V_2}{V_2 - V_1}\right)$$

We will use this final formula to calculate atmospheric pressure.

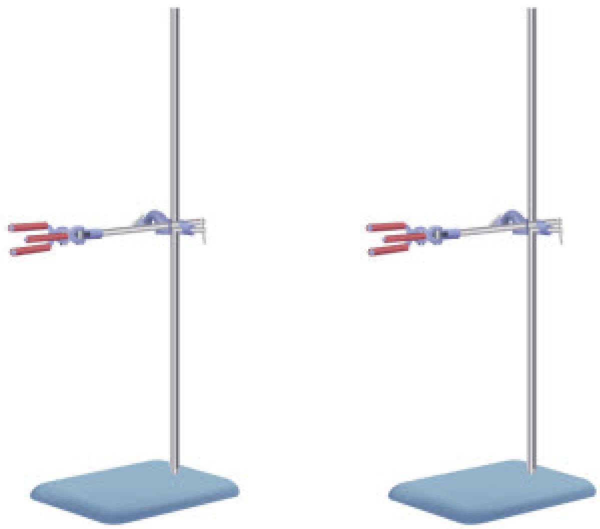
Equipment:

1. Safety glasses

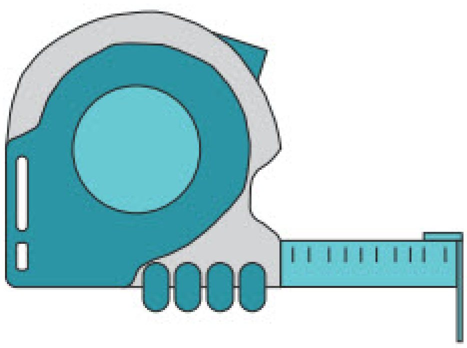
2. Several syringes of different sizes

3. Mass set

4. Two tripods



5. Measuring tape or ruler



Procedure:

1. By using trial and error determine mass m_C needed to eliminate the effect of the friction.
2. Measure and record V_1.
3. Put additional mass m_A and record it in table.
4. Measure and record V_2.
5. Measure and record radius of the piston of the syringe r.

6. Calculate and record p_1.
7. Change syringe and repeat steps 1-6 for all syringes.
8. Calculate average atmospheric pressure.

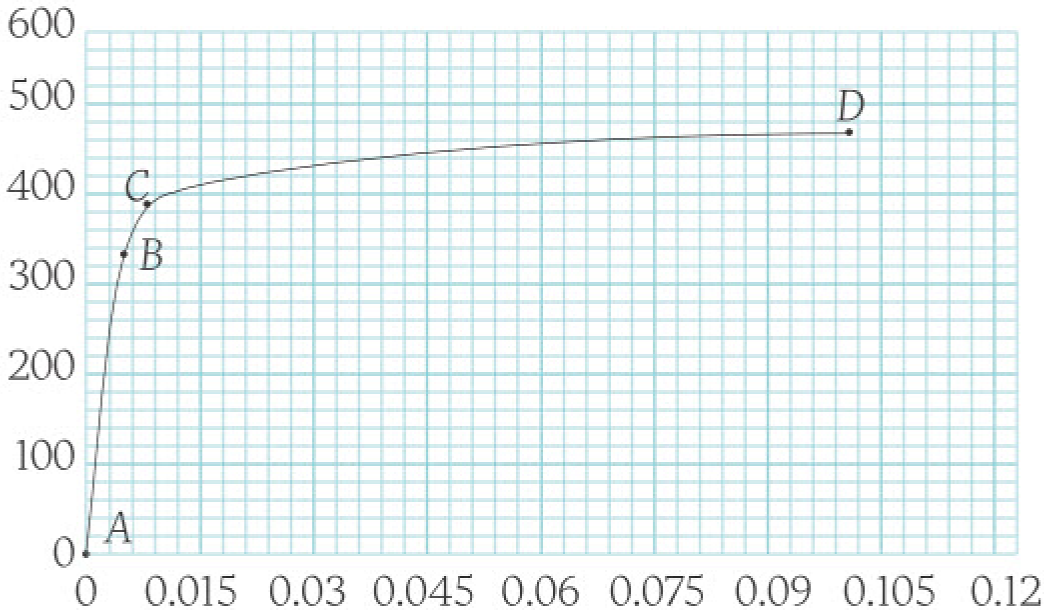
№	$m_A\ (kg)$	$r\ (m)$	$V_1\ (mL)$	$V_2\ (mL)$	$p_1\ (Pa)$
1					
2					
3					
4					
5					

Conclusion:

1. Compare average value of and atmospheric pressure at your location (search it on web). Which one is greater? Why?
2. Propose ways to decrease systematic and random errors of the experiment.

CHECK YOURSELF

There is graph that shows relationship between strain and stress of unknown material. Use graph to answer questions. Assume gravitational acceleration to be 10 m/s^2.



1. What parameter is shown by vertical axis?
A) Strain
B) Stress in MPa
C) Force in MegaNewton
D) Elongation in mm
E) There is no right answer

2. What parameter is shown by horizontal axis?
A) Strain
B) Stress in MPa
C) Force in MegaNewton
D) Elongation in mm
E) There is no right answer

3. Which point on the graph has the highest stress?
A) A
B) B
C) C
D) D
E) There is no right answer

4. Which point on the graph has the lowest stress?
A) A
B) B
C) C
D) D
E) There is no right answer

5. Which point on the graph has the highest strain?
A) A
B) B
C) C
D) D
E) There is no right answer

6. Which point on the graph has the lowest strain?
A) A
B) B
C) C
D) D
E) There is no right answer

7. What is stress at point A?
A) 468.8 MPa
B) 386.1 MPa
C) 308.9 MPa
D) 0

E) There is no right answer

8. What is stress at point B?
A) 468.8 MPa
B) 386.1 MPa
C) 328.2 MPa
D) 0
E) There is no right answer

9. What is stress at point C?
A) 468.8 MPa
B) 386.1 MPa
C) 308.9 MPa
D) 0
E) There is no right answer

10. What is stress at point D?
A) 468.8 MPa
B) 386.1 MPa
C) 308.9 MPa
D) 0
E) There is no right answer

11. What is strain at point A?
A) 0.10000
B) 0
C) 0.00744
D) 0.00437
E) There is no right answer

12. What is strain at point B?
A) 0.10000
B) 0
C) 0.00744

D) 0.00470
E) There is no right answer

13. What is strain at point C?
A) 0.10000
B) 0
C) 0.00744
D) 0.00470
E) There is no right answer

14. What is strain at point D?
A) 0.10000
B) 0
C) 0.00744
D) 0.00437
E) There is no right answer

15. Which point shows ultimate strength?
A) A
B) B
C) C
D) D
E) There is no right answer

16. Which point shows yield strength?
A) A
B) B
C) C
D) D
E) There is no right answer

17. Which point shows elastic limit?

A) A
B) B
C) C
D) D
E) There is no right answer

18. Which interval shows elastic region?
A) AB
B) BC
C) CD
D) AC
E) There is no right answer

19. Which interval shows plastic region?
A) AB
B) BC
C) CD
D) AC
E) There is no right answer

20. Which interval obeys Hooke’s law?
A) AB
B) BC
C) CD
D) AC
E) There is no right answer

21. Which interval is used to calculate Young’s modulus (modulus of elasticity or elastic modulus)?
A) AB
B) BC
C) CD
D) AC

E) There is no right answer

22. What is elastic modulus of this material?
A) 80 GPa
B) 200 GPa
C) 71 GPa
D) 110 GPa
E) There is no right answer

23. What is name of this material? Use tables in previous topics.
A) Copper
B) Gold
C) Steel
D) Aluminum
E) There is no right answer

24. How much load can wire made of this material hold without breaking? Assume diameter of wire to be 1 mm.
A) 168 Newton
B) 268 Newton
C) 368 Newton
D) 468 Newton
E) There is no right answer

25. What is elongation of 5 metre long wire made from this material that has 1 mm diameter when 10 kg load is suspended from it?
A) 8.97 mm
B) 7.97 mm
C) 6.97 mm
D) 5.97 mm
E) There is no right answer

26. What should be diameter of 5 metre long towing cable made from this material to tow 2000 kg car at 5 m/s^2 acceleration? Use safety factor of 2.
A) 9.37 mm
B) 8.37 mm
C) 7.37 mm
D) 6.37 mm
E) There is no right answer

27. What is elongation of 5 metre long towing cable made from this material when it is used to tow 2000 kg car at 5 m/s^2 acceleration?
A) 1.7 cm
B) 1.3 cm
C) 2.3 cm
D) 3.3 cm
E) There is no right answer

28. Where this material can be used?
A) Heavy duty machinery
B) Weapon making
C) Aerospace industry
D) Bridge construction
E) There is no right answer

29. What can you tell about abundance of this material?
A) It is rare
B) It is very abundant
C) It is common
D) It is impossible to determine
E) There is no right answer

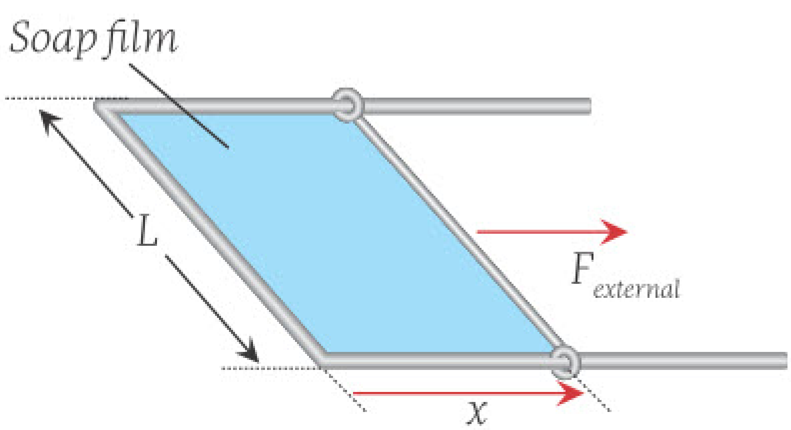
30. What is composition of this material?
A) It is pure aluminium
B) It is iron alloy
C) It is pure iron
D) It is aluminium alloy
E) There is no right answer

Surface Tension

1. Define surface tension. What is the SI unit for surface tension?

2. Why do we use hot water and detergent for washing clothes?

3. Consider the soap film stretched over a frame as in the figure. Do we need to increase the force $F_{external}$ in the figure, as the distance indicated by x increases?



Adhesive and Cohesive Forces

4. Define an ‘adhesive force’ and a ‘cohesive force’.

5. What is the condition for a liquid to ‘wet’ a solid surface?

6. Explain why a wetting liquid takes on a concave form in a capillary tube, while a non-wetting liquid takes on a convex shape?

Capillary Action

7. What is the relationship between capillary diameter and height of liquid column in the capillary?

8. To what height does water rise in a thin glass tube, having a 3 mm inner radius? Take the angle of contact to be 0°.

9. What is the mass of water, rising in a glass capillary having a 2 mm inner diameter? The angle of contact is 0°.

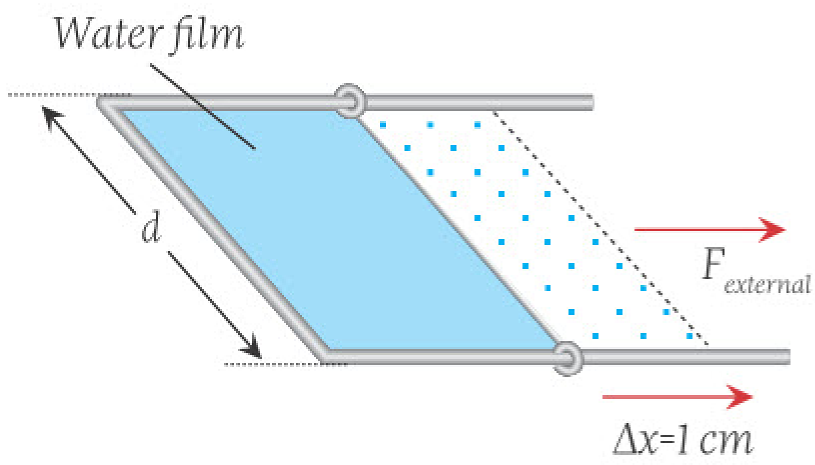
10. Show that work done by the force of surface tension, while rising a liquid in a capillary, is given by $4\pi\sigma^2/\rho g$.

11. Explain why water rises to different heights in capillaries made of different materials, even if the inner radii of the capillaries are equal.

Surface Potential Energy

12. A film of water is stretched over a U frame by a movable section, which freely slides along the frame. What work is done in stretching the film's

length by an additional length Δx=1 cm, as shown in the figure, if the width of the frame is d = 4 cm.



13. You are to peel the skins of 10 kg of potatoes. Would you prefer to work with large or small potatoes? Why?

14. What heat is released when 1000 small spherical droplets of mercury combine to form a large drop? The initial droplets are identical, each with a radius of 1 of mm.

The Exceptional Behaviour of Water

15. A cube of ice floats in a glass of water. Does the water level in the glass rise or fall when the ice melts?

16. What is the temperature of water at the bottom of a 35 m deep lake, when the outside temperature is –40 °C and the thickness of the ice over the lake surface is 1.5 m?

The Molecular Structure of Solid Substances

17. What is ‘allotropy’?

18. How can we explain the fact that a small cubic crystalline substance may assume a rectangular prism shape as it is heated?

19. Why are metals isotropic although they have a crystalline structure?

20. Can we define a latent heat of fusion for amorphous substances?

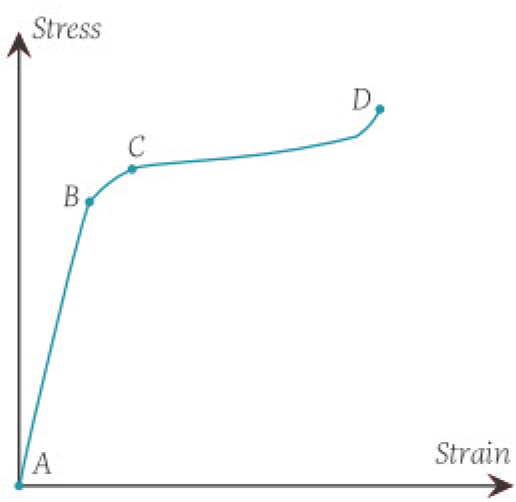
21. Show that the distance between centres of atoms in a solid is given by , where

$$l = \sqrt[3]{M/N_A\rho},$$

M is the molar mass, and ρ is the density of the substance.

Stress and Strain, Elasticity, Young's Modulus

22. The figure shows a typical strain-tensile stress graph for a steel wire.



a) Where does the wire break?
b) Between which points on the graph can we define a proportionality constant?
c) Point C shows the ‘elastic limit’. What happens when this limit is exceeded?

23. A wire of radius 1 mm, fixed to the ceiling at one end, carries a 20-kg load tied to its other end. What is the stress in the wire?

24. A cable has a length of 5 m and a cross-sectional area of 2.5 mm^2. The length of the cable increases by a 1 mm, as it is stretched by a 100 N force. Find:
a) Stress
b) Strain
c) Young's modulus for the cable

Hooke's Law

25. What force is needed to increase the length of a steel wire by 3 mm? The initial length of the wire is 6 m and its cross sectional area is 1 mm^2. (Take $E=20\cdot10^{10}$ Pa for steel)

26. The same stretching force is applied to two different wires, made of the same material. The diameter of one of the wires is twice the diameter of the other. What is the ratio of the strains in the wires?

27. A 50 kg metal ball is suspended by a steel wire of length 20-m and diameter 6-mm. What are the fractional and absolute changes in the length of the wire? (Take $E=20\cdot10^{10}$ Pa for steel)

28. At what load will a given metal wire of 2 cm diameter break, if its breaking limit of mechanical stress equals 1000 N/mm^2?

29. What stress value causes a strain of 0.001 in an aluminium cable? (Take $E =7\cdot10^{10}$ Pa for aluminium)

30. What length does a steel cable have, if it breaks under the action of its own weight when suspended freely from one end? The density of steel is 7800 kg/m^3, the breaking limit of mechanical stress is $3.2\cdot10^8$ Pa.

31. Show that the maximum possible height of a wall is given by $\sigma_{max}/\rho g$ where ρ is the density of the wall, g is the free-fall acceleration and σ_{max} is the maximum compressive stress the wall's material can stand.


16V
100µF

CHAPTER 10: ELECTROSTATICS

10.1 Electric charge. Surface charge density and volume charge density. Conservation of charge

You will

- apply law of conservation of electric charge and Coulomb's law for problem solving.

Question

Why does her hair stand up as shown on the figure?

Charge

Matter consists of atoms. Atoms consist of 3 particles: protons, neutrons, and electrons, Figure 74.

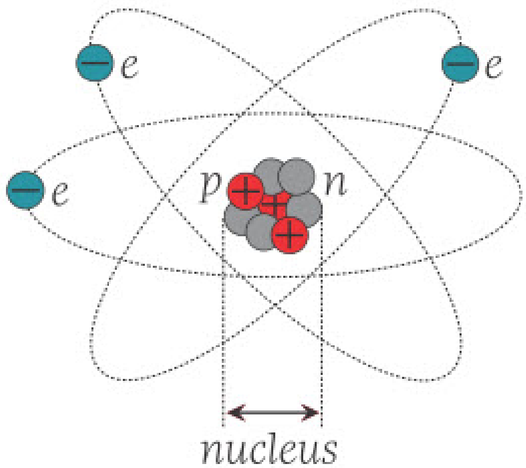


Figure 74

a) Protons are positively charged particles. The number of protons defines type of substance. For example, iron has 26 protons. Copper has 29 protons.

b) Neutrons are neutral particles of atom. Their charge is zero. Neutrons and protons constitute the nucleus of atom.

c) Electrons are negatively charged particles. They rotate around nucleus. They help to connect to other atoms.

Atoms can gain or lose electrons. That means electrons can freely move from one object to another. However, protons and neutrons can't.

When numbers of electrons and protons are the same, an object is neutral. Negatively charged object has more electrons than protons. Positively charged object has less electrons than protons.

Electric charge is measured in Coulomb (C). The smallest charge is charge of electron $e = -1.6 \cdot 10^{-19}$ C. The 1 Coulomb is a very large amount of charge. The $6.3 \cdot 10^{18}$ electrons produce 1 Coulomb charge. Formula of charge is

$$q = Ne$$

The charges can attract (pull) and repel (push) each other. Like (same) charges repel each other. Unlike (not same) charges attract each other, Figure 75. This force is called electrostatic force.

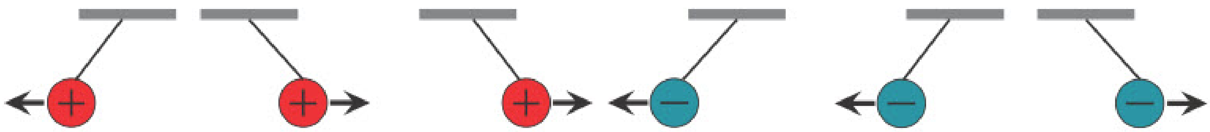


Figure 75

Conservation of charge

Let’s rub a balloon to cloth, each of them has 4 protons and 4 electrons. From the Figure 76 we can see that after rubbing, 3 electrons pass from cloth to balloon, but total number of charges remains the same. This is known as the law of conservation of electric charge: total amount of electric charge in an isolated system is constant.

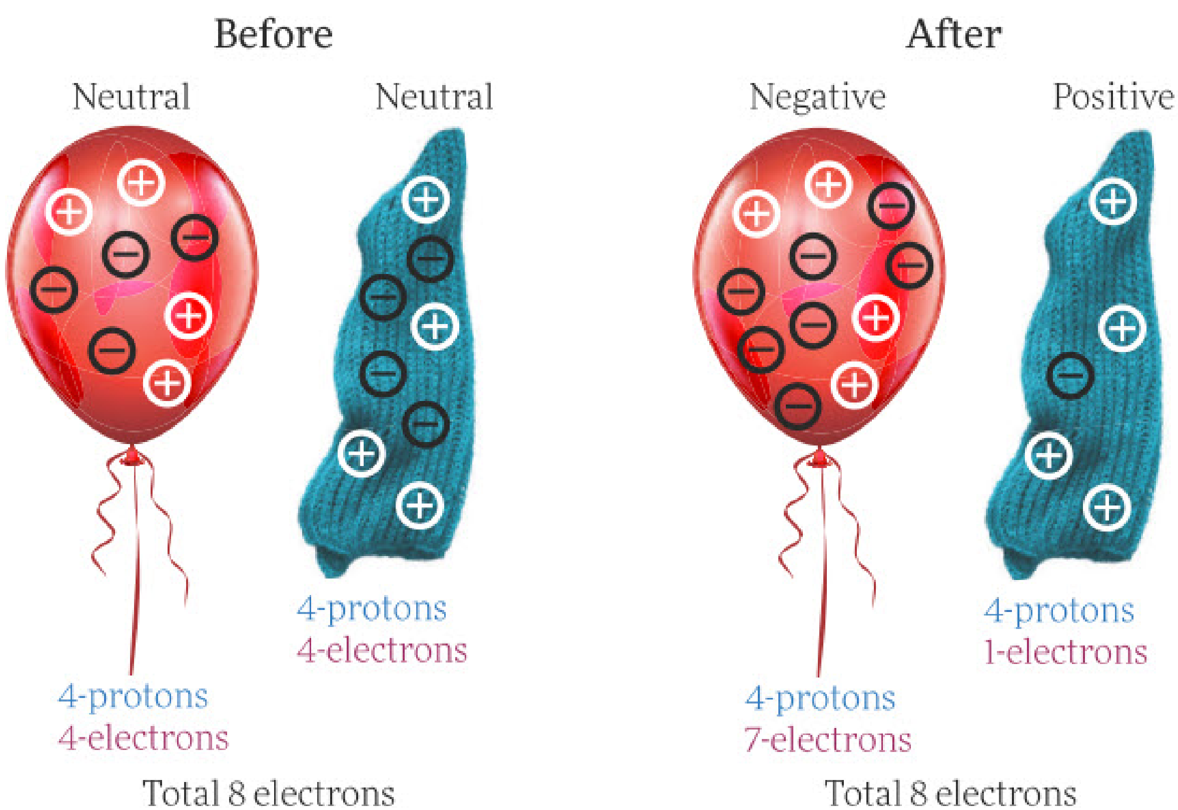


Figure 76

This is expressed as,

$$q_1 + q_2 + q_3 + \cdots + q_n = const$$

where q is the symbol for the electric charge on each object in the system.

Charge density

Charge density is used when charges are distributed evenly. Surface charge density is used when charge is distributed on surface. Formula of surface charge density is

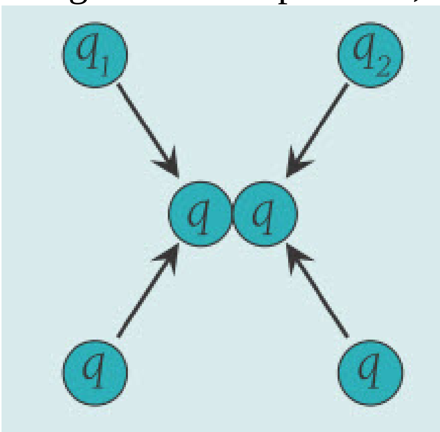
$$\sigma = \frac{q}{A}$$

If charge is distributed among volume we use volume charge density:

$$\rho = \frac{q}{V}$$

Example

Two identical spheres have charges of q_1=6 C and q_2=-12 C. What will the charges on each sphere be, if they are brought in contact and then separated?



Given:

$q_1 = 6 \cdot 10^{-6}\ C$

$q_2 = -12 \cdot 10^{-6}\ C$

Formulas:

$$(q_1 + q_2 + q_3 + \ldots + q_n)_{before} = (q_1 + q_2 + q_3 + \ldots + q_n)_{after}$$

Calculations:

$$(q_1 + q_2 + q_3 + \ldots + q_n)_{before} = (q_1 + q_2 + q_3 + \ldots + q_n)_{after}$$

Spheres are identical. That is why their charges will be same.

$$q_1 + q_2 = q + q \qquad q = \frac{6 \cdot 10^{-6} + (-12 \cdot 10^{-6})}{2}$$

$$q = \frac{q_1 + q_2}{2} \qquad q = -3 \cdot 10^{-6}\ C$$

Literacy

1. What is the definition of “charge”? Why do objects have charge?
2. Why do charges repel and attract each other? Why do electrons exchange photons?
3. How many electrons were removed from glass rod if its charge is 8.10^{-8} C?
4. Two identical spheres are brought into contact and separated. As a result charge of the first sphere increased by 40%. Initial charge of the second sphere was 1.8 C. Calculate charge of the first sphere before and after contact.
5. Metal sphere has charge of $3.14.10^{-7}$ C and diameter of 20 cm. Calculate surface charge density of the sphere.

Career

Electricians have to know how to prevent electrocution.

Research time

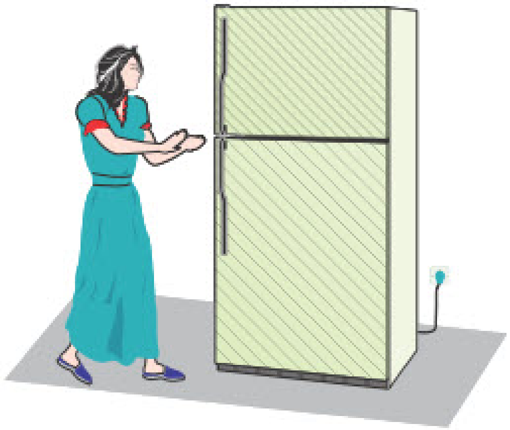
Open and play "Phet Balloons and Static electricity" and "Phet John Travoltage". Write down your observations.

Physics in life

Most copy machines use an electrostatic process called xerography.

Activity

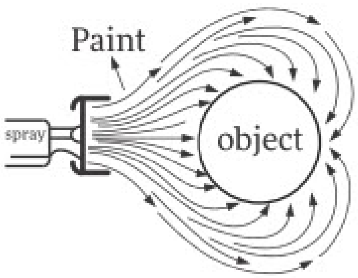
Electrostatics in daily life.
a) What does happen and why? Give more examples.



b) Electrical shocks can be dangerous. Why? What can we do to prevent accidents?

c) Electrostatics can be useful. How? Explain your answers by using figures.

Plastic Wrap



Electrostatic Paint

10.2 Coulomb's law

You will

- apply law of conservation of electric charge and Coulomb's law for problem solving.

Question

Why do leaves of electroscope repel each other?

We have seen that electric charges apply forces upon each other. The nature of these forces was explained by French scientist Charles Coulomb (1736-1806) in 1785. After carrying out a set of experiments, Coulomb established the fundamental law of electrostatics for point charges. This law describes the force between two point charges when they are at rest. The formula is:

$$F = k\frac{|q_1||q_2|}{r^2}$$

F- force between charges, Newton [N]
q_1- first charge, [C]
q_2- second charge, [C]

r - distance between charges, [m]

k - proportionality constant $k=9\cdot10^9$ nm^2/C^2,

The force always has a direction along the line joining the two point particles, Figure 77.

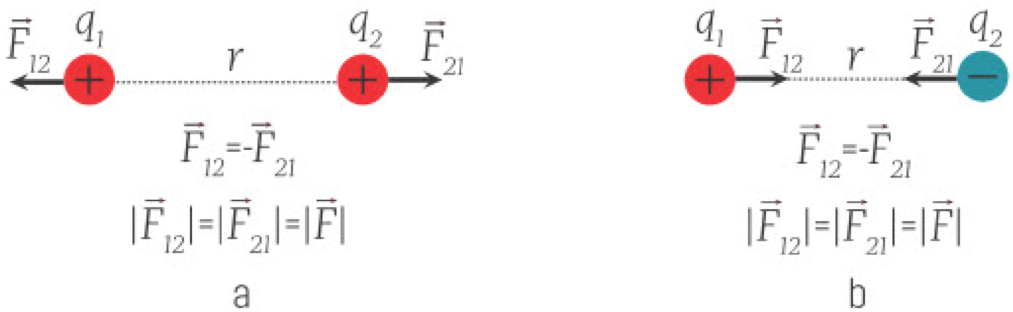


Figure 77

The constant, k in the equation above is often written in terms of another universal constant, the permittivity of free space, ε_0. It is related to k by

$$k = \frac{1}{4\pi\varepsilon_0}$$

$$\varepsilon_0 = \frac{1}{4\pi k} = 8.85 \cdot 10^{-12}\ \frac{C^2}{Nm^2}$$

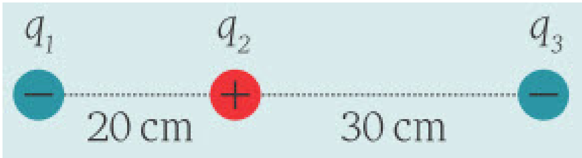
$$F = \frac{1}{4\pi\varepsilon_0}\frac{|q_1||q_2|}{r^2}$$

Note that the medium between the charges affects the electric force. However, as air has almost no effect on the electric force, we can treat it as a vacuum.

When more than two charges interact, the force between any pair is given by Coulomb's equation. The net force acting on any given single charge is the vector sum of all the forces experienced by the given charge.

Example

Three charges q_1=-6μC, q_2=2μC and q_3=-2μC are placed along a line, as shown in the figure. Find the resultant force acting on charge q_2.



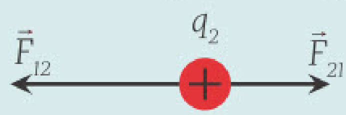
Given:

$q_1 = -6 \cdot 10^{-6}\ C$ $\quad r_{12} = 0.2\ m$ $\quad F_{net} = ?$

$q_2 = 2 \cdot 10^{-6}\ C$ $\quad r_{23} = 0.3\ m$ $\quad \vec{F}_{net} = \vec{F}_{12} + \vec{F}_{23}$

$q_3 = -4 \cdot 10^{-6}\ C$ $\quad k = 9 \cdot 10^9\ N \cdot m^2/C^2$ $\quad F_{net} = -F_{12} + F_{23}$

Formulas: $F = \dfrac{k\,|q_1|\,|q_2|}{r^2}$



Calculations:

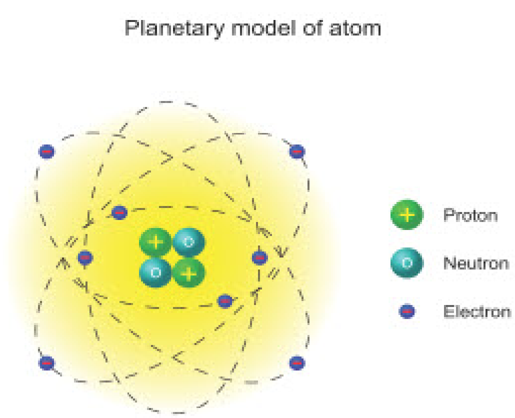
$$F_{net} = -k\frac{|q_1||q_2|}{(r_{12})^2} + k\frac{|q_2||q_3|}{(r_{23})^2}$$

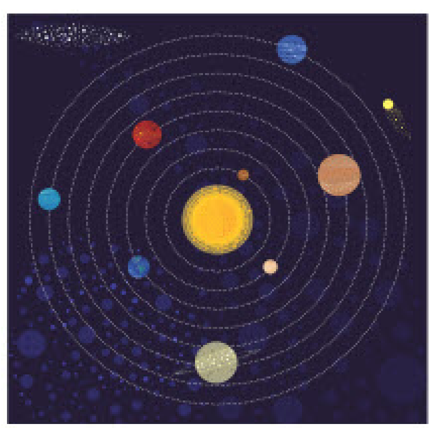
$$F_{net} = -1.9\ N$$

$$F_{net} = 9 \cdot 10^9 \cdot |2 \cdot 10^{-6}| \cdot \left(-\frac{|-6 \cdot 10^{-6}|}{(0.2)^2} + \frac{|-4 \cdot 10^{-6}|}{(0.3)^2}\right)$$

Research time

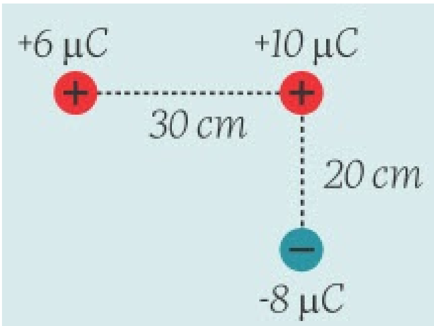
There is a similarity between Coulomb's law and law of universal gravitation. Why? Compare two formulas and two pictures.





Example

Three charges +6 μC, +10 μC and -8 μC are located as shown in the figure. What are the magnitude and direction of the net force acting on +10 μC?



Given:

$q_1 = 6 \cdot 10^{-6}\ C$

$q_2 = 10 \cdot 10^{-6}\ C$

$q_3 = -8 \cdot 10^{-6}\ C$

$r_1 = 0.3\ m$

$r_2 = 0.2\ m$

$k = 9 \cdot 10^9\ N \cdot m^2/C^2$

$F_{net} = ?$

Formulas:

$$F = \frac{k\,|q_1|\,|q_2|}{r^2}$$

$$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2$$

$$F_{net} = \sqrt{(F_1)^2 + (F_2)^2}$$

Calculations:

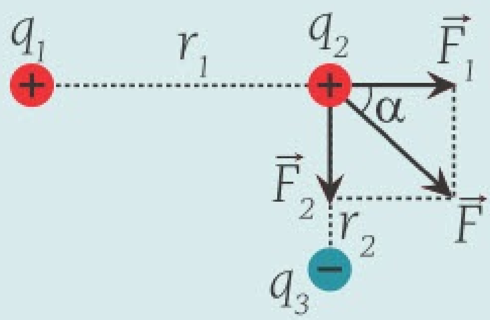
$$F_1 = 9 \cdot 10^9 \cdot \frac{|6 \cdot 10^{-6}| \cdot |10 \cdot 10^{-6}|}{(0.3)^2}$$

$$F_2 = 9 \cdot 10^9 \cdot \frac{|10 \cdot 10^{-6}| \cdot |-8 \cdot 10^{-6}|}{(0.2)^2}$$

$F_1 = 6\ N$ $\qquad$ $F_2 = 18\ N$

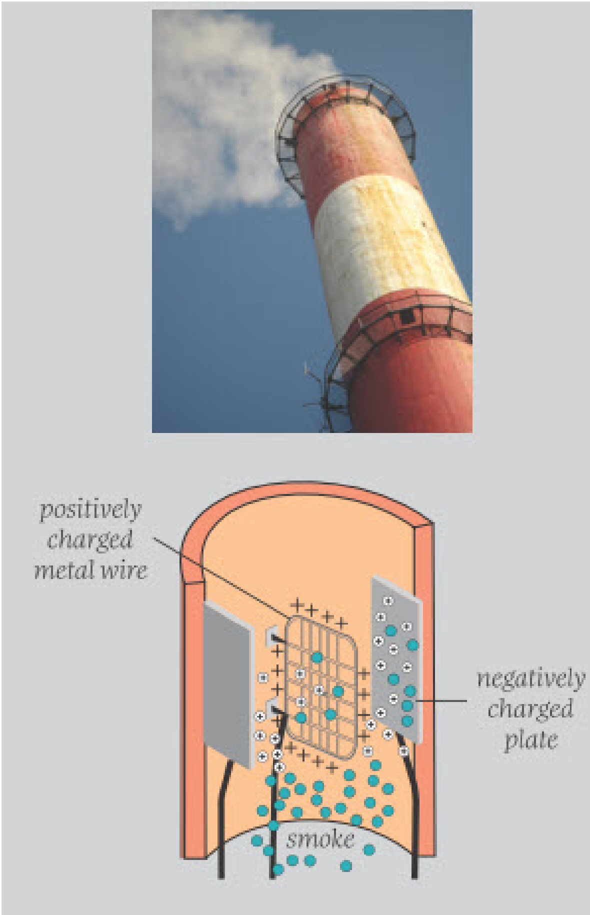
$F_{net} = \sqrt{6^2 + 18^2}$ $\qquad$ $F_{net} = 18.97\ N$

$\tan\alpha = \frac{18}{6} = 3$ $\qquad$ $\alpha = 71.56°$



Physics in life

An electrostatic precipitator (ESP) is a filtration device that removes fine particles, like dust, from a flowing gas using the electrostatic force.



Important note

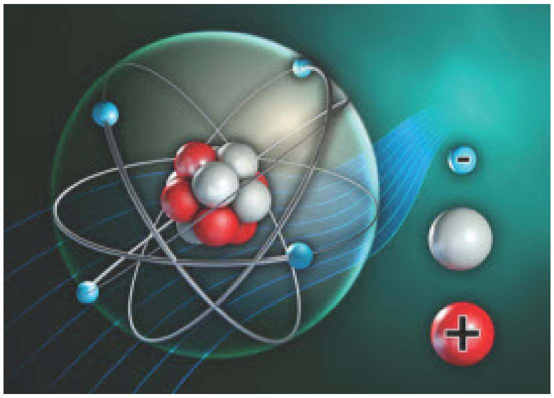
Interactions between two charged objects occur due to Newton's third law, so these forces are the same.

Activity

Open and play "Phet Electric Hockey". Arrange particle so that puck reaches the goal it hits. Try to pass all levels.

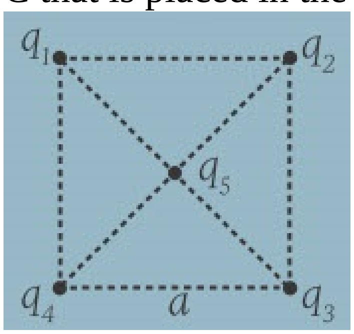
Is it true?

Coulomb’s force between proton and electron is 2.27×10^{39} bigger than the gravitational force between them.



Literacy

1. What is definition of “Coulomb’s force”? What would happen if Coulomb’s force disappears?
2. Two charges of 1 C and 10 nC apply 9 mN force on each other. Calculate distance between the charges.
3. In hydrogen atom electron rotates around proton at radius of $0.53.10^{-8}$ cm. Calculate speed of rotation of electron.
4. There is 0.58 C charge in the centre of equilateral triangle. What identical charges should be placed in the corners of the equilateral triangle so that all charges remain in equilibrium?
5. There are charges q_1= -1 C, q_2= -2 C, q_3= -3 C, q_4= -4 C in the corners of the square that has side of 10 cm. Calculate force acting on a charge q_5= -5 C that is placed in the center of the square.



10.3 Electric field strength. Uniform and non-uniform electric field. Electric field lines

You will

- apply superposition principle for determining net electric field strength.

Question

Why does stream of water bend?

When we want to move something, we need to push or pull it. In order to apply a force on an object, we must touch it. For example, Figure 78a. However, the Earth pulls objects with no contact, Figure 78b. Earth has a field that pulls everything. This field is called gravitational field. Gravitational field produces force – gravitational force.

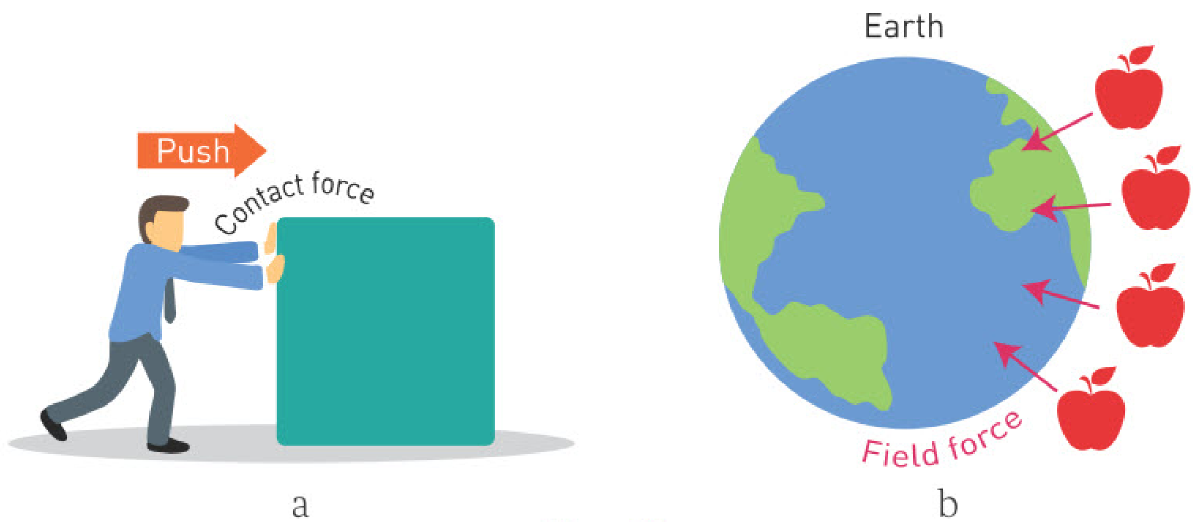


Figure 78

Similarly, there is no contact between charges when they push (or pull) each other. Charges produce field around them. This field is called electric field. Electric field produces electrostatic force (Coulomb's force).

We are not able to see gravitational field and electric field. However, we can feel (and measure) force they produce. Also, we can draw field. We can use lines to show electric field. These lines start at positive charges and end at negative charges, Figure 79a and Figure 79b.

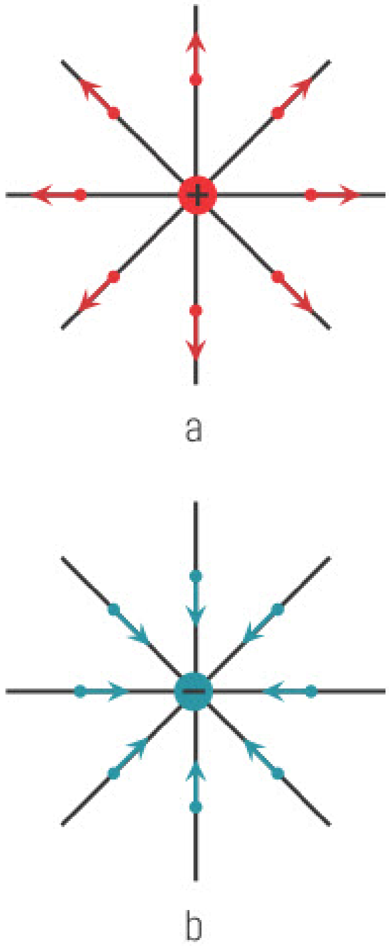


Figure 79

An electric field surrounds any electrically charged object. If we put second charge, it will experience a force of electric field produced by the first charge.

Consider a charged particle +q as shown in Figure 80a. This charge applies an electric force on a very small positive test charge, $+q_0$ when it is brought into the electric field of the charge, +q. Note that the test charge is positive and its magnitude is so small that it does not change the distribution of the charge, +q.

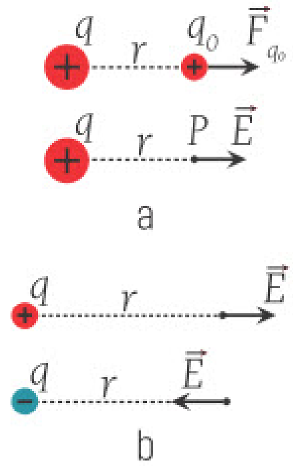


Figure 80

The electric field is defined as the force acting on a negligibly small positive test charge at that point divided by this test charge. Then

$$\vec{E} = \frac{\vec{F}}{q_0}$$

The magnitude of the electric field is force per unit charge. The electric field produced by a point charge q, can be found from

$$E = \frac{F_{q0}}{q_0} = \frac{k\dfrac{|q||q_0|}{r^2}}{|q_0|}$$

$$E = k\frac{|q|}{r^2} \quad \text{or} \quad E = \frac{|q|}{4\pi\varepsilon_0 r^2}$$

The unit of electric field is the Newton/Coulomb (N/C) or Volt/metre.

If you put positively charged small object in the field, the field line will show the direction of resultant force. If charge is negative, the direction is opposite, Figure 81.

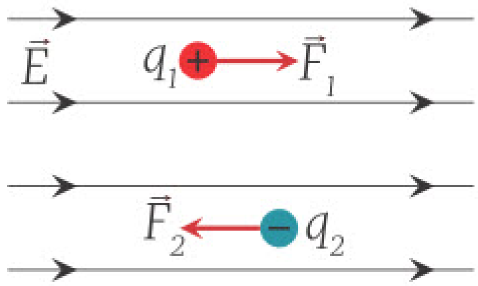


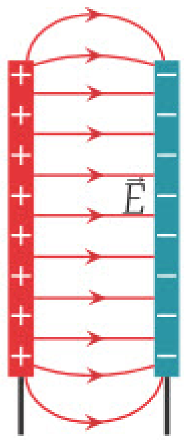
Figure 81

The resultant force acting on charge q placed in electric field can be found using formula:

$$\vec{F} = q\vec{E}$$

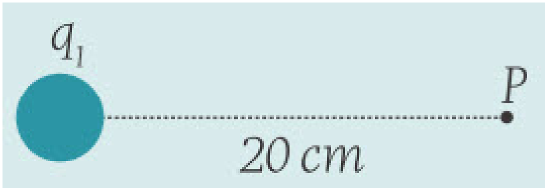
Uniform Electric field

An uniform electric field can be produced in the space between two oppositely charged metallic plates. The magnitude of the electric field in that region is constant as shown in Figure 81. The field lines are parallel to each other and equally spaced. Force will be equal in all parts, because field does not change in space.



Example

If the electric field at point P is 450 N/C, what is q_1 ?



Given:

$r = 0.2\ m$

$E = 450\ N/C$

$k = 9 \cdot 10^9\ N \cdot m^2/C^2$

$q_1 = ?$

Formulas:

$$E = k\frac{|q|}{r^2}$$

Calculations:

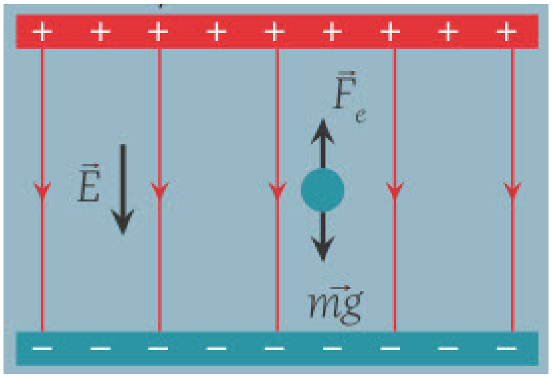
$$q_1 = \frac{E \cdot r^2}{k}$$

$$q_1 = \frac{450 \cdot 0.2^2}{9 \cdot 10^9}$$

$$q_1 = 2 \cdot 10^{-9}\ C$$

Literacy

1. What is definition of “electric field”? Why doesn’t your hand pass through the wall or desk?
2. Force of 0.015 N acts on a $2 \cdot 10^{-7}$ C charge in electric field. Calculate magnitude of electric field at that point.
3. How would electric field change if charge decreases by 30% and distance increases by 20%?
4. At what distance electric field of $8 \cdot 10^{-6}$ C charge is equal to $8 \cdot 10^{5}$ N/C?
5. An object of $4 \cdot 10^{-7}$ g mass is suspended in electric field of 245 V/cm. Calculate charge of the object and number of electrons on it.



Important note

The formula of E is analogical to F= m(mass) · g (gravity). This is because g means the force acting on each kilogram of mass, and E means the force acting on each Coulomb of charge.

Research time

Open "Phet Charges and Fields". Observe how electric field changes as you add charges. Use sensor to identify direction of electric field.

Is it true?

Sharks are able to sense electric field in their snouts as small as 100 mV/m.

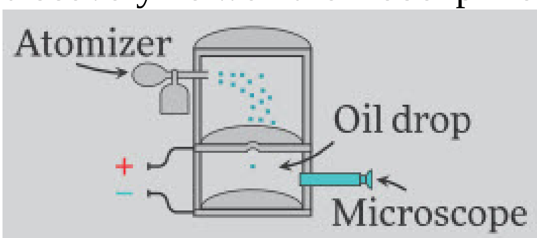
Activity

Take air balloon and small piece of plastic food wrap. Rub them against your hair or woolen cloth. Put wrap above balloon. What does happen? Why?

Physics in life

Robert Millikan sprayed tiny oil drops into a uniform electric field between horizontal pair of oppositely charged plates. The drops were observed with a microscope, and the electric field was adjusted so that the upward force $F=qE$ on some negatively charged oil drops was just sufficient to balance the force of gravity $F=mg$.

Millikan measured the charges on many oil drops and found the values to be whole-number multiples of $1.6.10^{-19}$ C - the charge of the electron. For this discovery he won the Nobel prize.



10.4 Superposition of electric fields

You will

- apply superposition principle for determining net electric field strength.

Question

What would happen if you wrap mobile phone in aluminum foil? Why?

The Superposition Principle

Every charge produces electric field around itself. If there is more than one charge, it means that there is more than one electric field. To find net electric field at any point we use principle of superposition.

The superposition principle states that, if there is more than one electric field at a point in space, the net electric field is the vector sum of all the fields at this point. That is

$$\vec{E} = \vec{E}_1 + \vec{E}_2 + \vec{E}_3 + \ldots + \vec{E}_n$$

Let's consider a charged conducting sphere of radius R, it has a charge +Q, which is uniformly distributed over the surface. To find the electric field of the sphere at any point in space, we assume that the charge on the sphere is composed of many point charges of q_1, q_2, q_3 ... on the upper hemisphere and symmetrically q_1', q_2', q_3' ... on the lower hemisphere, as shown in Figure 82.

In order to determine the electric field of the sphere at any point, first we must find the electric field produced by each point charge and finally we vectorially add up all these fields using the superposition principle. It can be seen that the electric field in the centre of sphere is zero since the electric field of each point charge, on the upper hemisphere is cancelled by the electric field of its symmetric charge, on the lower hemisphere. Their electric fields are equal in magnitude but opposite in direction.

The calculation for any point in the sphere ($r < R$) indicates that the situation is just the same as for the centre. Thus, the electric field inside the conducting charged sphere is zero.

Now let us find the electric field of the sphere at point A outside the sphere ($r \geq R$). Consider two point charges q_2 and q_2', which are same. They both produce electric fields at point A, as shown in the Figure 82.

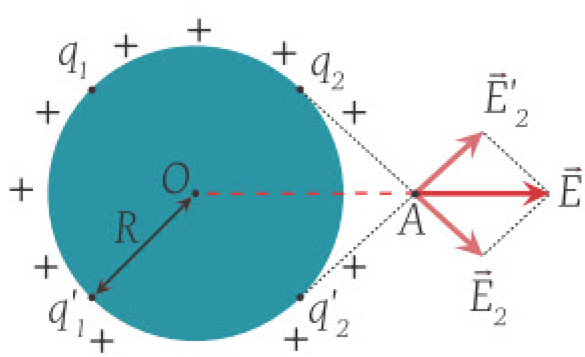


Figure 82

If we add them, we can determine the electric field of the charged sphere at distance r from its centre.

The formula of dependence of electric field on distance outside the sphere is equal to:

$$E = k\frac{|Q|}{r^2}$$

where r is distance from the centre of the sphere.

Graph of electric field versus distance for a charged conducting sphere is shown on Figure 83. Electric field is zero inside of a conductor - this property is used in electromagnetic shielding (Faraday's cage or Faraday's bag).

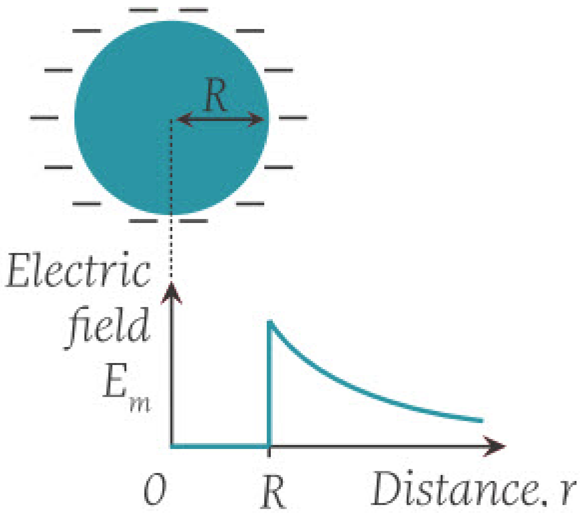
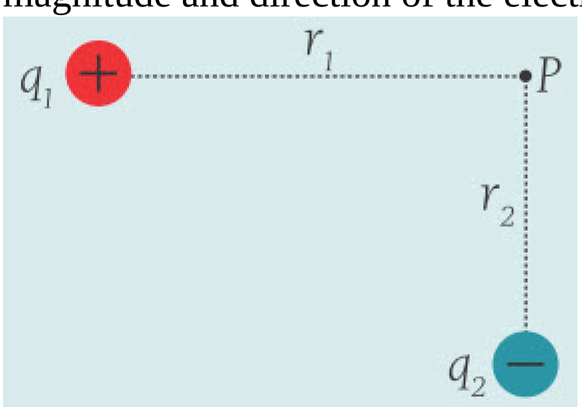


Figure 83

Example

Two charges of q_1=+10 nC and q_2=-20 nC are placed as shown in the figure. Distances are known to be r_1=50 cm and r_2=40 cm. What is the magnitude and direction of the electric field at point P?



Given:

$q_1 = 10 \cdot 10^{-9}\ C$

$q_2 = -20 \cdot 10^{-9}\ C$

$r_1 = 0.5\ m$

$r_2 = 0.4\ m$

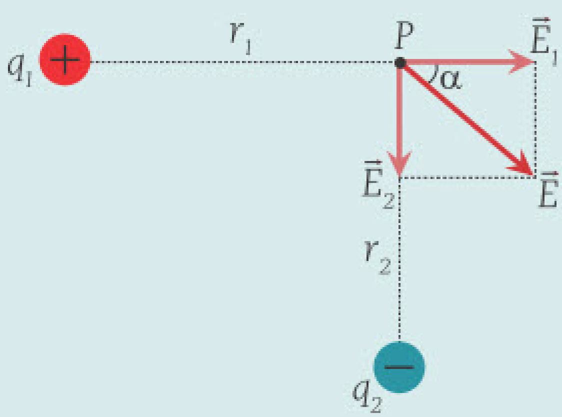
$k = 9 \cdot 10^9\ N \cdot m^2/C^2$

$E_{net} = ?$

Formulas:

$$E = k\frac{|q|}{r^2} \qquad \tan\alpha = \frac{E_2}{E_1}$$

$$E_{net} = \sqrt{(E_1)^2 + (E_2)^2}$$



Calculations:

$$E_1 = 9 \cdot 10^9 \cdot \frac{|10 \cdot 10^{-9}|}{0.5^2}$$

$$E_2 = 9 \cdot 10^9 \cdot \frac{|-20 \cdot 10^{-9}|}{0.4^2}$$

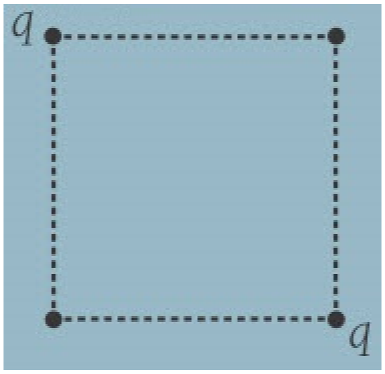
$$E_1 = 360\ N/C$$
$$E_2 = 1125\ N/C$$
$$E_{net} = \sqrt{360^2 + 1125^2}$$
$$E_{net} = 1181.20\ N/C$$

$$\tan\alpha = \frac{1125}{360} = 3.125$$

$$\alpha = 72.26°$$

Literacy

1. What is definition of “superposition principle”?
2. How can you calculate net electric field of two perpendicular electric fields?
3. There are two charges q_1=30 nC and q_2=-10 nC at distance d=20 cm from each other. Calculate net electric field at a point which is at distance r_1=15 cm from the first charge and r_2=10 cm from the second charge.
4. There two charges of $2 \cdot 10^{-7}$ Coulomb in opposing corners of square that has side of 30 cm. Calculate electric field in other two corners of square.



5. Calculate the net electric field generated by two charges at midpoint, if distance between them is 40 cm. Consider two cases:

a) q_1=+10 nC, q_2=+20 nC

b) q_1=+10 nC, q_1=-20 nC

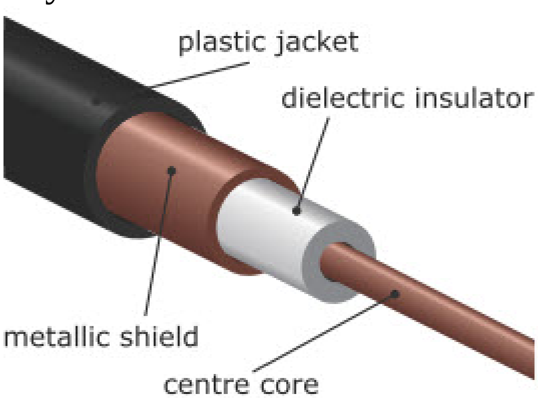
6. Metal sphere of 10 cm radius has charge of 10^{-7} C. Calculate electric field at distances r_1=5 cm, r_2=10 cm, r_3=30 cm from the centre of the sphere. Plot E(r) graph.

Activity

Open "Phet Charges and Fields". Put charges in the corners of shapes (triangle, square, rectangle and etc). Is there a point where electric field is zero? At which point electric field is maximum?

Research time

Why do cables have metallic shield?



Is it true?

Field lines never cross or touch each other.

10.5 Electric flux. Gauss's flux theorem

You will

- apply Gauss's flux theorem to determine electric field strength of uniformly charged infinite plane, uniformly charged spherical conducting shell, uniformly charged sphere and uniformly charged infinite wire.

Question

Why spare gasoline is carried in metal cans instead of plastic ones?

Electric flux

Electric flux is amount of electric field lines passing through given area, Figure 84a.

$$\Phi = EA$$

If electric field lines are not perpendicular to surface then you should multiply by cosine of angle between normal of surface and electric field lines, Figure 84b.

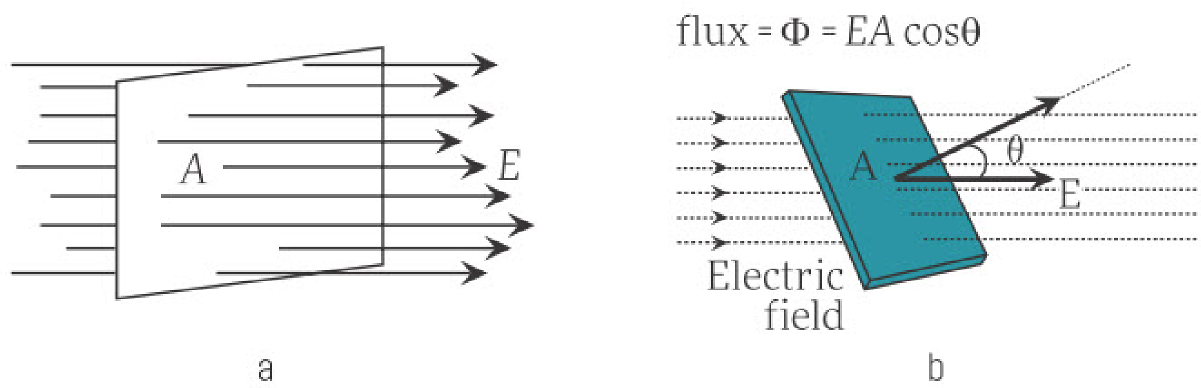


Figure 84

Gauss's law

The net electric flux through any hypothetical closed surface is equal to 1/ε times the net electric charge within that closed surface

For example, for spherical surface we may say that total flux from point charge is equal charge inside this area, Figure 85. We call it gaussian area.

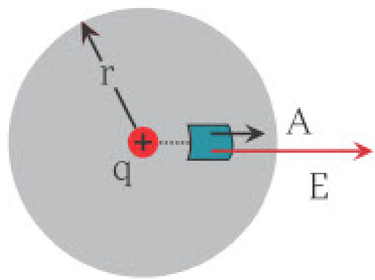


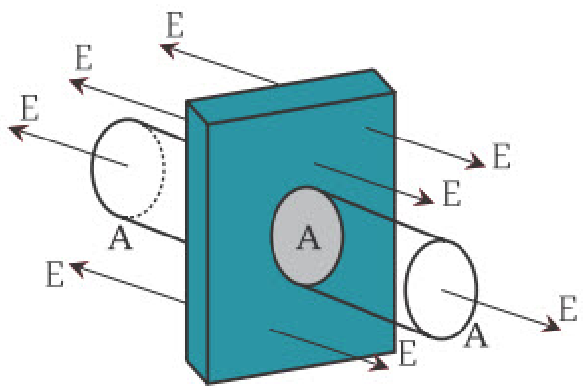
Figure 85

For following example:

$$\Phi_t = \frac{q}{\varepsilon_0}$$

$$\Phi_t = EA = k\frac{q}{r^2}\cdot 4\pi r^2 = \frac{1}{4\pi\varepsilon_0}\frac{q}{r^2}\cdot 4\pi r^2 = \frac{q}{\varepsilon_0}$$

This is right not only for point charge, but also all kind of charges that trapped inside this surface.



Electric field of a uniformly charged plane surface

Figure 86

Let’s look at another application of Gaussian principle. The uniformly charged infinite plane with charge density σ may be surrounded by imagniary cylinder, Figure 86, and total electric flux from one side may be calculated as:

$$\Phi = EA$$

Also we should add the same amount of flux which is going opposite direction, so total flux will be:

$$2EA = \Phi_t$$

Applying Gauss's law gives us:

$$2EA = \frac{q}{\varepsilon_0}$$

Where q is amount of charge surrounded by this cylinder.

The electric field will be equal to:

$$E = \frac{q}{2A\varepsilon_0} = \frac{\sigma}{2\varepsilon_0}$$

Gauss's law can be used for linear charged objects. Let’s consider infinitely long charged wire, Figure 87.

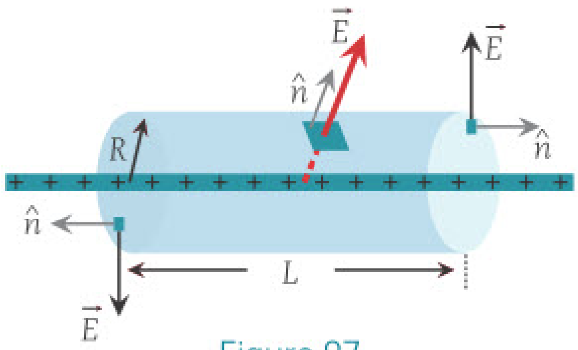


Figure 87

To find electric field, let's first find a flux and use Gauss law:

$$\Phi = E(2\pi RL)$$

$$Q_{in} = \lambda L$$

$$E(2\pi RL) = \frac{\lambda L}{\varepsilon_0}$$

$$E = \frac{1}{2\pi\varepsilon_0}\frac{\lambda}{R}$$

Example

Uniformly charged infinite plane has surface charge density of 0.354 nC/m^2 . What are electric fields of plane at distances of 10 cm and 20 cm?

Given:

$\sigma = 0.354\, nC/m^2 = 0.354 \cdot 10^{-9}\, C/m^2$

$\varepsilon_0 = 8.85 \cdot 10^{-12}\, C^2/(N \cdot m^2)$

$E_1 = ?$

$E_2 = ?$

Formulas:

$E = q/2A\varepsilon_0 = \sigma/2\varepsilon_0$

Calculations:

$E = \sigma/2\varepsilon_0$

$$E = \frac{0.354 \cdot 10^{-9}}{2 \cdot 8.85 \cdot 10^{-12}}$$

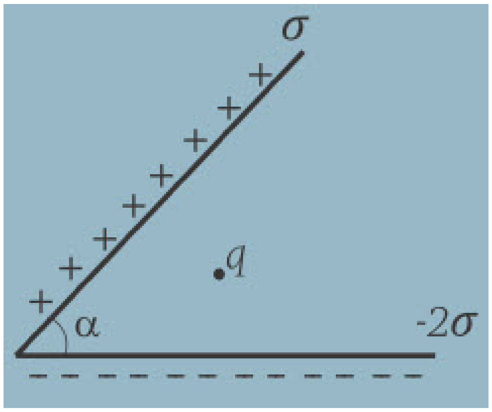
$E = E_1 = E_2 = 20\, N/C$

Discussion:

In formula $E = \sigma/2\varepsilon_0$ there is no distance. That means electric field of uniformly charged infinite plane does not depend on distance and is same at any distance.

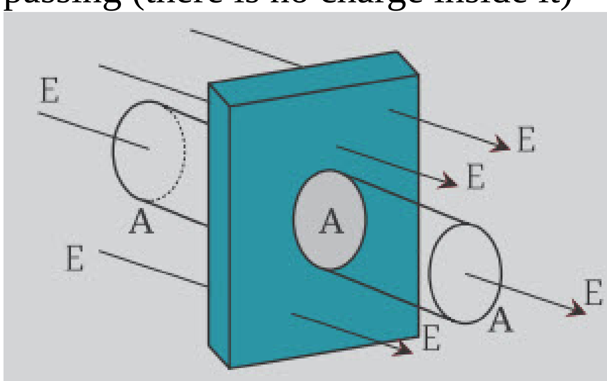
Literacy

1. What is “electric flux”? How can you calculate electric flux?
2. What is “Gauss’s flux theorem”? How can you use it?
3. Uniformly charged sphere of 10 cm radius has volume charge density of 0.75·10-4 C/m^3. Calculate electric field at distances r_1=5 cm, r_2=10 cm, r_3=30 cm from the centre of the sphere. Plot E(r) graph.
4. There are two perpendicular uniformly charged infinite planes that have surface charge densities of $2 \cdot 10^{-7}$ C/m^2 and $4.2 \cdot 10^{-7}$ C/m^2. Calculate electric field at all points and draw electric field lines.
5. Two uniformly charged planes that have surface charge densities of $\sigma = 1 \cdot 10^{-7}$ C/m^2 and $-2\sigma = -2 \cdot 10^{-7}$ C/m^2 are placed at an angle α=60o to each other. At what angle should third uniformly charged plane be placed so that point charge q=10 nC stays in equilibrium? Calculate surface charge density of the third plane.



Important note

If there is no charge inside of the Gaussian surface then total flux will be zero. For example, let us surround area through which electric field is passing (there is no charge inside it)



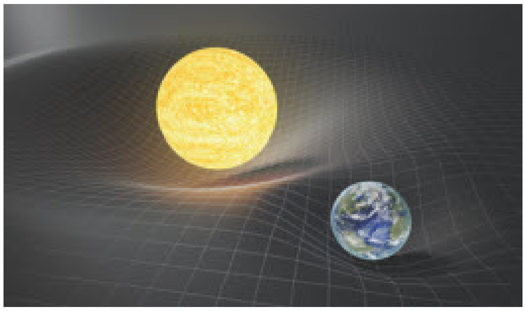
Flux coming inside cylinder will be equal to flux which is going out, so total flux will be: $\Phi = EA - EA = 0$
So according to Gauss law total charge will be equal to zero.

Activity

During storm it is safer to be in a car. Why?

Research time

Electric field can be shielded. But what about gravity? Can it be shielded?



Is it true?

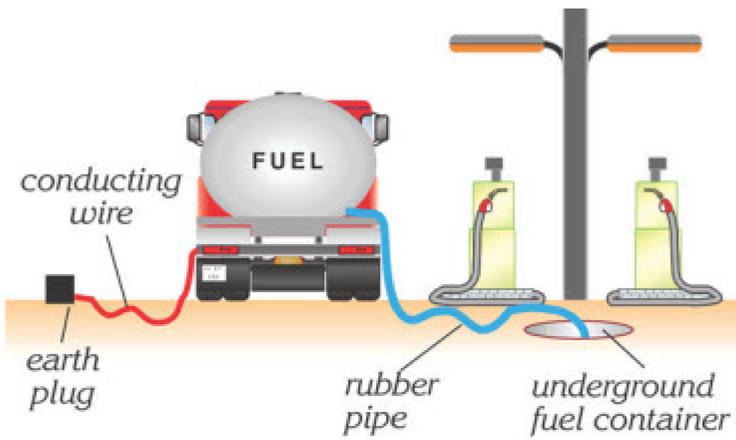
Bolt of lightning is hotter than the surface of the Sun.

10.6 Electric potential energy

You will

- calculate electric potential and electric work of point charge.

Question



On the figure you can see fuel truck that fills underground fuel container in a gasoline station. Why are there conducting wire and earth plug?

Concept of work and energy is used not only in mechanics but also in electricity. Mechanical and electrical energies may transform to each other and total amount of energy is conserved.

If we release an apple at point A, it will have kinetic energy at point B, Figure 88a. Similarly, when we release negative charge at point C, it will have kinetic energy at point D, Figure 88b.

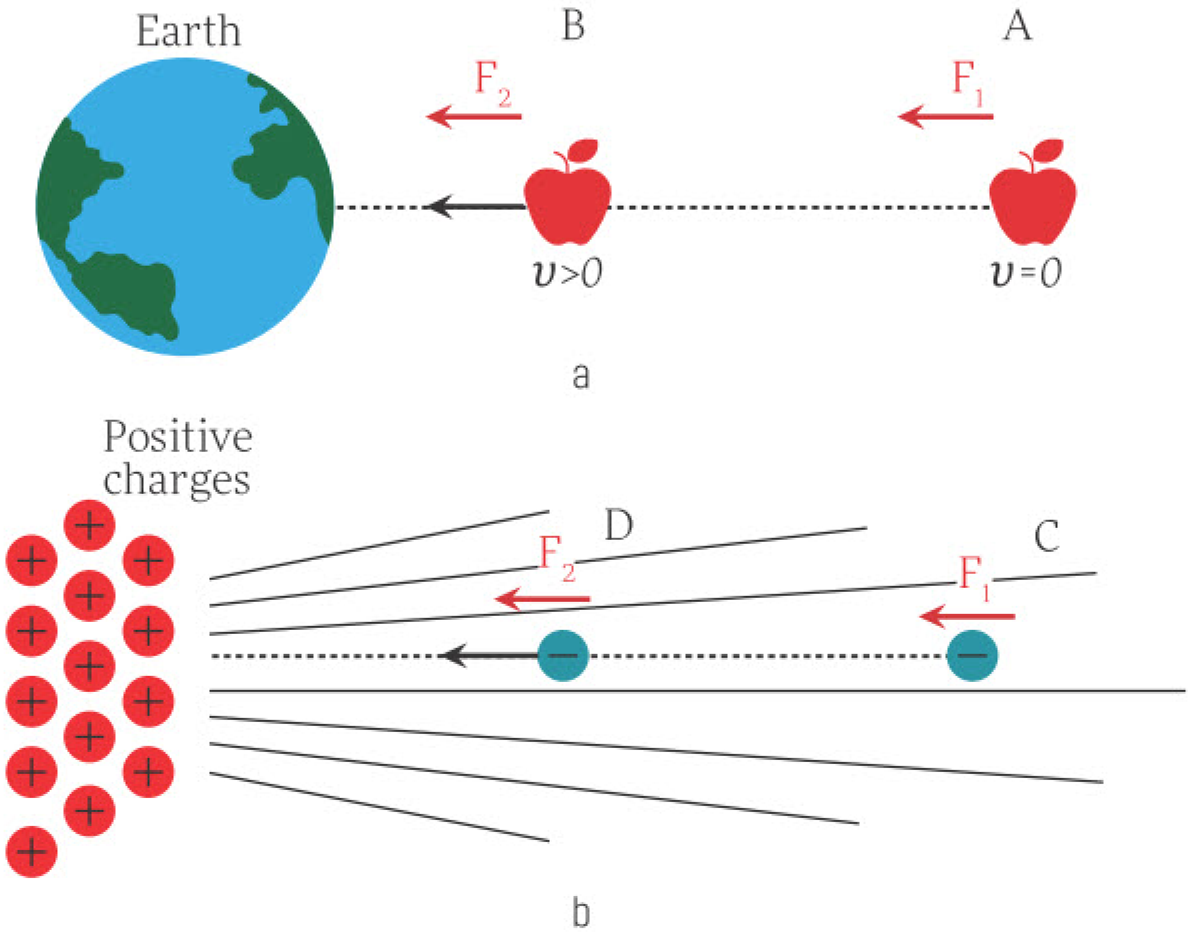


Figure 88

The apple gains speed from the difference in gravitational potential energies. The negative charge gains speed from difference in electric potential energies.

Suppose that a charge, q, is fixed at any point in space. When a test charge, q_O, is put near charge q, as shown in Figure 89,

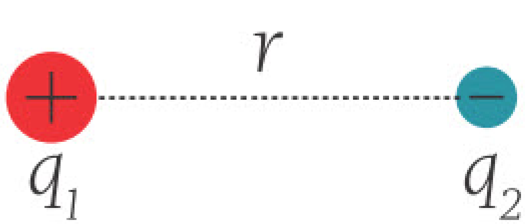


Figure 89

the electric potential energy of the system is given by

$$E_{\mathrm{p}} = k\frac{q_1 \cdot q_2}{r}$$

Electric potential energy is shown by E_p, and its unit is Joule [J].

A potential energy-distance graph for two electric charges is shown on Figure 90.

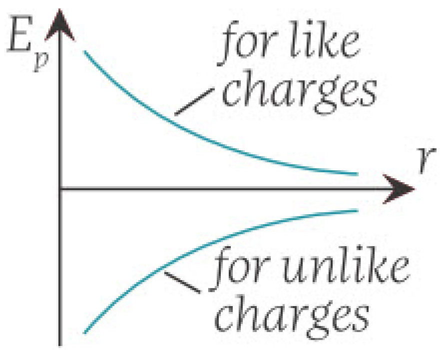


Figure 90

The work done by the electric forces is equal to the negative of the change in potential energy of the charge.

$$W = -E_p$$

$$qEd = -(E_{p2} - E_{p1})$$

$$qE(d_1 - d_2) = -(E_{p2} - E_{p1})$$

$$qEd_1 - qEd_2 = E_{p1} - E_{p2}$$

The equation shows us that the difference between initial and final values of (qEd) is equal to the difference between initial and final values of potential energy. Hence, the electric potential energy of charge q in a uniform electric field is

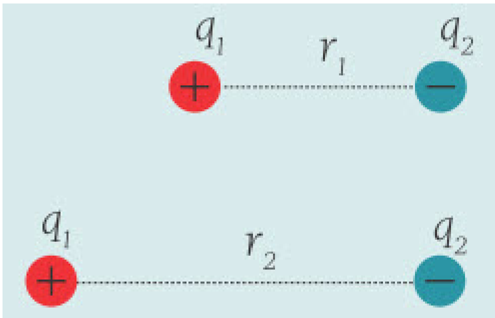
$$E_p = qEd$$

Activity

Why formulas of electric potential energy and gravitational potential energy are similar?

Example

Find the potential energy of a system of point charges of q_1=20 μC and q_2=-10 μC when they are r_1=20 cm apart. How does the potential energy change if we separate charges to a distance of r_2=40 cm?



Given:

$q_1 = 20\ \mu C = 20 \cdot 10^{-6}\ C$

$q_2 = -10\ \mu C = -10 \cdot 10^{-6}\ C$

$r_1 = 20\ cm = 0.2\ m$

$r_2 = 40\ cm = 0.4\ m$

$k = 9 \cdot 10^9\ N \cdot m^2/C^2$

$E_{p1} = ?$

$E_{p2} = ?$

$\Delta E = ?$

Formulas:

$$E_p = \frac{kq_1 q_2}{r}$$

$$\Delta E = E_{p2} - E_{p1}$$

Calculations:

$$E_p = \frac{kq_1\, q_2}{r}$$

$$E_{p1} = \frac{9 \cdot 10^9 \cdot 20 \cdot 10^{-6} \cdot (-10 \cdot 10^{-6})}{0.2} = -9\,J$$

$$E_{p2} = \frac{9 \cdot 10^9 \cdot 20 \cdot 10^{-6} \cdot (-10 \cdot 10^{-6})}{0.4} = -4.5\,J$$

$$\Delta E = E_{p2} - E_{p1}$$

$$\Delta E = -4.5 - (-9) = 4.5\,J$$

Discussion

The potential energy has increased because the potential energy of unlike charges increases as we separate them.

Literacy

1. What is definition of “electric potential energy”?
2. When electric work of field is negative? When electric work of field is positive?
3. Three identical charges of 6 nC are located at the corners of equilateral triangle with sides of 9 cm. Calculate the total potential energy of the system.
4. Two electrons move towards each other from infinity with same speeds of 1000 km/s. What will be the minimum distance between them?
5. There are four identical charges of 4 C that are placed along straight line at an interval of 10 cm. Calculate the total potential energy of the system.
6. A 20 nC charge is moved from infinity to point 50 cm apart from charge of 15 nC. Calculate the change of electric potential energy during this process.

Important note

Electric potential energy is a scalar quantity. The total potential energy of a system can be found as the sum of all energies in the system.

Research time

Why does our hair stand up when we put off sweater or touch Van de Graaff generator?

10.7 Electrical work. Electric potential. Potential difference

You will

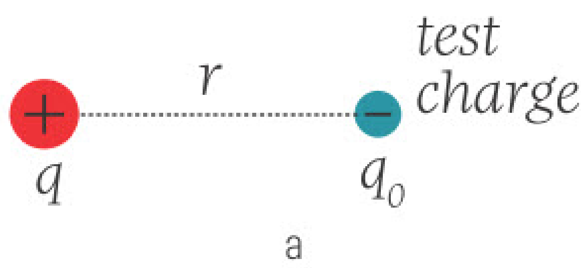
- calculate electric potential and electric work of point charge.

Question

Why do electricians have to approach to damaged power lines by very small steps?

We can define a new physical quantity that characterises the electric potential energy at a point near charge, q, Figure 91. This quantity is called electric potential and it is defined as the electric potential energy per unit charge. The electric potential at a point , where the test charge was placed is denoted by φ_a

$$\varphi_a = \frac{E_p}{q_0} = \frac{k\frac{q \cdot q_0}{r}}{q_0} = k\frac{q}{r}$$



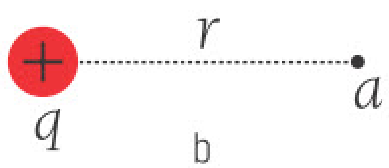


Figure 91

Note that the electric potential of the charge q at point a is independent of the test charge. Electric potential is a scalar quantity. The SI unit of electric potential is the Joule/Coulomb and it is given the special name of the Volt, (V), in honour of Alessandro Volta, the inventor of the electric battery. Then

1 V = 1 J/C

Potential Difference (Voltage)

Instead of potential energy or potential at a point, in practice the difference in potential between two points is important and measurable.

Suppose a positive charge, +q is placed at point a in a uniform electric field, E as shown in Figure 92. As the charge is moved from the initial point a to the final point b, by an external force, it does positive work against the electric force. The electric potential energy of the charge increases.

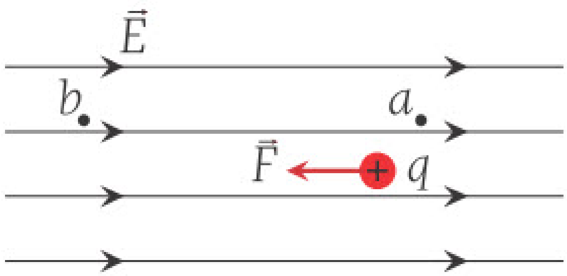


Figure 92

Now let us find the potential difference between the points a and b. The potential difference can be denoted as V which represents

$$V = \varphi_b - \varphi_a$$

Note that φ_b is the potential at the final point b and φ_a is the potential at the initial point a. We know that

$$\varphi_b = \frac{E_{pb}}{q} \quad \text{and} \quad \varphi_a = \frac{E_{pa}}{q}$$

where E_{pa}, and E_{pb} are the electric potential energies at the points a and b, respectively. By substituting these into the formula

$$V = \varphi_b - \varphi_a = \frac{E_{pb}}{q} - \frac{E_{pa}}{q} = \frac{E_{pb} - E_{pa}}{q}$$

$$V = \frac{\Delta E_p}{q} = \frac{W_{ab}}{q}$$

$$W_{ab} = qV$$

Thus

$$V = \varphi_b - \varphi_a = \frac{W_{ab}}{q} \quad \text{and} \quad W_{ab} = qV$$

Potential of a charged sphere

When a conducting sphere is charged, its charge, q is distributed uniformly over its surface area. Suppose that a test charge, q’ is moved from the point a on the sphere to another point b on the sphere. We have:

$$W_{ab} = q'V = q'(\varphi_b - \varphi_a)$$

We know that φ_b and φ_a are at the same potentials because they are on the same surface. So, the work done is zero, $W_{ab} = 0$. This shows that inside the sphere, the potential at every point is the same and is equal to the potential at the surface. The potential at any point outside the sphere is given by

$$\varphi = k\frac{q}{r}$$

r is the distance to the point from the center of sphere

The potential-distance graph of a conducting sphere is shown on Figure 93.

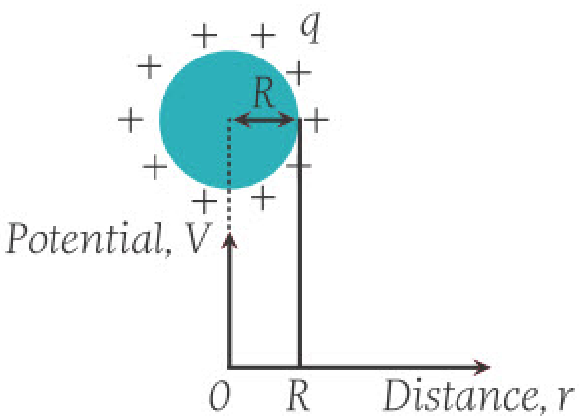
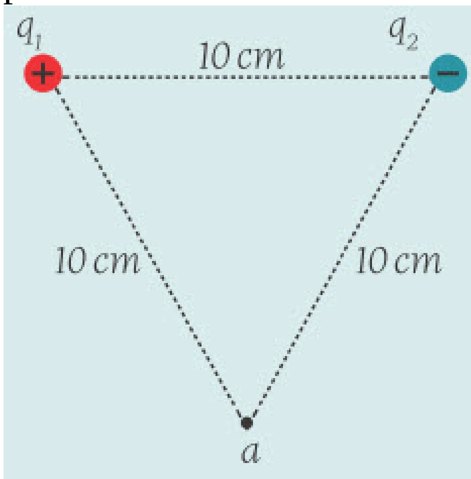


Figure 93

Example

Two charges of q_1=5 nC and q_2=-10 nC are placed at the corners of an equilateral triangle of side length 10 cm. Determine the electric potential at point a.



Given:

$q_1 = 5 \cdot 10^{-9}\ C$

$q_2 = -10 \cdot 10^{-9}\ C$

$r = 0.1$

$k = 9 \cdot 10^9\ N \cdot m^2/C^2$

$\varphi = ?$

Formulas:

$$\varphi = k\frac{q}{r}$$

$$\varphi = \varphi_1 + \varphi_2 + \varphi_3 + \cdots \varphi_n$$

Calculations:

$$\varphi = k\frac{q_1}{r} + k\frac{q_2}{r} \qquad \varphi = \frac{k}{r}(q_1 + q_2)$$

$$\varphi = \frac{9 \cdot 10^9}{0.1}(5 \cdot 10^{-9} - 10 \cdot 10^{-9})$$

$$\varphi = -450\ V$$

Literacy

1. How does electric potential change if distance from charge is doubled?
2. There is uniformly charged sphere of 20 cm radius that has volume charge density of $3 \cdot 10^{-5}$ C/m^3. Plot φ(r) graph, where r is distance from the centre of sphere and φ is electric potential of sphere.
3. What is the work done by electric field when 20 nC charge is moved from point at φ_1=-100 V to point at φ_2=400 V?
4. Charge of -25 nC is moved 2 cm along electric field lines of 1 kV/m. Calculate work done by field, and potential difference between two points.
5. Two identical charges of 0.1 μC are placed at a distance of 6 cm from each other. Calculate electric potential at distance of 5 cm from both charges. Consider two cases:
a) both charges are positive
b) first charge is positive, second charge is negative.

Activity

Electric potential energy is similar to gravitational potential energy. What is the mechanical analogue of electric potential?

Is it true?

Electric eel produces voltage up to 500 volts. Such shock can kill human.

10.8 Equipotential surfaces. Electric field strength and potential difference of uniform electric fields

You will

- apply formula that connects electric field and potential difference for problem solving.
- compare field strengths and potentials of gravitational and electric fields.

Question

What is electrostatic coating? Why it is used?

In the most cases electric field is not uniform, but we could make special conditions to make it uniform. That concept is useful when we deal with small particles or when we need precise results.

The electric field between two parallel metal plates which are oppositely charged is almost uniform, especially when the distance between the plates is small. We can charge the plates oppositely by connecting them to the terminals of a battery, Figure 94.

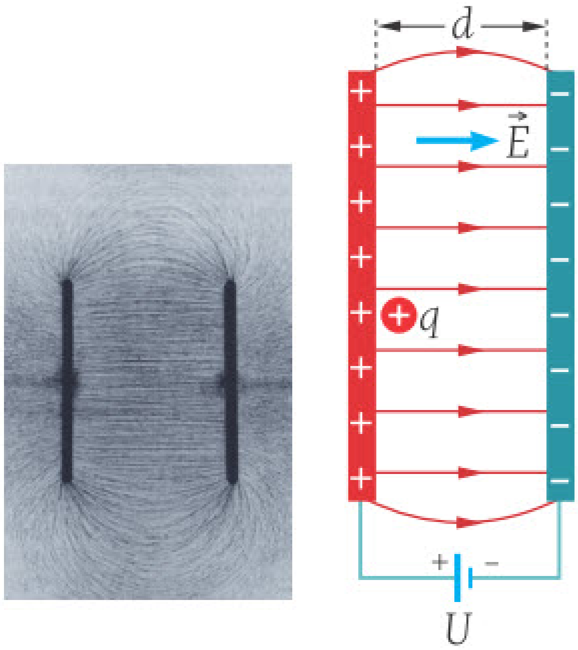


Figure 94

Suppose that a positive charge +q is placed at a point just near the positive plate, as shown on Figure 95.

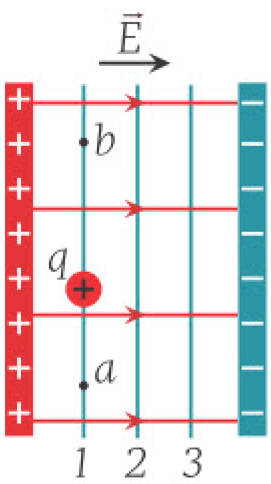


Figure 95

If the distance between the plates is d, the electric potential energy of the charge is given by

$$E_p = qEd$$

For simplicity, we choose the potential at the negative plate to be zero, thus the electric potential energy of the charge at the negative plate will also be zero. We know that potential difference is given by

$$V = \frac{W_{ba}}{q} = \frac{Ep - 0}{q} = \frac{qEd}{q}$$

$$V = Ed$$

The SI unit of electric field can be expressed in terms of the unit of voltage, i.e, Volt per metre (V/m) as well as the Newton per Coulomb (N/C).

Equipotential lines

Suppose a charge q is displaced from point a to point b along a line perpendicular to the electric field, as shown in Figure 95. The work done by the electric force is zero because force and distance are perpendicular. This means that the points on this line are all at the same potential. When we move a charge on line 2 in the figure, work done is also zero. The potential energy of the charge remains constant ($E_p = qEd$). So lines 1, 2, and 3 are called equipotential lines.

Where are the equipotential lines of a point charge? They are perpendicular to the electric field lines at any point as shown on Figure 96a, thus they form concentric circles around the charge.
The equipotential lines for two equal but oppositely charged point particles are shown on Figure 96b.

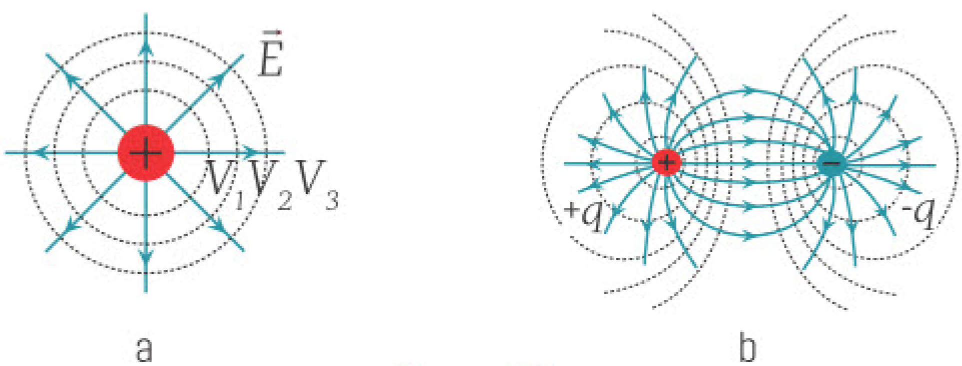


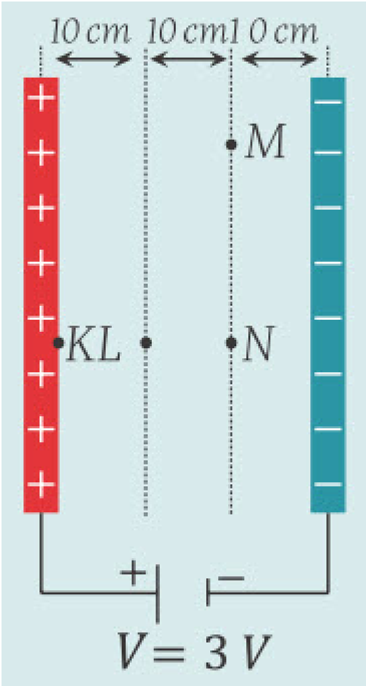
Figure 96

Example

Two parallel plates are connected to a battery of potential difference of 3 V. If the distance between the plates is 30 cm, find:

a) The magnitude of the electric fields at points K, L, N and M.

b) The potential differences V_{NM}, V_{LK} and V_{MK} between points N and M, L and K, M and K, respectively.



Given:

$V = 3\ V$

$d = 30\ cm = 0.3\ m$

E_K, E_L, E_N, E_M?

V_{NM}, V_{LK}, V_{MK} ?

Formulas:

$$E = \frac{V}{d}$$

$$V = \varphi_b - \varphi_a$$

Calculations:

a) $$E = \frac{3}{0.3} = 10\ V/m$$

Electric field is the same at every point between the charged parallel plates.

b) The points N and M are located on the same equipotential line.

$$V_{NM} = \varphi_M - \varphi_N = 0 \qquad V_{LK} = 1\ V$$

$$E = \frac{V}{d} \qquad V_{MK} = 2\ V$$

$$V = Ed$$

Activity

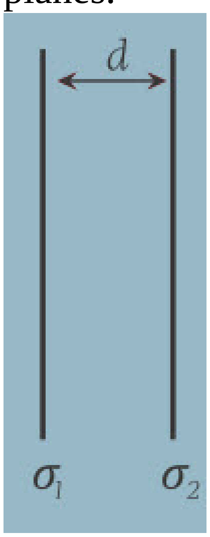
Open "Phet Charges and Fields". Put one (or two charges). Draw equipotential lines. Write down your observations.

Research time

Research similarity between equipotential lines and lines of topographic map.

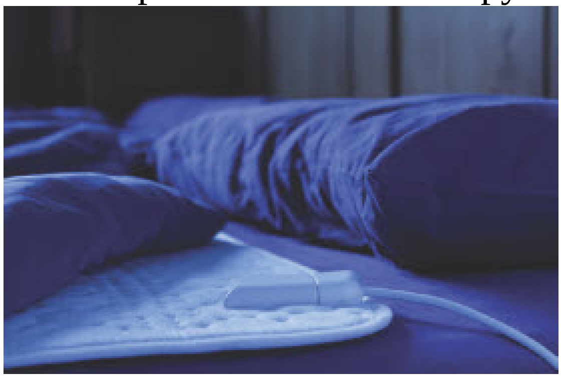
Literacy

1. What is “equipotential surface”? Can you make analogy with “contour lines of topographic map”?
2. Electric field between two plates that are separated by 5 cm is 10 kV/m. Calculate potential difference between plates.
3. Electric field is 77 V/m at a distance of 16 cm from the centre of a sphere that has 11 mm radius. Calculate electric potential of sphere and surface charge density of the sphere.
4. Dielectric strength of air is 3 MV/m. That means after 3 MV/m air becomes conductor and charge starts to flow through air. Calculate maximum possible electric potential of sphere that has diameter of 1 metre.
5. Two infinite uniformly charged planes are placed in a vacuum at a distance of 10 cm from each other. Surface charge densities are known to be σ_1=-5 nC/m^2 and σ_2=13.85 nC/m^2. Calculate potential difference between planes. Plot φ(r) graph, where φ is potential and r is line perpendicular to planes.



Physics in life

Electric potential thermotherapy mattress.

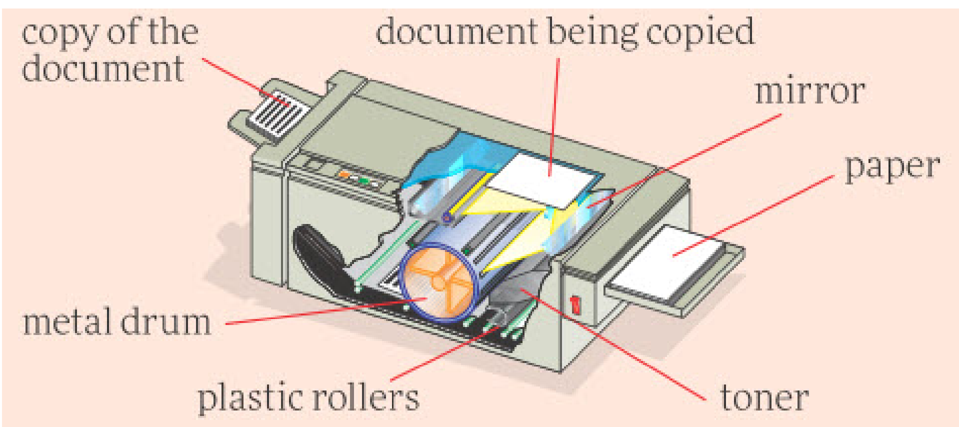


10.9 Conductors and dielectrics in electric field

You will

- make comparative analysis of electrostatic induction in conductors and polarization in dielectrics.

Question



Why do papers that come out of photocopier stick to each other? How does a photocopying machine work? Why is there light in photocopying machine?

Conductors are materials whose atoms contain free electrons. These electrons can move freely within the material. What happens if we place a conductor such as a metal slab in a uniform electric field?

The free electrons experience an electric force and they begin to move in a direction opposite the electric field direction as shown in Figure 97a. The electrons accumulate on the left surface and the right surface of the metal slab becomes positively charged. Thus, an electric field, E is produced inside the slab with a direction opposite the external field as shown in Figure 97b. Charge accumulation continues until the magnitude of the electric field inside the slab is equal to the magnitude of the external field. Consequently the total electric field inside the metal slab is zero as shown in Figure 97c.

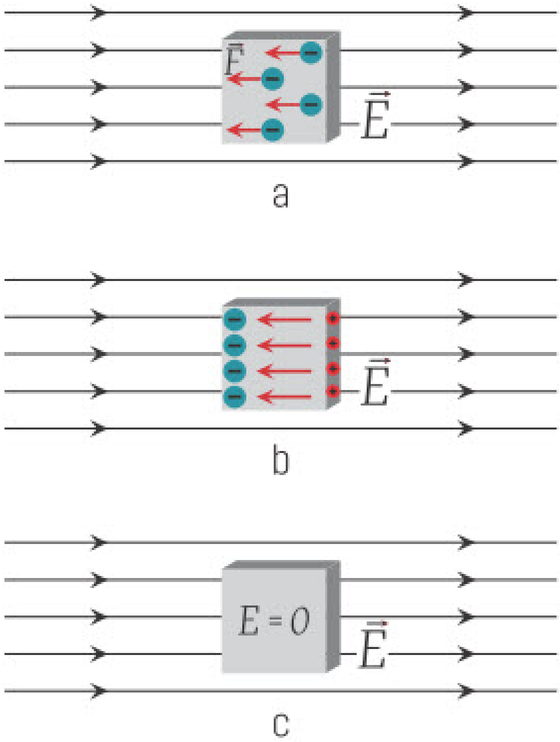
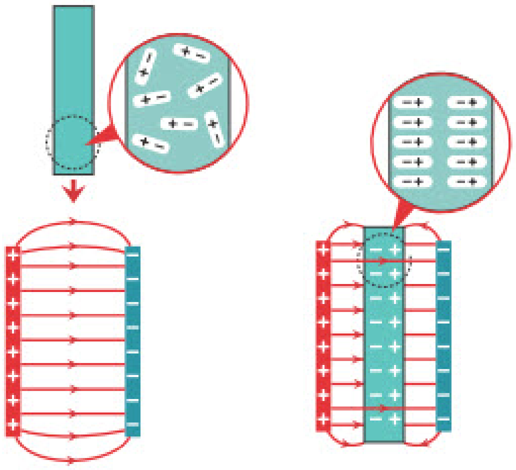


Figure 97

Dielectrics

Many materials, such as paper, plastic and glass, do not conduct electricity (under normal conditions). We call these materials dielectrics. Although, they do not conduct electricity, they change the external electric fields in which they are placed. Dielectric materials consist of dipoles – molecules that have negative and positive sides, Figure 98a.



a b

Figure 98

When dielectric is inserted in electric field, dipole molecules align as shown on the Figure 98b. As you can see, internal electric field is opposite to the external electric field. That means net electric field becomes lower in dielectric.

How many times does electric field become lower? It is given by dielectric constant ε. Formula of dielectric constant is

$$\varepsilon = \frac{E_0}{E}$$

E is electric field in a dielectric

E_0 is the electric field before the dielectric material is inserted.

ε is dielectric constant.

Values of dielectric constants are given in Table 8.

Material	Dielectric constant ε
Vacuum	1
Air	1,00054
Paraffin	2,0–2,5
Teflon	2,1
Nylon	3,5
Paper	3,7
Rubber	6,7
Silicone	12
Germanium	16
Water	80

Table 8

You can see decreasing electric field on the Figure 99. There insertion of dielectric decreases potential difference because dielectric becomes polarised.

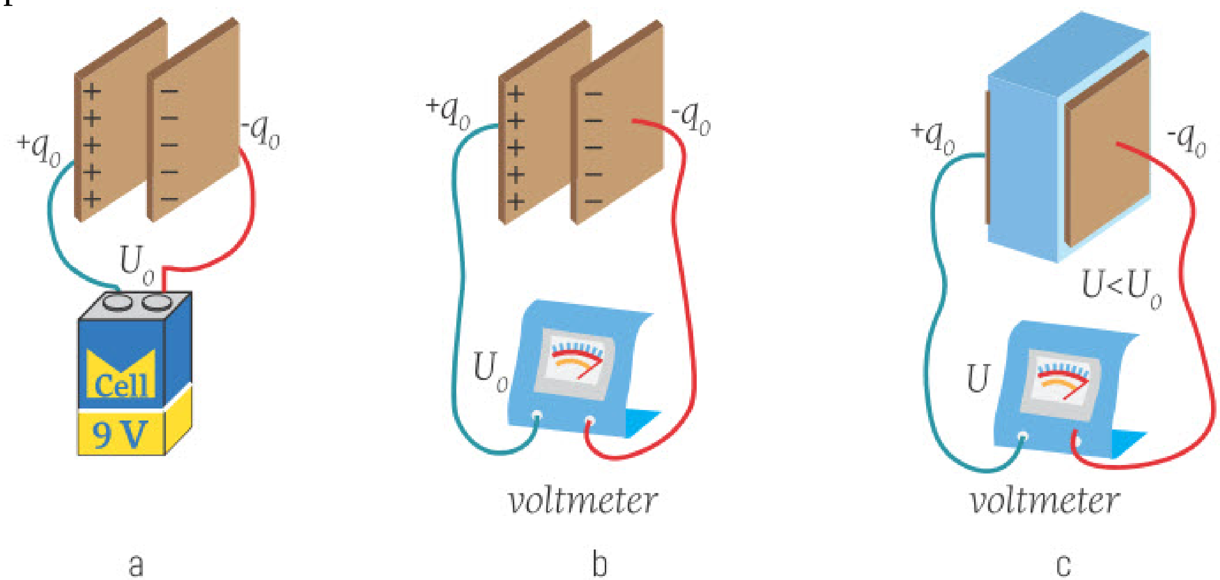


Figure 99

Example

Calculate potential difference between parallel plates located at distance 2 mm, if dielectric of ε inserted between plates. Initial potential difference is 20 V.

Given:

$V_0 = 20\ V$

$d = 2\ mm = 2 \cdot 10^{-3}\ m$

$\varepsilon = 4$

$V = ?$

Formulas:

$$\varepsilon = \frac{E_0}{E}$$

$$E = \frac{V}{d}$$

Calculations:

$$E_0 = \frac{V_0}{d} = \frac{20}{2 \cdot 10^{-3}} = 10^4\ V/m$$

$$\varepsilon = \frac{E_0}{E} \Rightarrow E = \frac{E_0}{\varepsilon} = \frac{10^4}{4} = 0.25 \cdot 10^4\ V/m$$

$$E = \frac{V}{d} \Rightarrow V = Ed = 0.25 \cdot 10^4 \cdot 2 \cdot 10^{-3} = 5V$$

Discussion:

Potential difference decreases 4 times or by 75%

Activity

Open "Phet Capacitor Lab". Change properties and observe how dielectric affects electric field between parallel plates.

Research time

Why cables are coated with rubber? What are electrical properties of rubber? What can you say about molecules of rubber?

Literacy

1. What does happen to electrons, protons and neutrons of conductor when it is placed in electric field?
2. What does happen to electrons, protons and neutrons of dielectric when it is placed in electric field?
3. Two identical thin metallic plates are placed very close to each other. Charge of 5 nC is given to the first plate and charge of 15 nC is given to the second plate. Determine charges of the four surfaces of plates. Draw electric field lines of plates.
4. Electric field in vacuum is $8.1 \cdot 10^5$ V/m, electric field in water is 10^4 V/m. Calculate relative permittivity (dielectric constant) of the water.
5. What is the Coulomb's force between two water droplets that are at a distance of 3 mm from each other in kerosene? Charges of droplets are $-2.1 \cdot 10^{-9}$ Coulomb and $-3 \cdot 10^{-9}$ Coulomb.

Important note

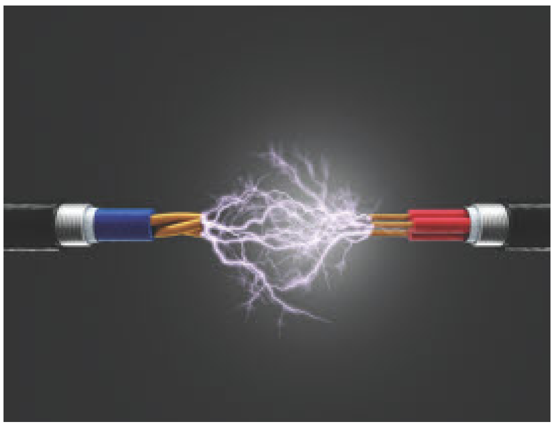
Conductors have important applications. Scientists can study sensitive electronic experiments safely in laboratories which are enclosed by metallic plates (called a Faraday Cage). The external electric fields do not affect their experimental work or harm them.

Is it true?

One gram of gold can be drawn into a wire 2.13 km long.

Physics in life

Static electricity is based on insulators but dynamic electricity is based on conductors.

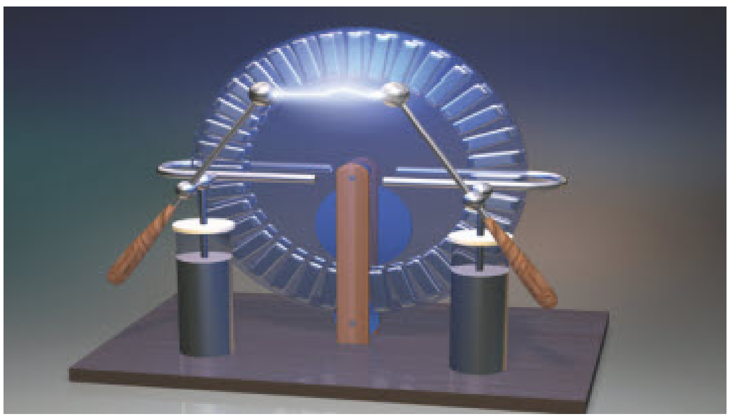


10.10 Capacitance. Capacitors

You will

- analyse relationship between capacitance of capacitor and other parameters of capacitor (dimensions, shape, materials, etc.).

Question



On the figure you can see Wimshurst machine. It is used to generate electrostatic charges. Why there are two cylinders?

Capacitors are devices that store charge and energy, so they can be used as energy-storing devices in electronic circuits, Figure 100. They are also commonly used in electrical circuits to tune the frequency of radio receivers and as filters in power supplies. In nature clouds and Earth make capacitor which discharges by lightning, Figure 101.

Figure 100

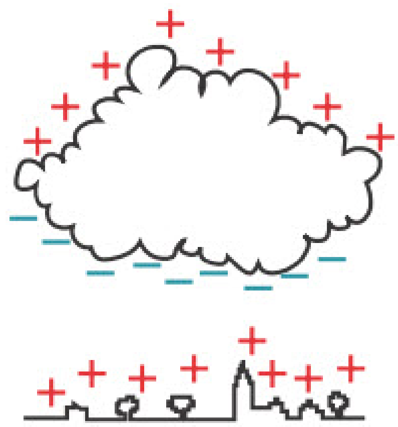
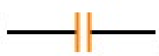


Figure 101

A system consisting of two conductors with an insulating medium placed between them is called a capacitor. Such a device is shown in Figure 102 and it is symbolised by



Capacitors are devices which store electric charge.

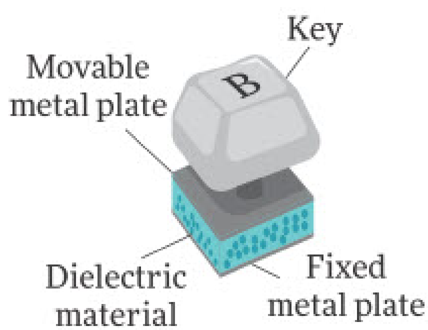


Figure 102

Once the capacitor is charged, the two conductors carry equal but opposite charges. There are some common types of capacitors, parallel plate-capacitors, cylindrical and concentric spheres capacitors.

When the plates of a capacitor are connected to the terminals of a battery, the capacitor becomes charged. The plate connected to the positive terminal of the battery is charged to +q and the plate connected to the negative terminal is charged to –q. The charge of a capacitor is the quantity (q) of charge on one plate. Figure 103 shows how a capacitor can be charged.

Figure 103

The capacitance of a capacitor having a charge q and potential difference U between its plates is defined as,

$$C = \frac{q}{V}$$

The capacitance is a measure of its ability to store charge and hence electrical potential energy.

In the SI system the unit of capacitance is Farad (F), 1 Farad = 1 C / V.

A parallel plate capacitor consists of two parallel plates each of area A, separated by a distance, d, as shown in Figure 104.

As the area of the plates increases the capacitance also increases. This means that the capacitance is directly proportional to the area of capacitor's plates. Thus,

C ~ A

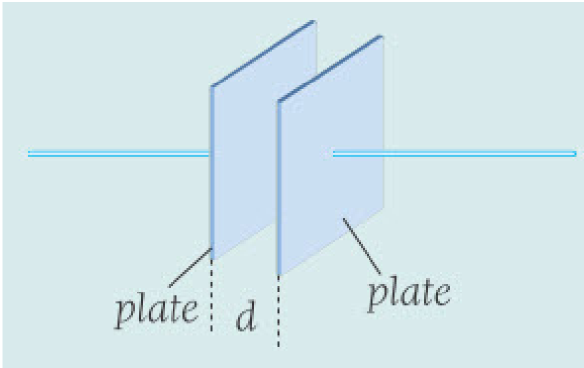
If the distance between the plates decreases their capacitance increases. Thus, capacitance is inversely proportional to plate separation. Then C~1/d.

Therefore, the equation can be completed by including a dielectric constant ε which depends on the medium between the plates. If this medium is a vacuum the constant ε_0 is , which is called the permittivity of a vacuum (free space) and has the value $8.85.10^{-12}$ F/m and the capacitance is,

$$C = \frac{\varepsilon\varepsilon_0 A}{d}$$

Example

A parallel plate capacitor has an area of 40 cm·50 cm and plate separation of 1 cm.



a) What is the capacitance of this capacitor?

b) If it has a charge of $3.6 \cdot 10^{-3}$ C, what is the potential difference across the capacitor?

Given:

$A = 0.4 \cdot 0.5 = 0.2\ m^2$

$d = 0.01\ m$

$q = 3.6 \cdot 10^{-3}\ C$

$\varepsilon = 1$ (dielectric permeability of air)

$\varepsilon_0 = 8.85 \cdot 10^{-12}\ F/m$

$C = ?$

$V = ?$

Formulas:

$$C = \varepsilon\varepsilon_0 \frac{A}{d} \qquad C = \frac{q}{V}$$

Calculations:

$$C = 1 \cdot 8.85 \cdot 10^{-12} \cdot \frac{0.2}{0.01}$$

$$C = 1.77 \cdot 10^{-10}\ F$$

$$V = \frac{qd}{\varepsilon\varepsilon_0 A}$$

$$V = \frac{3.6 \cdot 10^{-3} \cdot 0.01}{1 \cdot 8.85 \cdot 10^{-12} \cdot 0.2}$$

$$V = 2.03 \cdot 10^{7}\ V$$

Activity

Open "Phet Capacitor Lab Basics". Change the parameters and observe the changes. What parameters allow capacitor to store more charge?

Literacy

1. How does capacitance of parallel plate capacitor change when separation between plates is doubled?

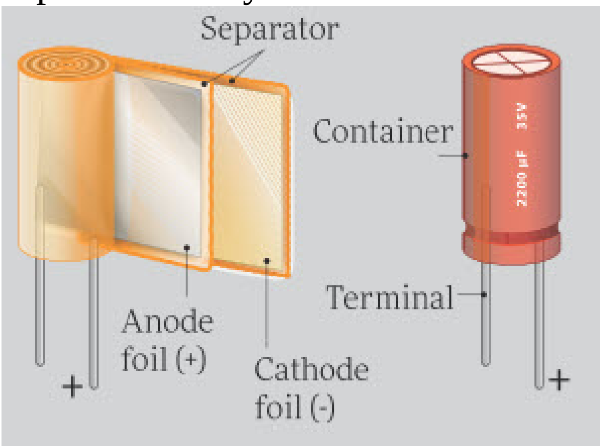
2. Calculate capacity of a conductor that can store 5 nC charge at 10 kV voltage.
3. There are two charged conductors that have charges q_1=600 nC, q_2=-200 nC and capacitances C_1=10 pF, C_2=30 pF. Calculate charges and potentials after conductors are connected by wire.
4. Parallel plate capacitor is made of two circular plates of 20 cm diameter that are separated by 1 mm thick paraffin slab. Calculate capacitance of capacitor.
5. Separation between plates of parallel plate capacitor is 0.5 mm. Voltage of the capacitor is 10 Volt and it is disconnected from battery. How would voltage change if separation between plates is increased to 5 mm?

Research time

Make “Leiden jar”. Where it can be used?

Important note

There are also other various geometrical shapes of capacitors, i.e. cylindrical capacitors. They consist of metal foil and waxed paper.



Career

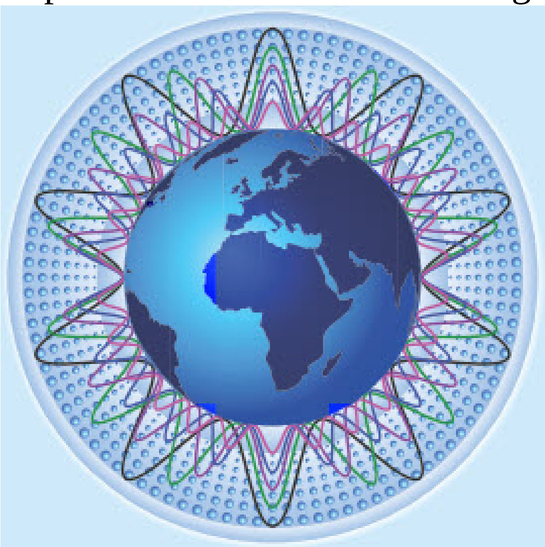
Professional photographers use capacitors for powering flashlight in their cameras.

Physics in life

These are defibrillators. How do you think why do we use them?

Is it true?

Capacitance of the Earth is so big that it is only 1 Farad.



10.11 Combination of capacitors

You will

- apply formula of parallel and series combination of capacitors for problem solving.

Question

Why are capacitors used in computer motherboard? What would happen if there are no capacitors in motherboard?

In an electric circuit, we may need capacitors of various capacitance values. However, capacitors only come in certain fixed values. The required capacitance value can be obtained by connecting capacitors in series and parallel.

Series Combinations

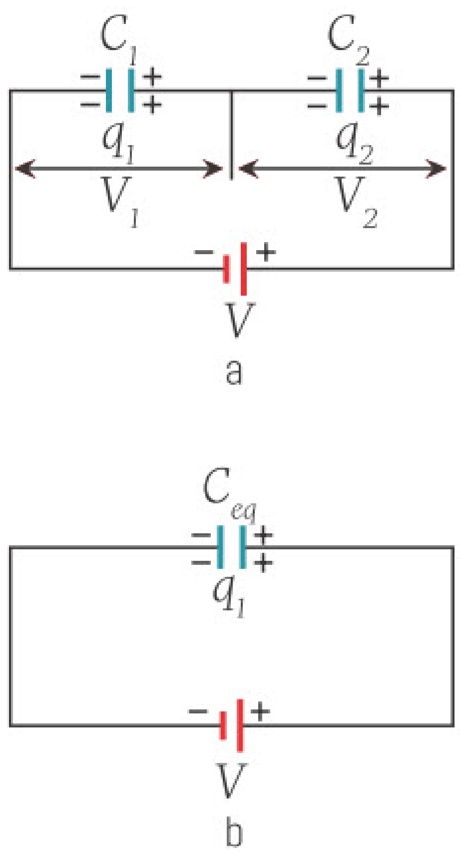


Figure 105

If two or more capacitors are connected as shown in Figure 105a, they are said to be connected in series. In series combinations, charges on each capacitor are equal. If q_t is the total charge, we can write

$$q_t = q_1 = q_2$$

If the voltage supplied by the battery is V, it is equal to the sum of the potential differences across each capacitor. If V_1 and V_2 are potentials across capacitors C_1 and C_2 respectively, the potential difference of the system is

$$V = V_1 + V_2$$

The equivalent capacitance is denoted C_{eq} as shown in Figure 105b. This capacitor stores the charge q_t of the system.

If the potential differences,

$$V = \frac{q_t}{C_{eq}} \qquad V_1 = \frac{q_1}{C_1} \qquad V_2 = \frac{q_2}{C_2}$$

are substituted in,

$$V = V_1 + V_2$$

$$\frac{q_t}{C_{eq}} = \frac{q_1}{C_1} + \frac{q_2}{C_2}$$

Since

$$q_t = q_1 = q_2$$

we can simplify this equation by cancelling these same charges.Thus we obtain,

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2}$$

If there are ‘n’ capacitors connected in series:

$$q_t = q_1 = q_2 = \cdots = q_n$$

$$V = V_1 + V_2 + \cdots + V_n$$

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \cdots + \frac{1}{C_n}$$

Parallel Combinations

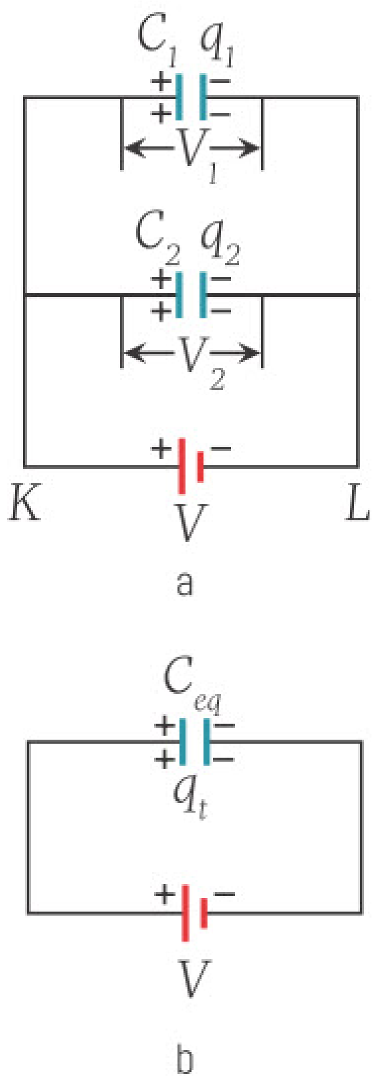


Figure 106

If two or more capacitors are connected as shown in Figure 106a, they are said to be connected in parallel.

Since the plates of each capacitor are connected to the same potential difference, their potentials are equal.

$$V = V_1 = V_2; \qquad q_t = q_1 + q_2;$$

and using the equations we obtain,

$$q_t = C_{eq}V; \qquad q_1 = C_1V_1; \qquad q_2 = C_2V_2;$$

; ; ;

Then since

$$V = V_1 = V_2$$

we can cancel out these same potential differences and obtain,

$$C_{eq}V = C_1V_1 + C_2V_2; \qquad C_{eq} = C_1 + C_2;$$

If there are ‘n’ capacitors connected in parallel, Figure 106b:

$$q_t = q_1 + q_2 + \cdots + q_n$$

$$V = V_1 = V_2 = \cdots = V_n$$

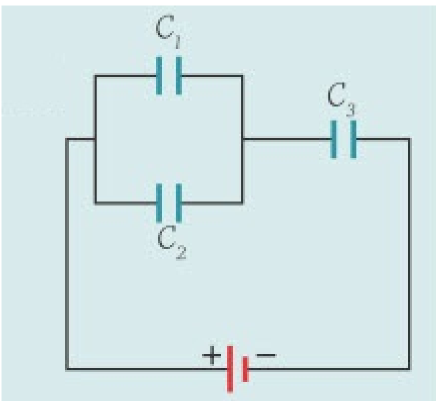
$$C_{eq} = C_1 + C_2 + \cdots + C_n$$

Activity

Open "Phet Capacitor Lab". In the simulation open “multiple capacitors” tab. Make series and parallel connection for capacitors. Write down your observation.

Example

Three capacitors of capacitance C_1=1 μF, C_2=2μF and C_3=6 μF are connected as shown in the figure, and charged by a 100 V battery.



Find:
a) The equivalent capacitance of the system.
b) The total charge of the system.
c) The potential difference on each capacitor.

Given:

$C_1 = 1\ \mu F = 1 \cdot 10^{-6}\ F$

$C_2 = 2\ \mu F = 2 \cdot 10^{-6}\ F$

$C_3 = 6\ \mu F = 6 \cdot 10^{-6}\ F$

$V = 100\ V$

$C = ?$

$q = ?$

$V_1, V_2, V_3\ ?$

$q_1, q_2, q_3 ?$

Formulas:

$$C_{parallel} = C_1 + C_2 + C_3 + \ldots + C_n$$

$$\frac{1}{C_{series}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots + \frac{1}{C_n}$$

$$C = \frac{q}{V}$$

Calculations:

a) $C_{parallel} = C_1 + C_2$

$$C_{parallel} = 1 \cdot 10^{-6} + 2 \cdot 10^{-6} = 3 \cdot 10^{-6}\ F$$

$$\frac{1}{C_{series}} = \frac{1}{C_3} + \frac{1}{C_{parallel}}$$

$$\frac{1}{C_{series}} = \frac{1}{6 \cdot 10^{-6}} + \frac{1}{3 \cdot 10^{-6}}$$

$$C_{series} = 2 \cdot 10^{-6}\ F$$

b) $C = \dfrac{q}{V}$

$$2 \cdot 10^{-6} = \frac{q}{100}$$

$$q = 2 \cdot 10^{-4}\ C$$

c) $q = q_3 = 2 \cdot 10^{-4}\ C$

$$C_3 = \frac{q_3}{V_3}$$

$$6 \cdot 10^{-6} = \frac{2 \cdot 10^{-4}}{V_3}$$

$$V_3 = 33.3\ V$$

$$V = V_1 + V_3$$

$$V_1 = V_3 - V$$

$$V_1 = 100 - 33.3 = 66.7\ V$$

$$V_1 = V_2 = 66.7\ V$$

Research time

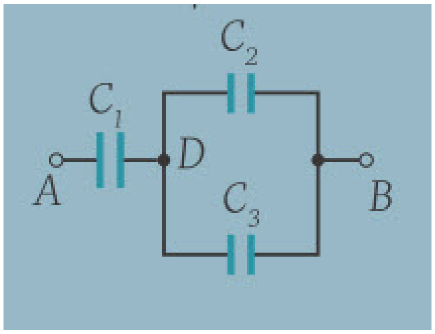
Capacitors unlike batteries discharge very fast. What can you do to make capacitors lose charges slowly?

Is it true?

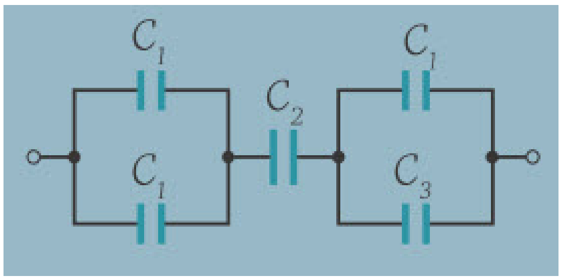
Supercapacitors are made with graphene as the conducting plate. They are capable of storing a charge similar to lithium-ion batteries.

Literacy

1. How should you connect capacitors to increase total capacitance?
2. Capacitor C_1 is charged up to 500 Volt. Then C_2=4 μF capacitor is connected in parallel so that voltage decreases to 100 Volt. Calculate capacitance of C_1 .
3. Potential difference between points A and B is 30 Volt. Capacitances are given as C_1=5 pF ,C_2=2 pF ,C_3=3 pF. Calculate charge and voltage of each capacitor and potential difference between points A and D.



4. There are three 12 μF capacitors that are designed for potential difference of 600 Volt. What capacitances can be obtained by using these capacitors? What is voltage in each case?
5. Calculate equivalent capacitance if C_1=4 μC ,C_2=10 μF, C_3=2μF.



10.12 Energy of electric field

You will

- calculate energy of electric field.

Question

On the figure you can see capacitor and supercapacitor (ultracapacitor). Which one can store more energy? How much more energy does it store?

From previous chapters you learned that electricity has an energy which may be converted to another form of energy. It will be more useful if we could find energy of electric fields of any device, especially capacitors. The energy of electric field is used in many areas including the light emission, electronic circuits, etc.

The total work needed to increase the capacitor's charge from zero to q is

$$W = V\Delta q$$

This is also equal to the total work done by the electric field on the charge when the capacitor discharges. Consider a parallel plate capacitor that is initially uncharged, so that the initial potential difference is zero. After charging it, the final potential difference across the capacitor reaches V.

The average potential difference during the charging process is

$$\frac{0+V}{2} = \frac{V}{2}$$

thus, we can say that the work needed to charge the capacitor is

$$W = \frac{qV}{2}$$

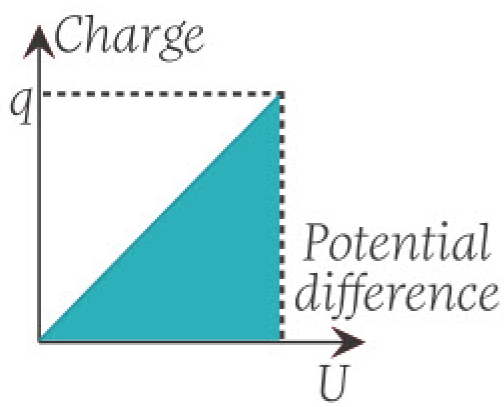


Figure 107

From Figure 107, we also see that the total amount of work done in charging a capacitor up to a potential difference is given by the area of the triangle under the voltage-charge curve.
In the SI system the unit of energy is the Joule (J)
1 Joule = 1 Volt · Coulomb
We know that q=C×V then

$$V = \frac{q}{C}$$

If this is substituted into the energy equation W=ΔE , equations for energy can be written as follows;

$$E = \frac{qV}{2} = \frac{CV^2}{2} = \frac{q^2}{2C}$$

For every capacitor there is a limit to the quantity of charge which can be stored, therefore the energy that can be stored also has a maximum level.

Energy density of electric field can be found by formula:

$$\frac{E}{V} = w = \frac{1}{2}\varepsilon_0 \varepsilon E^2$$

where E is electric field strength [N/C].

Example

Two capacitors C_1=12 μF and C_2=4 μF are connected in series to the terminals of a 24 Volt battery. Find the energy stored in capacitor C_1.

Given:	Formulas:
$C_1 = 12\,\mu F = 12 \cdot 10^{-6}\,F$ $C_2 = 4\,\mu F = 4 \cdot 10^{-6}\,F$ $V = 24\,V$ $E_1 = ?$	$C = \frac{q}{V}$ $E = \frac{qV}{2} = \frac{CV^2}{2} = \frac{q^2}{2C}$

Calculations:

$V = V_1 + V_2$

$24 = V_1 + V_2$

$q_1 = q_2$

$C_1V_1 = C_2V_2$

$12 \cdot 10^{-6} \cdot V_1 = 4 \cdot 10^{-6} \cdot V_2$

$3V_1 = V_2$

$24 = 4V_1$

$V_1 = 6\ V$

$V_2 = 18\ V$

$E_1 = \frac{1}{2}C_1V_1^2 \qquad E_1 = \frac{1}{2} \cdot 12 \cdot 10^{-6} \cdot 6^2$

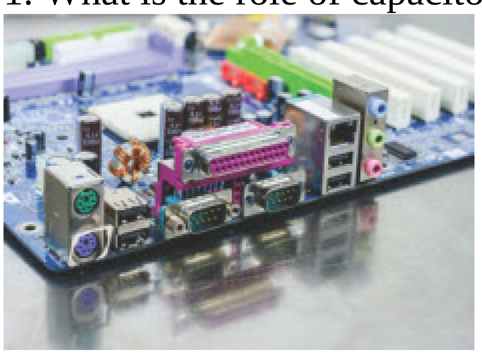
$E_1 = 2.16 \cdot 10^{-6}\ J$

Activity

Open "Phet Capacitor Lab Basics". Find the amount of charge the capacitor can store and energy stored in capacitor.

Literacy

1. What is the role of capacitors in the motherboard of computer?



2. What is the role of capacitors in the camera?

3. Separation between plates of parallel plate capacitor of 900 pF capacitance is 4 cm, voltage on capacitor is 200 Volt. Calculate electric field between the plates, force between the plates, energy of electric field of capacitor, energy density of electric field of capacitor.
4. A 200 μF capacitor is charged up to 100 Volt. What amount of heat is released if capacitor is discharged through resistor?
5. Photoflash of camera takes its energy from 800 μF and 300 Volt capacitor. Calculate energy of photoflash and average power if time of discharge of capacitor is 2.4 ms.
6. Parallel plate capacitor with dielectric material of volume 10^{-3} m^3 has relative permittivity of dielectric material $\varepsilon=5$. Electric field in dielectric material is 10^6 V/m. Calculate energy of capacitor.

Is it true?

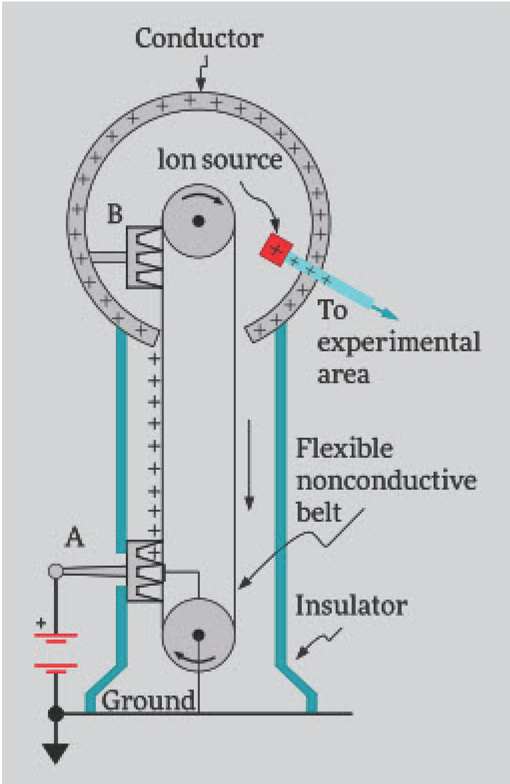
If you touch charged capacitor, it can cause dangerous electric shock.

Physics in life

Energy stored in the large capacitor is used to preserve the memory of a RAM in computer when its batteries are charged.

Important note

Van de Graaff generators are devices used to demonstrate high voltage due to static electricity.

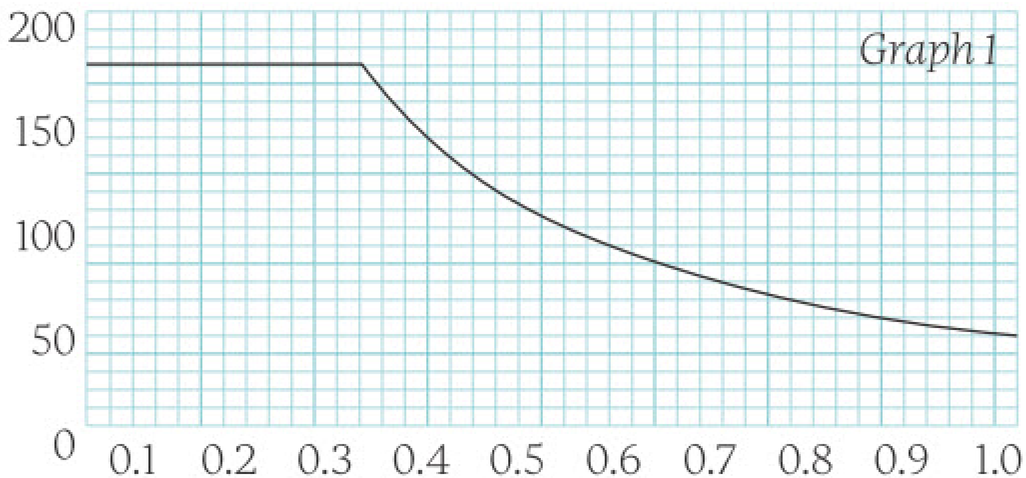


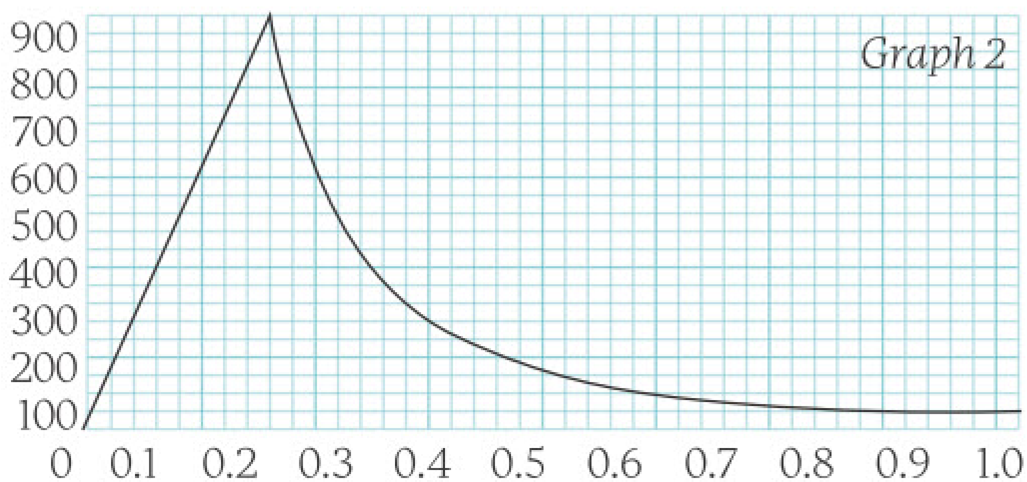
Research time

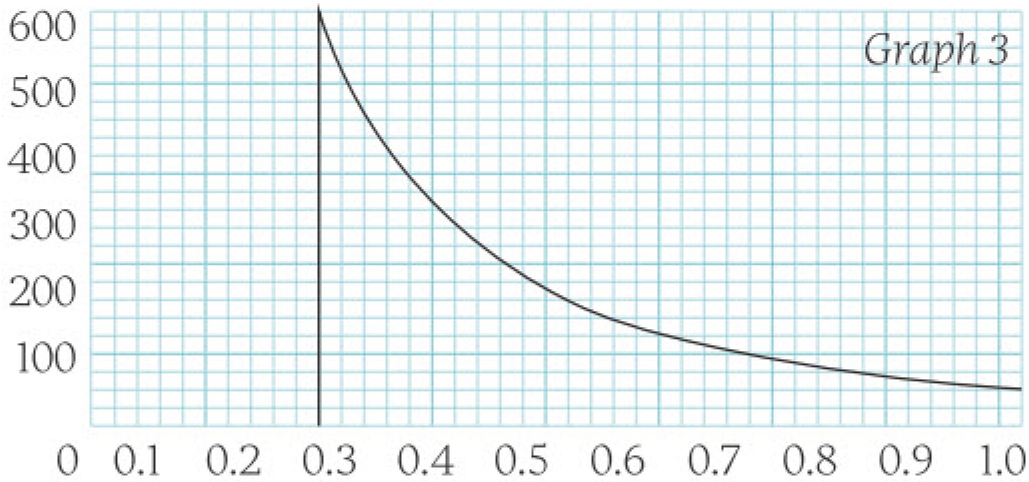
Why are capacitors cylinder-like?

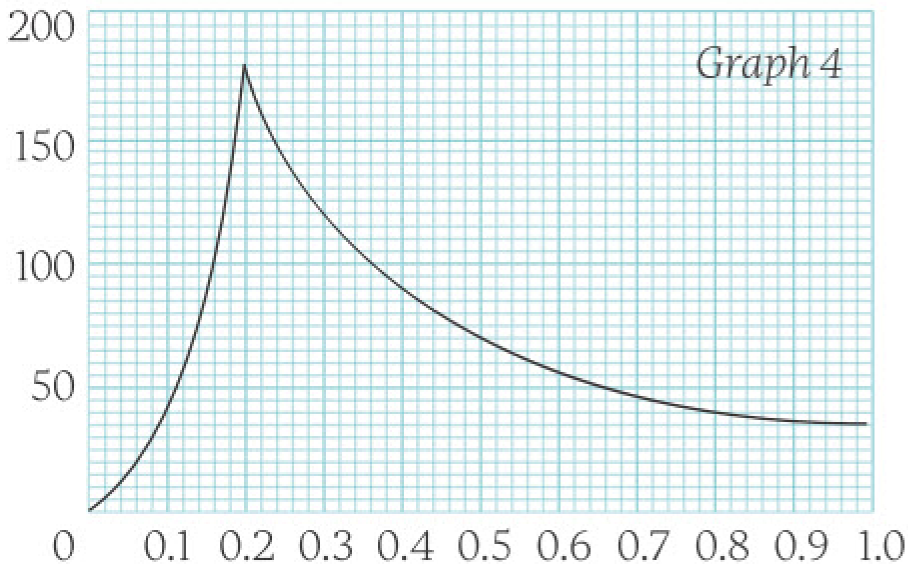
CHECK YOURSELF

There are four graphs that show relationship between electric potential, electric field and distance from the centre of dielectric sphere and conducting sphere. Charge is uniformly distributed through dielectric sphere. Use graphs to answer questions 1-40.









1. Which graphs (or one graph) show parameters of dielectric sphere?
A) Graph 1
B) Graph 2
C) Graph 3
D) Graph 4
E) There is no right answer

2. Which graphs (or one graph) show parameters of conducting sphere?
A) Graph 1
B) Graph 2
C) Graph 3

D) Graph 4
E) There is no right answer

3. Which graphs (or one graph) show relationship between distance and electric potential?
A) Graph 1
B) Graph 2
C) Graph 3
D) Graph 4
E) There is no right answer

4. Which graphs (or one graph) show relationship between distance and electric field?
A) Graph 1
B) Graph 2
C) Graph 3
D) Graph 4
E) There is no right answer

5. What parameter is shown by vertical axis of Graph 1?
A) Electric field in Volt per metre
B) Distance from the centre of sphere in metre
C) Electric potential in Volt
D) Distance from the surface of sphere in metre
E) There is no right answer

6. What parameter is shown by vertical axis of Graph 2?
A) Electric field in Volt per metre
B) Distance from the centre of sphere in metre
C) Electric potential in Volt
D) Distance from the surface of sphere in metre
E) There is no right answer

7. What parameter is shown by vertical axis of Graph 3?
A) Electric field in Volt per metre
B) Distance from the centre of sphere in metre
C) Electric potential in Volt
D) Distance from the surface of sphere in metre
E) There is no right answer

8. What parameter is shown by vertical axis of Graph 4?
A) Electric field in Volt per metre
B) Distance from the centre of sphere in metre
C) Electric potential in Volt
D) Distance from the surface of sphere in metre
E) There is no right answer

9. What parameter is shown by horizontal axis of Graph 1?
A) Electric field in Volt per metre
B) Distance from the centre of sphere in metre
C) Electric potential in Volt
D) Distance from the surface of sphere in metre
E) There is no right answer

10. What parameter is shown by horizontal axis of Graph 2?
A) Electric field in Volt per metre
B) Distance from the centre of sphere in metre
C) Electric potential in Volt
D) Distance from the surface of sphere in metre
E) There is no right answer

11. What parameter is shown by horizontal axis of Graph 3?
A) Electric field in Volt per metre
B) Distance from the centre of sphere in metre
C) Electric potential in Volt

D) Distance from the surface of sphere in metre
E) There is no right answer

12. What parameter is shown by horizontal axis of Graph 4?
A) Electric field in Volt per metre
B) Distance from the centre of sphere in metre
C) Electric potential in Volt
D) Distance from the surface of sphere in metre
E) There is no right answer

13. What is radius of dielectric sphere?
A) 0.1 m
B) 0.2 m
C) 0.3 m
D) 0.4 m
E) There is no right answer

14. What is radius of conducting sphere?
A) 0.1 m
B) 0.2 m
C) 0.3 m
D) 0.4 m
E) There is no right answer

15. What is charge of dielectric sphere?
A) 3 nC
B) 4 nC
C) 5 nC
D) 6 nC
E) There is no right answer

16. What is charge of conducting sphere?

A) 3 nC
B) 4 nC
C) 5 nC
D) 6 nC
E) There is no right answer

17. What is electric potential at a distance of 10 cm from centre of conducting sphere?
A) 0
B) 45 V
C) 90 V
D) 135 V
E) 180 V

18. What is electric potential at a distance of 10 cm from centre of dielectric sphere?
A) 0
B) 45 V
C) 90 V
D) 135 V
E) 180 V

19. What is electric potential at a distance of 50 cm from centre of conducting sphere?
A) 144 V
B) 108 V
C) 72 V
D) 36 V
E) 0

20. What is electric potential at a distance of 50 cm from centre of dielectric sphere?
A) 144 V

B) 108 V
C) 72 V
D) 36 V
E) 0

21. What is electric field at a distance of 10 cm from centre of conducting sphere?
A) 5400 V/m
B) 4320 V/m
C) 3240 V/m
D) 2160 V/m
E) 0

22. What is electric field at a distance of 10 cm from centre of dielectric sphere?
A) 900 V/m
B) 675 V/m
C) 450 V/m
D) 225 V/m
E) 0

23. What is electric field at a distance of 50 cm from centre of conducting sphere?
A) 0 V/m
B) 72 V/m
C) 144 V/m
D) 216 V/m
E) 288 V/m

24. What is electric field at a distance of 50 cm from centre of dielectric sphere?
A) 0 V/m
B) 72 V/m
C) 144 V/m

D) 216 V/m
E) 288 V/m

25. What is force acting on a 10 nC charge that is located at a distance 20 cm from the surface of dielectric sphere?
A) 1.25×10^{-6} N
B) 2.25×10^{-6} N
C) 3.25×10^{-6} N
D) 4.25×10^{-6} N
E) 0.25×10^{-6} N

26. What is force acting on a 10 nC charge that is located at a distance 20 cm from the surface of conducting sphere?
A) 4.16×10^{-6} N
B) 3.16×10^{-6} N
C) 2.16×10^{-6} N
D) 1.16×10^{-6} N
E) 0.16×10^{-6} N

27. Distance between centres of dielectric sphere and conducting sphere is 1 metre. What is net electric field at a point that is located 30 cm away from the surface of dielectric sphere and 20 cm away from the surface of conducting sphere?
A) 360 V/m
B) 288 V/m
C) 216 V/m
D) 144 V/m
E) 72 V/m

28. Distance between centres of dielectric sphere and conducting sphere is 1 metre. What is net electric field at a point that is located 70.71 cm away from the centre of dielectric sphere and 70.71 cm away from the centre of conducting sphere?
A) 0 V/m
B) 29.8 V/m
C) 129.8 V/m
D) 229.8 V/m
E) 329.8 V/m

29. Distance between centres of dielectric sphere and conducting sphere is 1 metre. At what distance from the surface of the dielectric sphere is the point in which electric field is zero?
A) 14.95 cm
B) 24.95 cm
C) 34.95 cm
D) 44.95 cm
E) 54.95 cm

30. Distance between centres of dielectric sphere and conducting sphere is 1 metre. What is electric potential at a point that is located 30 cm away from the surface of dielectric sphere and 20 cm away from the surface of conducting sphere?
A) 180 Volt
B) 144 Volt
C) 108 Volt
D) 72 Volt
E) 36 Volt

31. Distance between centres of dielectric sphere and conducting sphere is 1 metre. What is electric potential at the point in which electric field is zero?
A) 78.18 Volt
B) 178.18 Volt
C) 278.18 Volt

D) 378.18 Volt
E) 478.18 Volt

32. Distance between centres of dielectric sphere and conducting sphere is 100 metre. What is electric potential energy of the spheres?
A) 0.16 nJ
B) 1.16 nJ
C) 2.16 nJ
D) 3.16 nJ
E) 4.16 nJ

33. Distance between centres of dielectric sphere and conducting sphere is 100 metre. What work should be done to bring them to distance of 10 metre?
A) 49.44 nJ
B) 39.44 nJ
C) 29.44 nJ
D) 19.44 nJ
E) 9.44 nJ

34. How many electrons has conducting sphere lost?
A) 0.75×10^{-10}
B) 1.75×10^{-10}
C) 2.75×10^{-10}
D) 3.75×10^{-10}
E) 4.75×10^{-10}
35. Dielectric strength of air is 3 MV/m. What is the maximum charge that conducting sphere can hold?
A) 10 μC
B) 20 μC

C) 30 μC
D) 40 μC
E) 50 μC

36. Dielectric strength of air is 3 MV/m. What is the electric potential on the surface of conducting sphere when it holds maximum charge?
A) 900 kV
B) 800 kV
C) 700 kV
D) 600 kV
E) 500 kV

37. What is electric flux generated by dielectric sphere?
A) 51.98 V·m
B) 151.98 V·m
C) 251.98 V·m
D) 351.98 V·m
E) 451.98 V·m

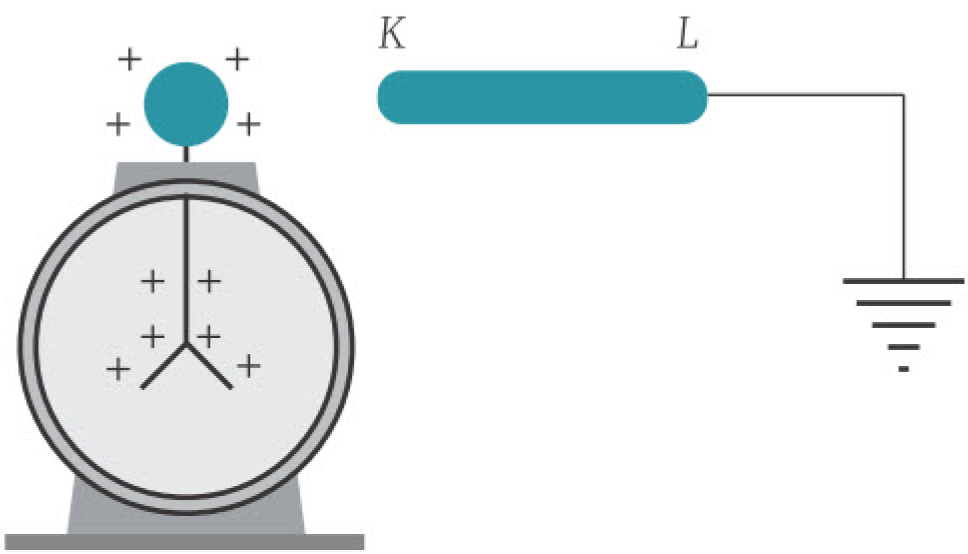
38. What is electric flux generated by conducting sphere?
A) 377.97 V·m
B) 477.97 V·m
C) 577.97 V·m
D) 677.97 V·m
E) 777.97 V·m

39. What is ratio of charges of conducting sphere and dielectric sphere?
A) 0.5
B) 1
C) 1.5
D) 2
E) There is no right answer

40. How much work should be done to bring 40 nC charge from infinity to the surface of conducting sphere?
A) 5.2 μJ
B) 6.2 μJ
C) 7.2 μJ
D) 8.2 μJ
E) 9.2 μJ

Electrostatics

1. A positively charged electroscope is brought close to the end K of the grounded conducting rod KL, as shown in the figure. Which of the following statements may be correct?
I. The separation between the leaves of the electroscope decreases a little.
II. The end, K of the conductor is negatively charged.
III. The end, L of the conductor is neutral.



A) I only
B) II only
C) III only
D) I and II

E) I, II and III

2. When conducting rod L is brought close to conducting sphere K suspended by a string, the position of the conducting sphere K is as shown in the figure. When conducting rod L is brought close to the positively charged electroscope, the separation between the leaves of the electroscope decreases a little.

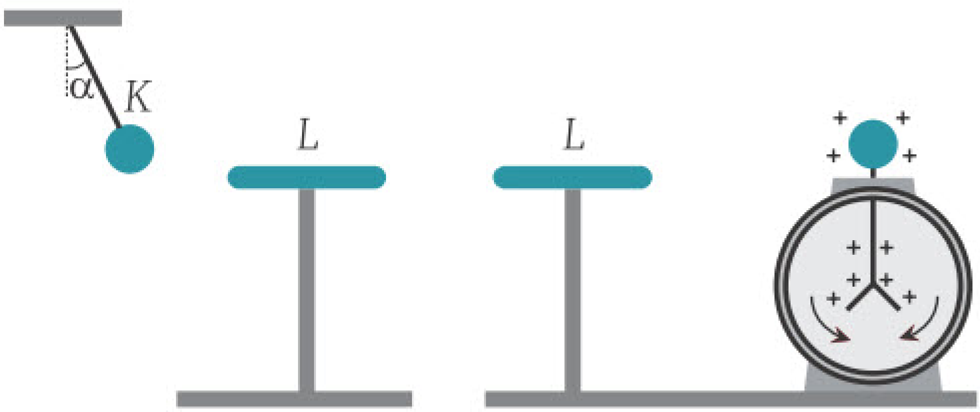


Figure-I Figure-II

What are the signs of the final charges of conducting objects K and L?

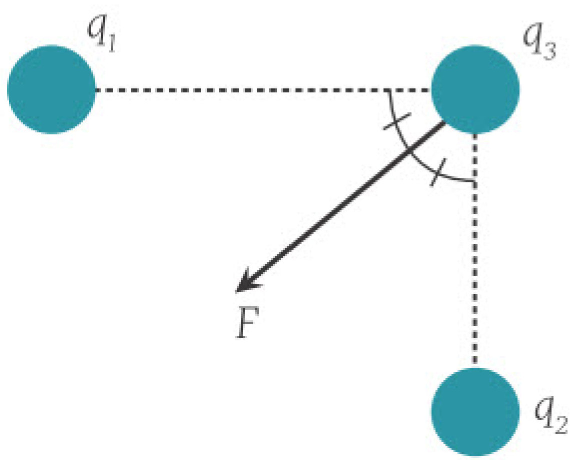
A) K : –
L : +
B) K : +
L : –
C) K : –
L : –
D) K: +
L : +
E) K : +
L : 0

3. A rod of charge –q is brought into contact with the knob of an electroscope charged to +q. Which of the following statements concerning the leaves of the electroscope is/are correct?

I. The leaves of the electroscope collapse completely.
II. The leaves of the electroscope separate further.
III. The leaves of the electroscope first collapse and then diverge again.

A) I only
B) II only
C) III only
D) I and III
E) I, II and III

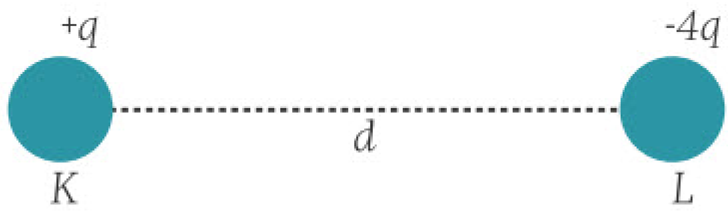
4. The resultant of the forces exerted on a charge q_3 due to charges q_1 and q_2, as shown in the figure, is F.



Which of the following statements must be true?
I. The charges q_1 and q_2 have the same sign.
II. The charges q_1 and q_3 have the opposite signs.
III. The magnitude of charge q_1 is equal to the magnitude of charge q_2.
A) I only
B) II only
C) III only
D) I and II

E) I, II and III

5. Spheres K and L of charge +q and -4q, respectively, are fixed as shown in the figure. Sphere M of charge +q remains at rest under the effects of spheres K and L.



What is the location of sphere M?

A) On the right side of K at a distance 2d
B) On the left side of K at a distance d
C) On the right side of L at a distance 2d
D) On the left side of L at a distance 3d
E) At the midpoint of K and L

6. When one of the two identical, conducting, equally charged spheres is allowed to touch the knob of positively charged electroscope X, shown in Figure-I, its leaves close a little. When the other sphere is allowed to touch the knob of electroscope Y, shown in Figure II, the leaves of the electroscope Y first collapse and then diverge.

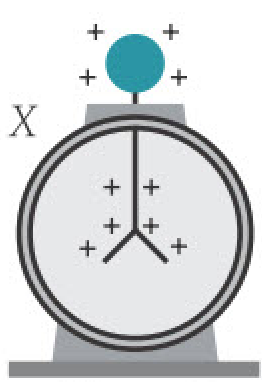


Figure-I

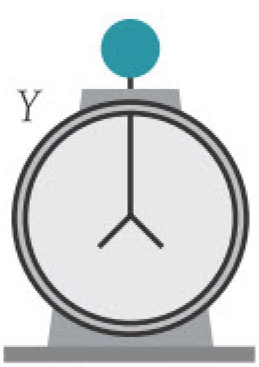


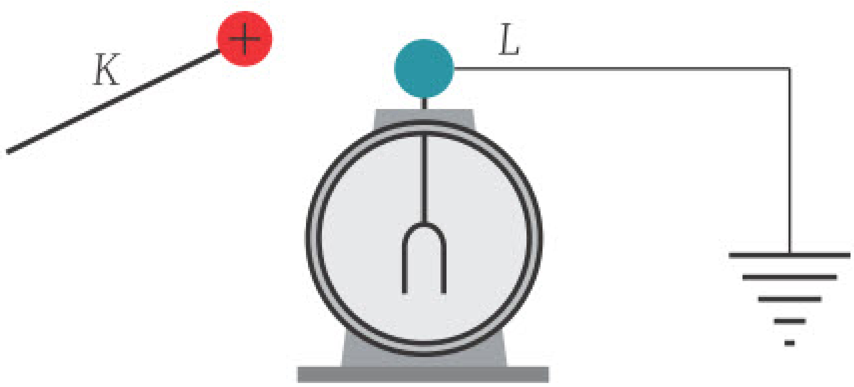
Figure-II

Which of the following statements is/are correct?
I. The spheres are negatively charged.
II. Electroscope Y is positively charged.
III. The amount of charge on electroscope X is greater than that of electroscope Y.

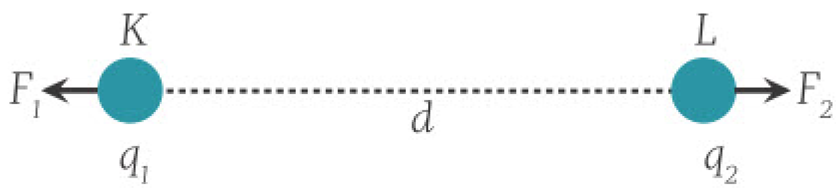
A) I only
B) II only
C) III only
D) I and III
E) I, II and III

7. A positively charged object, K, is brought near to a neutral electroscope L grounded from its knob. The connection between the electroscope L and the ground is cut and then object K is removed. Which of the following statements concerning the leaves of the electroscope is/are correct?

A) They are charged positively and move apart.
B) They are charged negatively and separate.
C) They remain neutral and do not move.
D) They are charged positively, they first separate and then collapse.
E) They are charged negatively, they first collapse and then separate



8. The forces F_1 and F_2 applied by charges q_1 and q_2 fixed at points K and L upon each other are as shown in the figure.



Which of the following statements is/are correct?
I. The magnitudes of the forces F_1 and F_2 are equal
II. The signs of the charges q_1 and q_2 are opposite
III. The signs of the charges q_1 and q_2 are the same

A) Only I
B) Only II
C) Only III
D) I and II
E) I and III

9. Three charges are fixed as shown in the figure. The force applied on charge K by charge 9q is F. What is the resultant force applied on the charge K, in terms of F?

A) –1
B) 0
C) 1
D) 3
E) 5

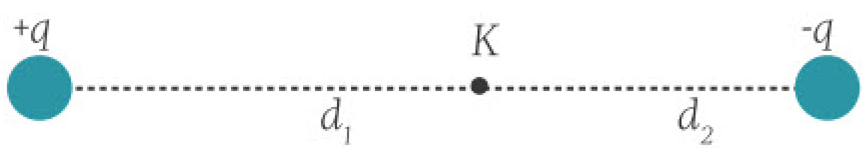
10. A positively charged object is brought into contact with a positively charged electroscope.
Which of the following statements may be correct?

I. The separation between the leaves of the electroscope increases a little more.
II. The separation between the leaves of the electroscope decreases a little.
III. The leaves of the electroscope do not move.

A) I only
B) II only
C) III only
D) I and II
E) I, II and III

Electric Potential Energy and Electric Potential

1. In order to increase the electric potential at point K, shown in the figure, which of the following operations must be carried out?

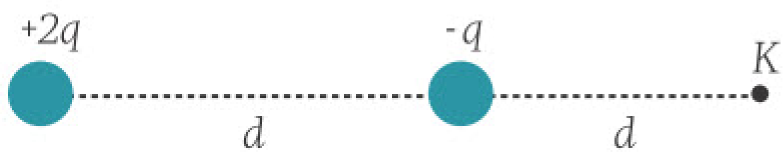


I. Decreasing the distance d_1
II. Increasing the charge +q
III. Increasing the charge –q
A) I only
B) II only
C) III only
D) I and II
E) I, II and III

2. Electric potential due to charge q_1 a distance x away from charge q_1 is equal to electric potential due to charge q_2 a distance 5x away from charge q2. What is the ratio of charges, q_1 / q_2?

A) 1/2
B) 1
C) 2
D) 5
E) 1/5

3. What is the total electric potential at point K due to the charges 2q and –q? (k: Coulomb's constant)



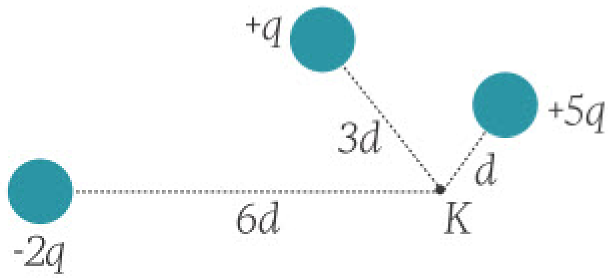
A) 0
B) kq/d

C) 2kq/d

D) – kq/d

E) -2kq/d

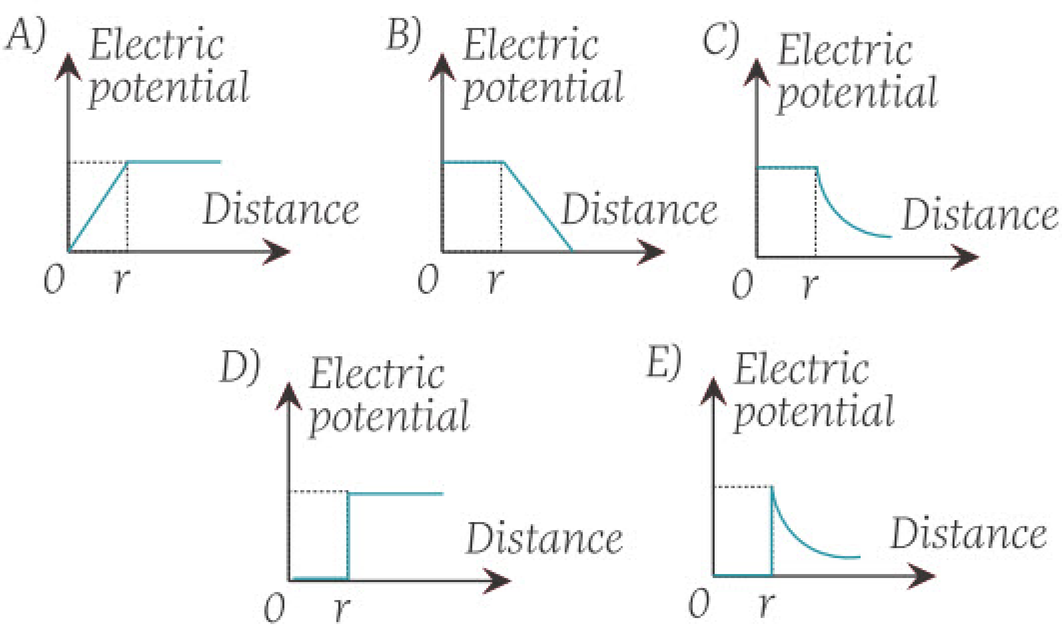
4. The charges –2q, q, and 5q are placed close to point K, as shown in the figure.



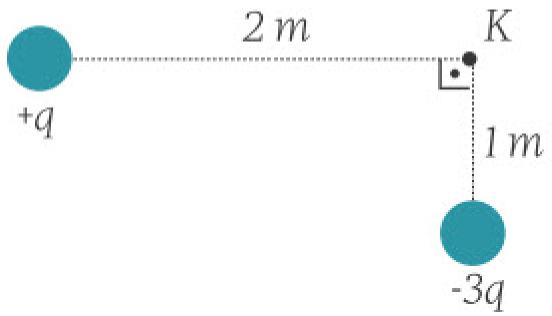
What is the electric potential at point K, in terms of kq/d? (k: Coulomb's constant)

A) 1
B) 2
C) 3
D) 4
E) 5

5. Which of the following graphs show the relationship between the electric potential of a charged conducting sphere of radius r versus distance from its centre?

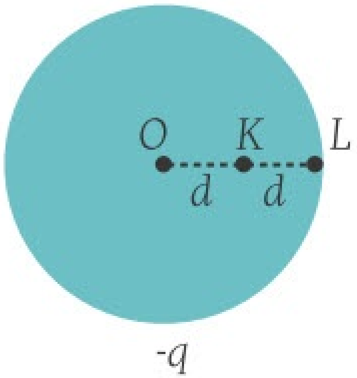


6. If the electric potential of charge q at point K is 6 V, what is the potential of charge –3q at point K, in volts?



A) –42
B) –36
C) –18
D) –12
E) –67

7. The electric potentials of a conducting sphere of charge –q at points K and L are V_K and V_L, respectively.



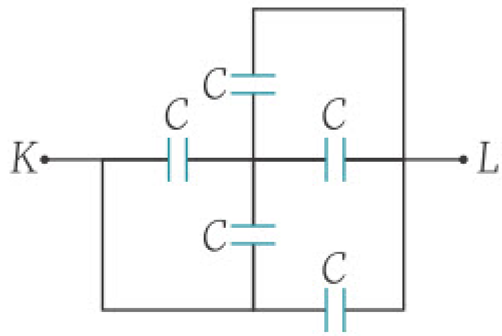
What is the ratio V_K/V_L?

A) 1/2
B) 1

C) 2
D) 3
E) 4

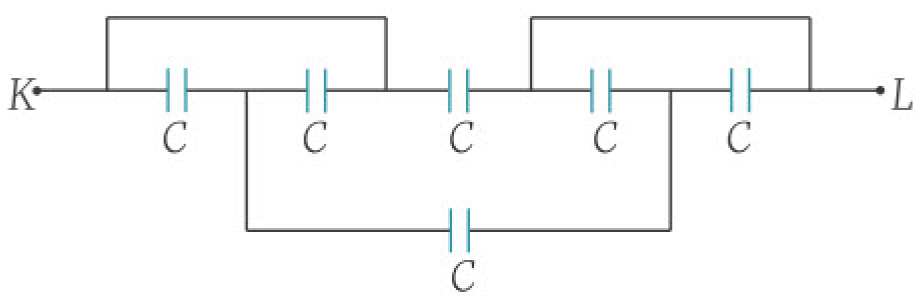
Capacitance and Capacitors

1. In the network shown in the figure, what is the equivalent capacitance between points
K and L, in terms of C?



A) 1
B) 2
C) 3
D) 4
E) 5

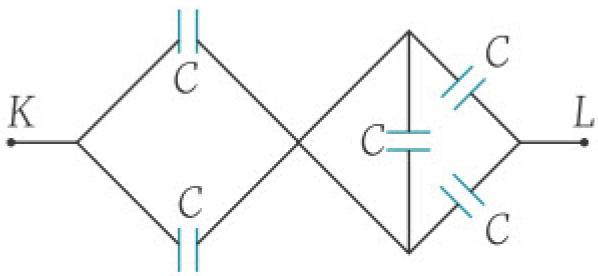
2. In the network shown in the figure, what is the equivalent capacitance between points K and L, in terms of C?



A) 2/3

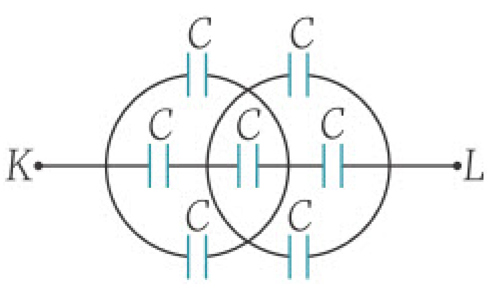
B) 3/4
C) 1
D) 4/3
E) 3/2

3. In the capacitor network constructed of identical capacitors, what is the equivalent capacitance between points K and L, in terms of C?



A) 0.5
B) 1
C) 2
D) 3
E) 5

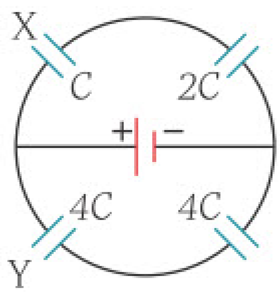
4. The network shown in the figure consists of seven identical capacitors. What is the equivalent
capacitance between points K and L, in terms of C?



A) 2/3
B) 1
C) 3/2
D) 2

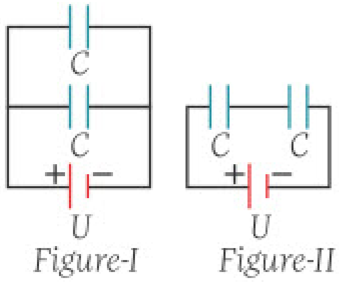
E) 3

5. In the circuit shown, the charge on capacitor X is q_X and the charge on capacitor Y is q_Y.
What is the ratio q_X/q_Y ?



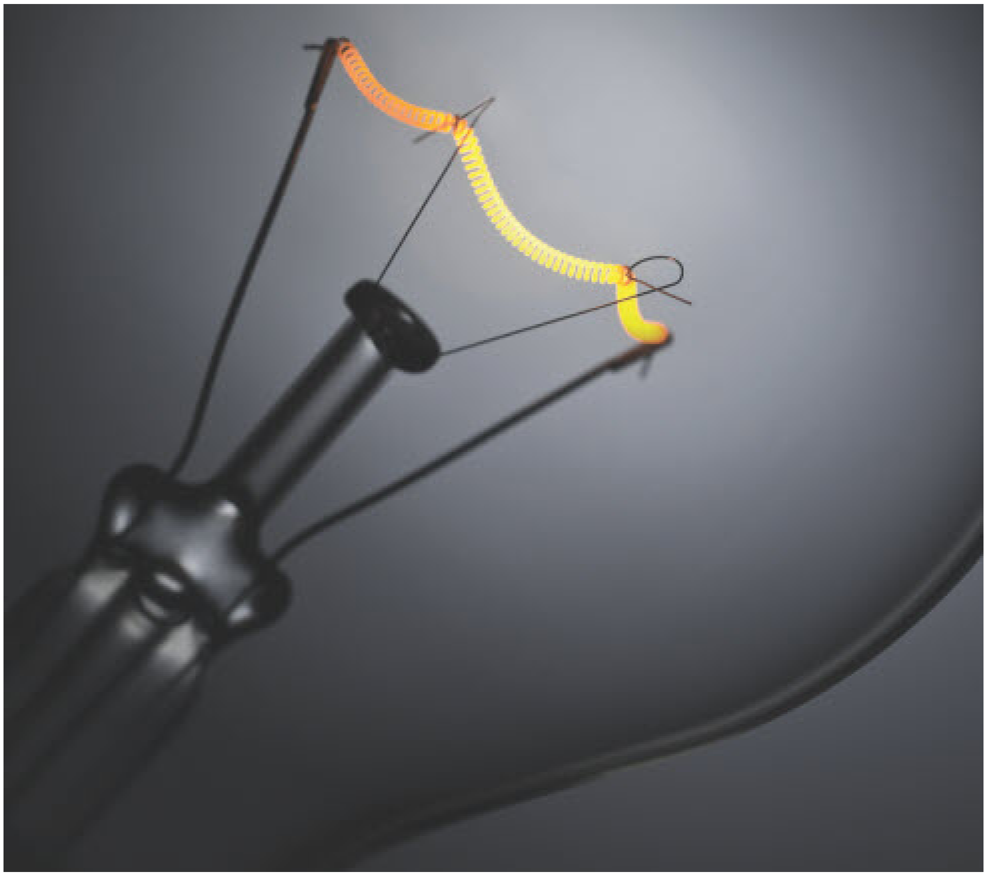
A) 1/4
B) 1/3
C) 1/2
D) 1
E) 2

6. The total energy stored in the capacitors in the circuit shown in Figure I is E_1 and the total energy stored in the capacitors shown in the circuit in Figure II is E_2. What is the ratio E_1/E_2?



A) 1

B) 2
C) 3
D) 4
E) 5



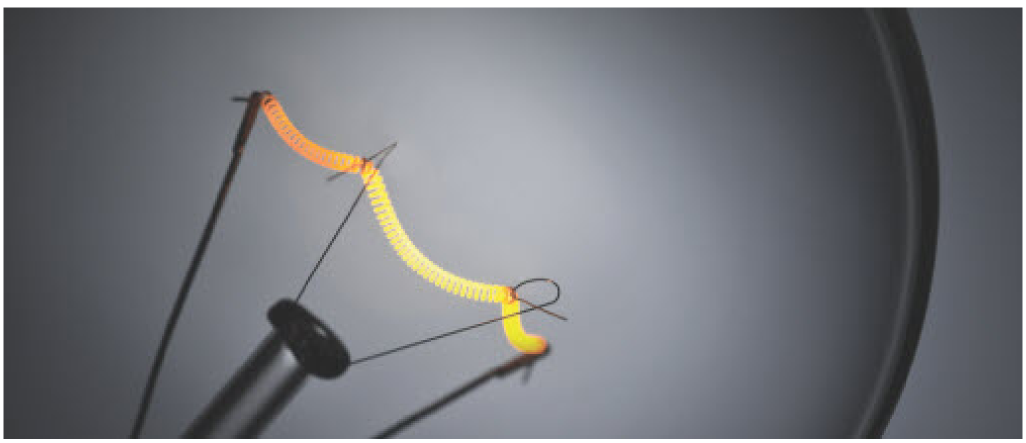
CHAPTER 11: ELECTRICITY

11.1 ELECTRIC CURRENT. OHM'S LAW FOR PART OF ELECTRIC CIRCUIT

You will

- apply Ohm's law for part of electric circuit that consists of complex combination of resistors.

Question



Why does tungsten filament become hot when light bulb is connected to electricity?

How you ever wondered how electronic devices work? Do you know from what lightning consists of? How our muscles contract? To understand these phenomena we should move deeper inside of atom. The main thing that plays role in that natural processes is flow of charges - electric current.

More precisely, electric current is defined as the net amount of charge passing through a cross-sectional area in unit time. Current is

$$I = \frac{\Delta q}{\Delta t} = \frac{Ne}{\Delta t}$$

symbolised by I, where, Δq is the amount of charge passing through a cross-sectional area in time, Δt. The SI unit of current is the Ampere (A) after the physicist Andre Ampere.

$$1\ A = 1\ \frac{C}{s}$$

For smaller units of current, milliampere, mA (1 mA = 10^{-3} A), and microampere, μA, (1 μA = 10^{-6} A) are used. The current is measured by ammeter. The symbol of an ammeter used in a circuit diagram is shown as

The charges passing through a cross-sectional area can be positive, negative or both. Since much work on electric current had been performed prior to any knowledge of what the charge carrying particles really were, the direction of current was taken to be the direction of positive charges, Figure 108.

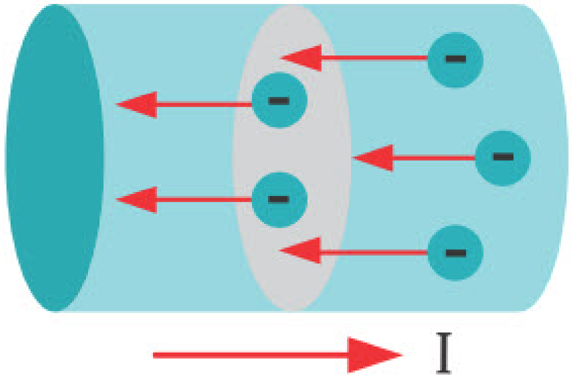


Figure 108

If we apply potential difference (voltage) V between two ends of a wire, that is, if a wire is connected between the terminals of a battery, a current I will flow through the wire, as in Figure 109.

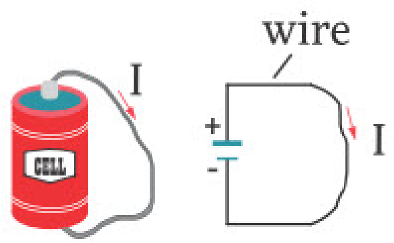


Figure 109

Ratio of potential difference to current for a conductor is known as resistance R. Resistance is degree of opposition to the flow of electrons. The relation between current, voltage, and resistance is given in Ohms' law:

$$R = \frac{V}{I}$$

If we increase potential difference V between the terminals, it increases the drift velocity υ of electrons so that current increases. Thus

$$I = neA\upsilon$$

where n is concentration of electrons, is charge of electron ($1.6.10^{-19}$ C), A is cross-sectional area of wire,υ is drift speed of electrons. Next we can introduce concept of density of current j:

$$j = \frac{I}{A} = ne\upsilon$$

Resistance R of conductor depends on cross-sectional area A of conductor, its length l and resistivity ρ of conductor, Figure 110.\

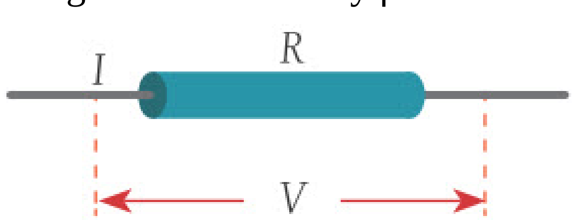


Figure 110

Formula of resistance is

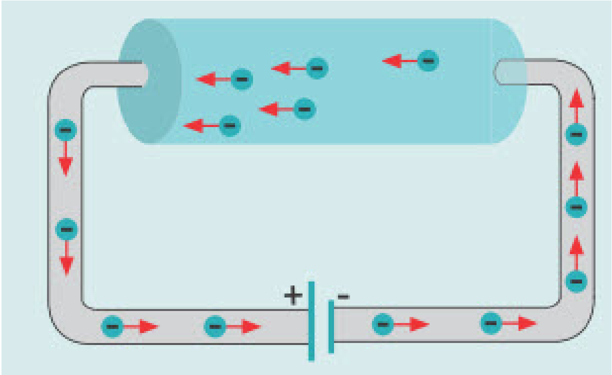
$$R = \rho \frac{l}{A}$$

Activity

Open "Phet Ohm's Law". Change the variables and observe the changes. Write down your observations.

Example

A current of 2 Ampere flows through the cross-section of a conductor for 5 sec.



Calculate:
a) The amount of charge that passes through the conductor.
b) The number of electrons that passes through the cross-section of the conductor. (Take $e=1.6 \cdot 10^{-19}$ Coulomb)

Given:

$I = 2\ A$

$t = 5\ s$

$e = 1.6 \cdot 10^{-19}\ C$

$q = ?$

$N = ?$

Formulas:

$$I = \frac{q}{t} \qquad q = Ne$$

Calculations:

$$q = It$$

$$q = 2 \cdot 5 = 10\ C$$

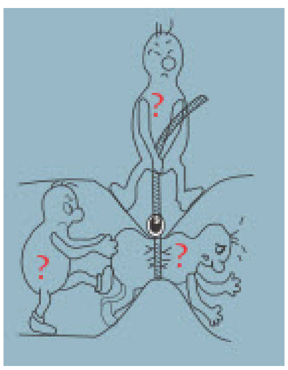
$$N = \frac{It}{e}$$

$$N = \frac{2 \cdot 5}{1.6 \cdot 10^{-19}}$$

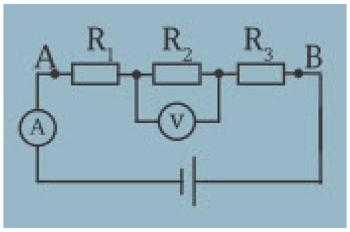
$$N = 6.25 \cdot 10^{19}$$

Literacy

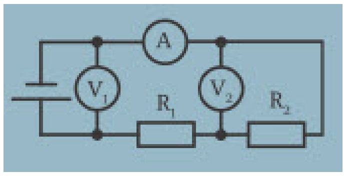
1. Which one is Volt, which one is Ampere, which one is Ohm on this caricature?



2. What is definition of “electric current”?
3. How many electrons pass through lamp of flashlight when 0.32 Ampere current passes through it in 0.1 sec?
4. Calculate current density through 0.17 mm^2 wire when 0.15 Ampere flows through it.
5. Voltmeter reading is 1.2 Volt in the electric circuit shown on the figure. R_1 is 5 Ohm, R_2 is 6 Ohm, R_3 is 12 Ohm. What is potential difference between points A and B? What is reading of ammeter?

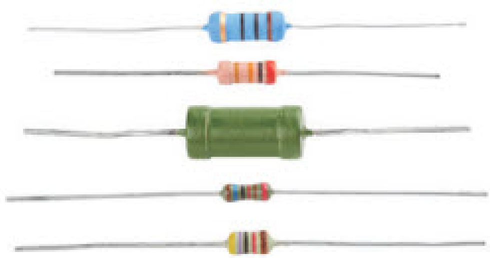


6. Voltmeter V_1 shows 12 Volt in the electric circuit shown on the figure. R_1 is 5 Ohm, R_2 is 10 Ohm. Calculate reading of ammeter and voltmeter V_2.



Research time

What is resistor made of? Why do resitors have coloured strips?

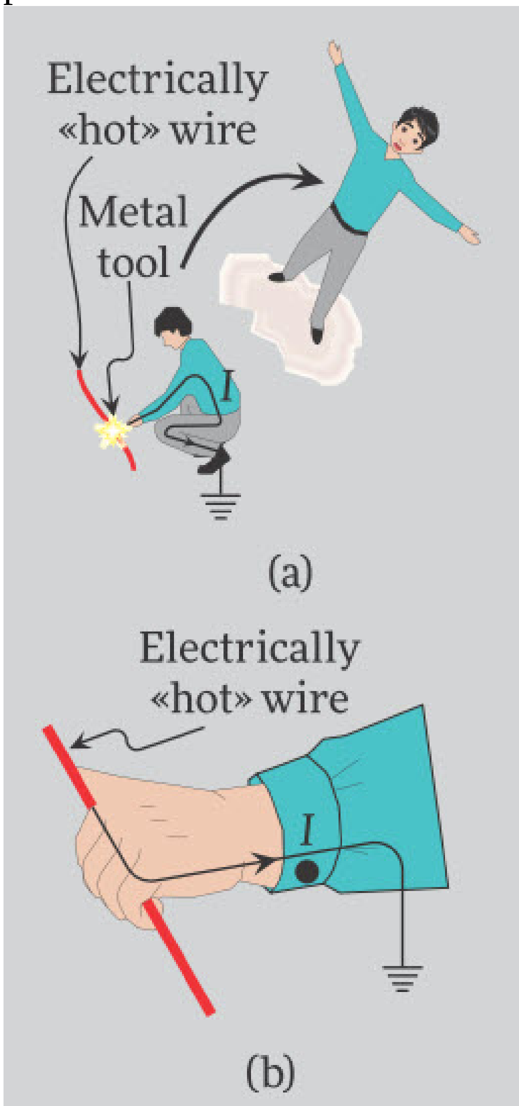


Is it true?

Voltage of lightning is 120 million Volts.

Physics in life

Never touch uninsulated wires because it is dangerous. But if you touch wire with external part of hand, you are thrown backwards. But if you touch it with internal part, you cannot let go of the wire. What is the reason of this phenomenon?

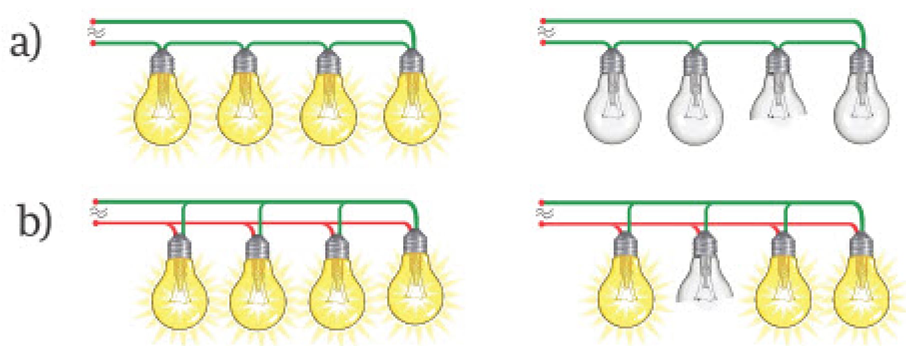


11.2 Complex combinations of resistors.

You will

- apply Ohm's law for part of electric circuit that consists of complex combination of resistors.

Question



What is difference between these combinations of light bulbs? What connection is used in your home?

A simple circuit contains a source of electrical energy, an energy consuming unit (i.e. a resistor) and wires that connects the circuit elements to each other, as shown in Figure 111.

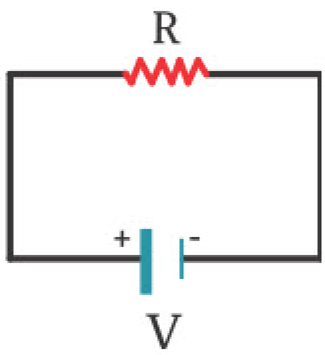


Figure 111

In order for current to flow, the circuit must be closed, that is, there must be a path from the positive to the negative terminal of the source through the circuit.

Electric circuits usually contain combinations of resistors in many configurations. This is required in order to obtain specific currents or to maintain a required potential difference across a circuit element. In this section we will examine combinations of resistors. A single resistor can always be found which would replace a combination of resistors. The value of this single resistor is called the equivalent resistance of the combination.

Series Combinations of Resistors

Let's look at the combination of resistors in Figure 112. The electrons leave the negative terminal and pass through resistors R_2 and R_1 to travel to the positive terminal of the battery. This kind of combination is called a series combination of resistors. In series combinations, we have the following characteristics in terms of potential difference, current and resistance relationships.

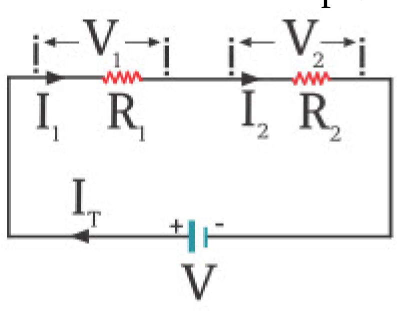


Figure 112

$$V = V_1 + V_2 + V_3 + \ldots + V$$
$$I = I_1 = I_2 = \ldots = I_n$$
$$R_{eq} = R_1 + R_2 + R_3 + \ldots + R_n$$

Parallel Combinations of Resistors

Look at the combination of resistors in Figure 113. When resistors are connected to the same two points of two different wires they are said to be connected in parallel. In Figure 113 resistors R_1 and R_2 are connected to the same points, A and B. Electrons from the negative side will arrive at point B, then separate into two different branches.

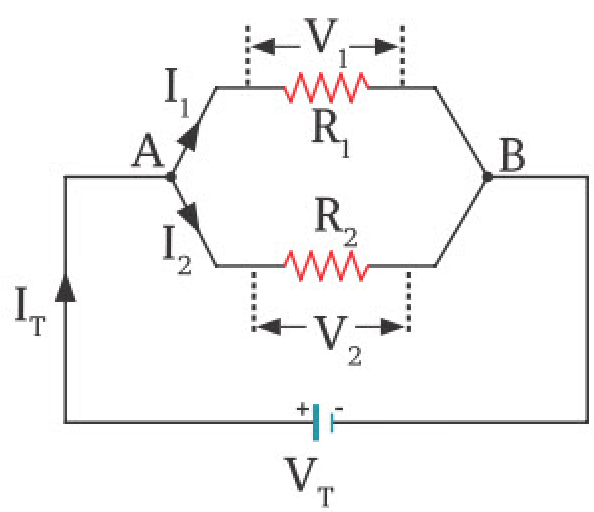


Figure 113

If R_1 is smaller than R_2 , a greater number of electrons will flow through R_1 as it has less opposition to flow of charge than R_2. Amount of charge passing through a resistor is proportional to the amount of current.

The characteristics of parallel combinations can be listed as follows in terms of V, I and R.

$$I = I_1 + I_2 + I_3 + \ldots + I_n$$

$$V = V_1 = V_2 = \ldots = V_n$$

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots + \frac{1}{R_n}$$

Complex Combinations of Resistors

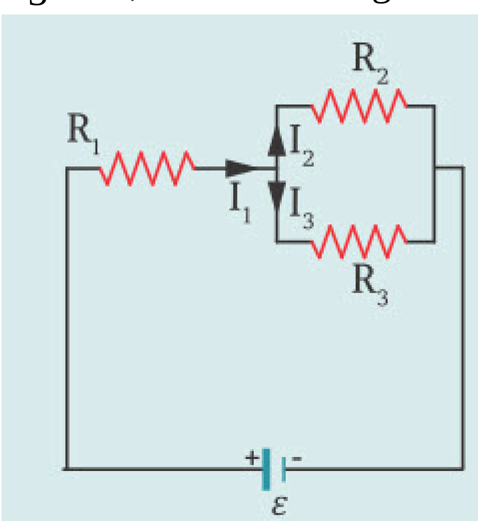
When there are both series and parallel combinations of resistors then such circuit is called complex circuit. In order to determine equivalent resistance circuit should be divided into several simple parts. Then equivalent resistance of each part should be determined. Finally equivalent resistance of complex circuit should be calculated.

Activity

Open "Phet Circuit Construction Kit". Make parallel, series and complex combination with four resistors. In which case current flows faster? Why?

Example

Determine currents I_1, I_2, I_3 and voltages V_1, V_2, V_3 . R_1=3.8 Ω, R_2=2 Ω, R_3=3 Ω, ε=50 Volt. Neglect internal resistance.



Given:	Formulas:
$R_1 = 3.8\ \Omega$	$V_2 = I_2 R_2$
$R_2 = 2\ \Omega$	$V_3 = I_3 R_3$
$R_3 = 3\ \Omega$	$V_1 = I_1 R_1$
$\mathcal{E} = 10\ V$	$V_2 = V_3$
$I_1, I_2, I_3?$	$I_1 = I_2 + I_3$
	$\varepsilon = V_1 + V_2$

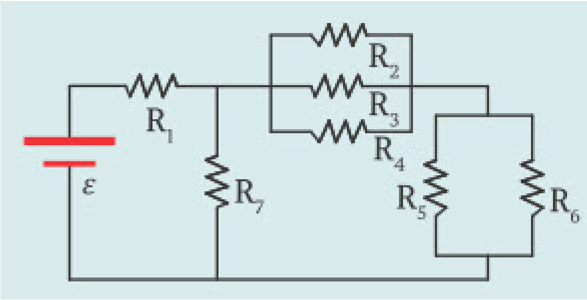
Calculations:

$$V_2 = I_2 \cdot 2$$
$$V_3 = I_3 \cdot 3$$
$$I_2 \cdot 2 = I_3 \cdot 3$$
$$I_2 = I_3 \cdot 1.5$$
$$I_1 = I_2 + I_3$$
$$I_1 = I_3 \cdot 1.5 + I_3 = I_3 \cdot 2.5$$
$$V_1 = I_1 \cdot 3.8 = I_3 \cdot 2.5 \cdot 3.8$$
$$V_1 = I_3 \cdot 9.5$$
$$\mathcal{E} = V_1 + V_2$$

$$50 = I_3 \cdot 9.5 + I_3 \cdot 3$$
$$50 = I_3 \cdot 12.5$$
$$I_3 = 4\ A$$
$$I_2 = 6\ A$$
$$I_1 = 10\ A$$
$$V_2 = 12\ V$$
$$V_3 = 12\ V$$
$$V_1 = 38\ V$$

Example

Determine currents and voltages, and fill the table. EMF is 50 Volt, neglect internal resistance.



	Resistor						
	1st	2nd	3rd	4th	5th	6th	7th
Resistance, Ohm	2.6	6	6	6	4	4	6
Current, A							
Voltage, V							

Calculations:

2nd, 3rd and 4th resistors are connected in parallel. Their equivalent resistance is 2 Ohm. 5th and 6th resistors are connected in parallel. Their equivalent resistance is 2 Ohm. These 2 Ohm and 2 Ohm are connected in series, so their equivalent resistance is 4 Ohm. This 4 Ohm and 6 Ohm are connected in parallel. Their equivalent resistance is
2.4 Ohm. 2.6 Ohm and 2.4 Ohm are connected in series, so their equivalent resistance is 5 Ohm.

	Resistor						
	1st	2nd	3rd	4th	5th	6th	7th
Resistance, Ohm	2.6	6	6	6	4	4	6
Current, A	10	2	2	2	3	3	4
Voltage, V	26	12	12	12	12	12	24

Physics in life

Complex combinations of resistors are used in motherboards to (control electric current very precisely or) to obtain definite value of current.

Is it true?

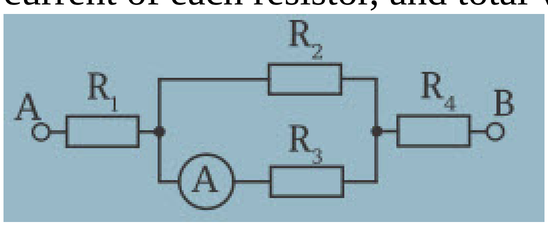
Under dry conditions, the resistance offered by the human body may be as high as 100000 Ohms.

Research time

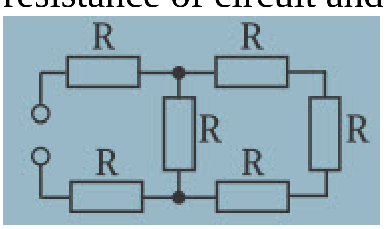
Open "Phet Circuit Construction Kit". Make the scheme of lamps of a house-room or classroom.

Literacy

1. What is definition of “Ohm’s law”?
2. Why do electrons in resistor move when it is connected to battery?
3. Ammeter in the electric circuit shown on the figure reads 2 A. R_1 is 2 Ohm, R_2 is 10 Ohm, R_3 is 15 Ohm, R_4 is 4 Ohm. Calculate voltage and current of each resistor, and total voltage of circuit.

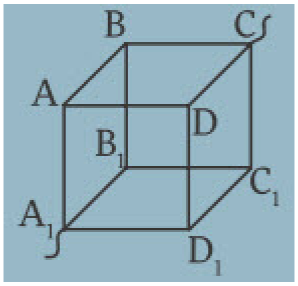


4. Electric circuit shown on the figure consists of identical R=21 Ω resistors. Voltage of 100 Volt is given to circuit. Calculate equivalent resistance of circuit and current and voltage of each resistor.

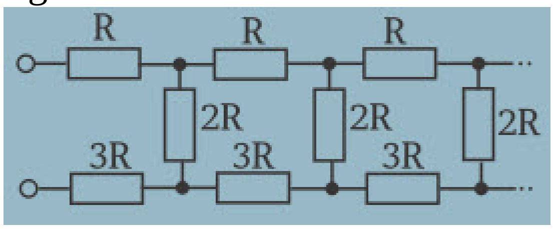


5. Electric circuit is composed of wire shaped in form of cube. 30 Volt power source is connected at points

A_1 and C. Resistance of one edge of cube is 12 Ohm. Calculate equivalent resistance and current and voltage of each edge of cube.



6. Calculate equivalent resistance of infinite ladder circuit shown on the figure. R is 10 Ohm.



11.3 Electromotive force and internal resistance

You will

- analyse relationship between electromotive force and voltage of battery during different modes of work of electric circuit (work mode, open-circuit mode, short-circuit mode).

Question

Why does light bulb stop emitting light on the second figure? What does happen if same operation is performed on the second light bulb?

A device such as a battery or generator that converts chemical or mechanical energy into electrical energy is called a source of electromotive force, symbolised by ε , Figure 114.

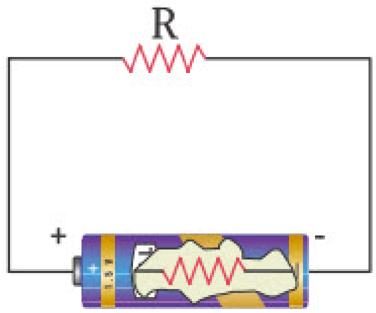


Figure 114

Electromotive force (emf) is not a force, it is the work done on each charge by a battery to move them around the circuit. Thus, emf is work done per unit charge by the source. We can write

$$emf = \frac{Work}{Charge}; \qquad \varepsilon = \frac{W}{q}$$

;

The SI unit of emf is Joule/Coulomb or the “Volt” (V).

In Figure 115, emf not only drives the current through the external resistor but it also drives the current through the battery itself. The atoms inside a power supply are resistant to the motion of electrons inside the power supply. This resistance is called internal resistance of a battery and is denoted by r.

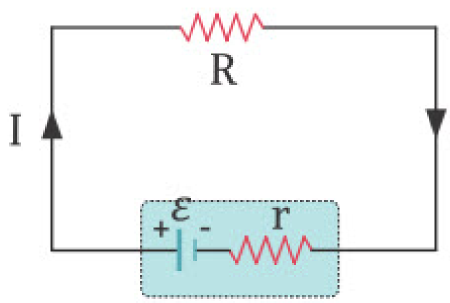


Figure 115

We can represent the relationship between potential difference across the terminals of battery V, and emf, as follows: Since energy is conserved, energy produced by the battery is completely converted into heat. For the external circuit V = IR, thus

$$W = \varepsilon I t$$

$$W_{electrical} = W_{heat}$$

$$\varepsilon I t = I^2 (R + r) t$$

$$\varepsilon = I(R + r)$$

$$I = \frac{\varepsilon}{R + r}$$

Ordinary batteries run down with age, not only because their emf decreases, but because their internal resistance increases. Thus, the current they are able to supply decreases.

There are three modes of electric circuit: work mode, open-circuit mode, short-circuit mode.

Work mode: $\varepsilon = I(R+r)$, Figure 116. In this mode circuit works in its full mode. Circuit is not broken or etc.

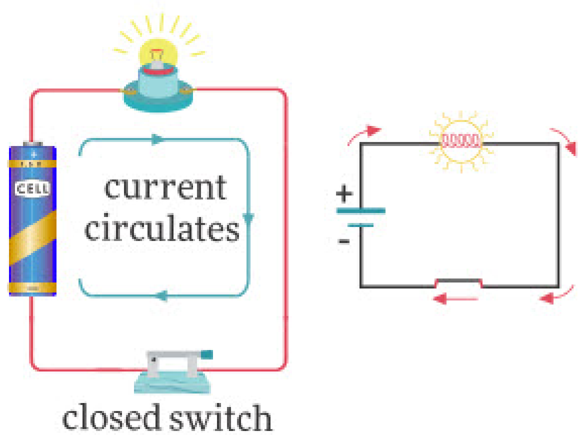


Figure 116

Formula of work mode is

$$\varepsilon = I(R + r)$$

Open-circuit mode: $\varepsilon = V$, Figure 117. In this mode circuit is not closed, current does not pass through it because air resistance is infinite.

$$R \to \infty \qquad I = 0 \qquad V = \varepsilon$$

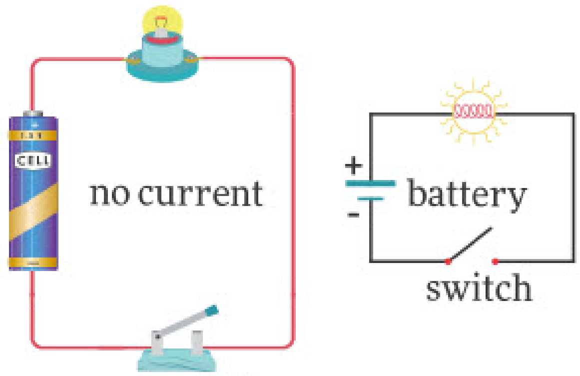


Figure 117

Short-circuit mode: ε= Ir. In this mode current does not pass through resistance R because it has shorter way to get back to battery. Practically it is dangerous to come to this mode.

$$R = 0 \qquad I = \frac{\varepsilon}{r}$$

When a fault, such as a short circuit, occurs in an electrical device, very high current flows through, Figure 118. This current overheats the cables and may start a fire, Figure 119.

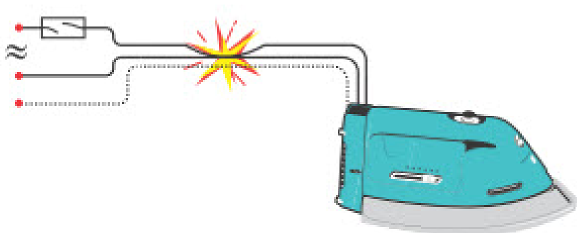


Figure 118

Figure 119

Example

A new battery has an emf of 1.5 V. When a wire of negligible resistance is connected between the terminals of the battery, a current of 5 A is produced. Find the internal resistance of the battery.

Given:

$\mathcal{E} = 1.5\ V$

$R = 0$ (negligible resistance)

$I = 5\ A$

Formulas:

$$I = \frac{\mathcal{E}}{R + r}$$

Calculations:

$$r = \frac{\mathcal{E} - IR}{I}$$

$$r = \frac{1.5 - 5 \cdot 0}{5}$$

$$r = 0.3\ \Omega$$

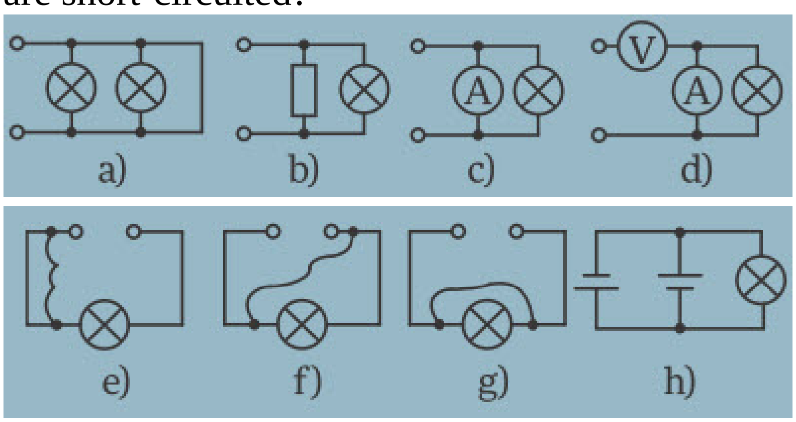
Activity

Draw a 10 cm · 10 cm box. Divide it into 4 boxes. Into the first, write the word “Short-circuit”. Into the second, write your own definition. Into the third, draw a picture that resembles the word. Into the fourth, write a translation of the word in your native language.

Word: Short-circuit	Your own definition:
Picture:	Translation:

Literacy

1. What is definition of “electromotive force”? What is unit of electromotive force?
2. Why do batteries become hot when current flows through them?
3. Find mistakes in the electrical circuits shown on the figure. Which circuits are short-circuited?



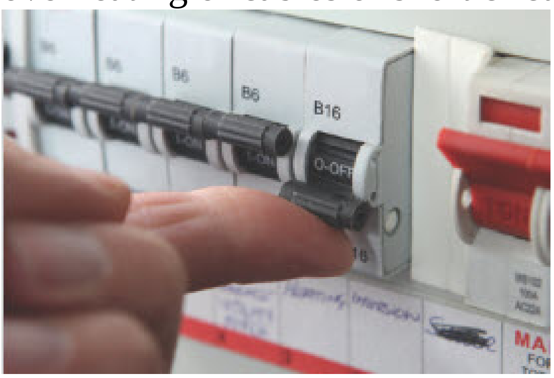
4. Battery that has EMF of 1.5 Volt and internal resistance of 0.5 Ohm is short-circuited. Calculate current during short circuit.
5. Calculate internal resistance of battery that has EMF of 1.2 Volt if 0.2 Ampere current flows through external resistance of 5 Ohm.
6. Current of 0.5 Ampere flows through external resistance of 2 Ohm that is connected to battery of 1.1 Volt EMF. What is short-circuit current?

Research time

Open "Phet Circuit Construction Kit". Find open-circuit voltage of a battery. Make short circuit.

Physics in life

Circuit breakers or fuse boxes are devices that are used to prevent overheating of cables or short circuit.



Is it true?

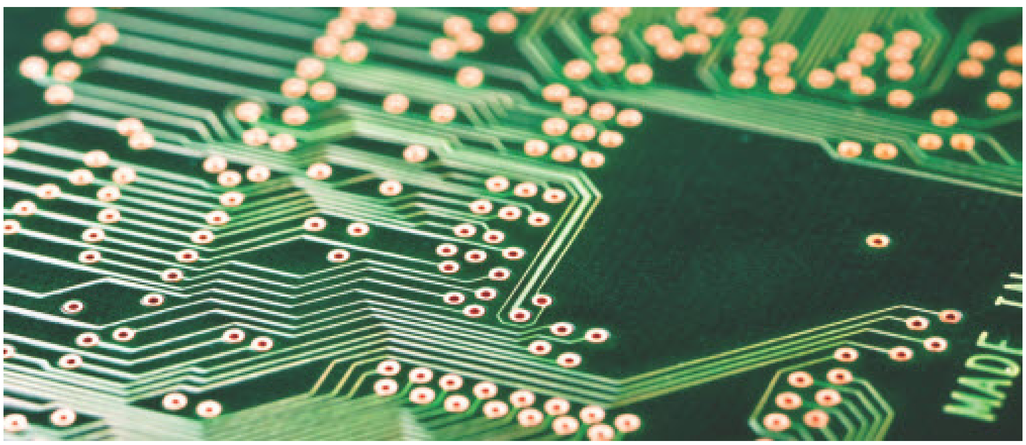
Electromotive force of batteries is always equal to potential difference of them.

11.4 Kirchhoff's circuit laws

You will

- apply Kirchhoff's circuit laws to complex electric circuits.

Question



What is this? Why are there many tracks on this green board? Where is it used?

There are circuits that cannot be reduced to simple series and parallel circuits, thus Ohm’s Law cannot be used. One such circuit is shown in Figure 120. Gustav Robert Kirchhoff (1824 - 1887) produced a set of rules which offer a general method to analyze electric circuits. Applying Kirhhoff’s rules we can find the parameters of these circuits.

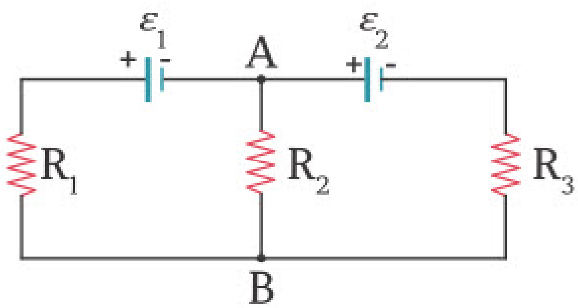


Figure 120

a. Kirchhoff's First Rule

The sum of the currents flowing into a junction (any point that joins three or more conductors in a circuit) is equal to the sum of the currents leaving that junction. In Figure 121 the points A and B are junctions. The currents entering either junction, must be equal to the currents leaving the junction so we can write

$$I = I_2 + I_1$$

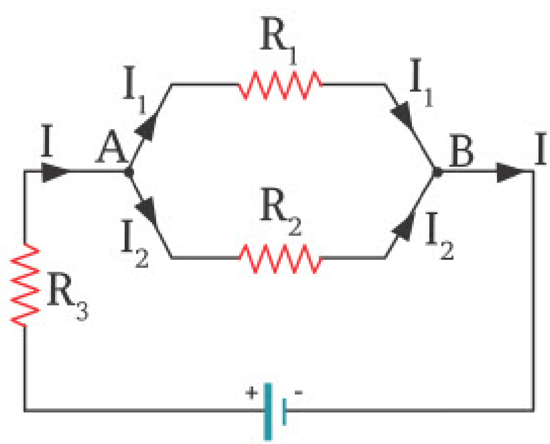


Figure 121

This rule comes from the law of conservation of electric charge. The latter states that electric charge entering the junction cannot be created or destroyed.

b. Kirchhoff's Second Rule

The second rule is applied to any closed path made by the conductors of the circuits. The closed path is called a loop. Kirchhoff's second rule states:

The algebraic sum of the emf's and the potential differences around a closed loop is zero.

$$\Sigma\varepsilon + \Sigma IR = 0$$

The second law comes from the law of conservation of energy. The energy given to electrons to move along a path is dissipated by the resistors as heat. In applying Kirchhoff's Rules, the following rules should be noted:

1. Select a direction for current and show it on each branch of the circuit. The direction can be chosen arbitrarily. If the current is in the opposite direction, the result will have a negative sign in the answer.
2. Apply the first rule paying attention to the directions of currents.
3. For each loop draw a circular arrow indicating the direction (clockwise or anti-clockwise) which describes the path you'll follow while applying the second rule.
4. Apply the second rule. However, while applying the second rule, for a resistor the sign of potential drop (IR) is negative if the direction of the loop and direction of the current are the same, Figure 122a. The sign of potential drop (IR) is positive if the direction of the loop and the direction of the current are opposite, Figure 122b. For a battery the sign of potential drop is positive if the direction of the loop is moving from the negative to the positive terminal of the battery, Figure 123a. It is negative if the direction of the loop is moving from the positive to the negative terminal of the battery, Figure 123b.

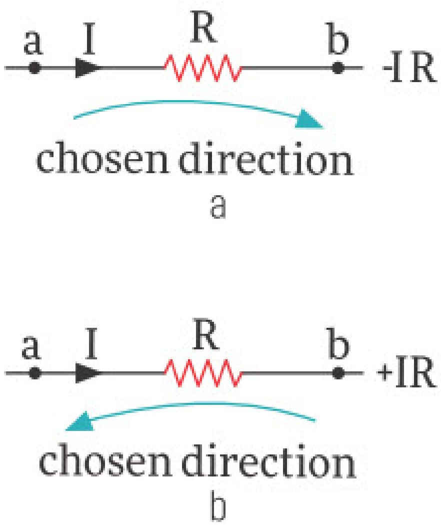


Figure 122

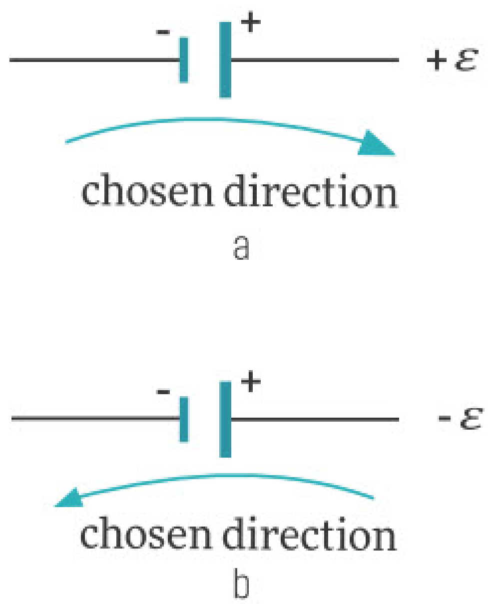
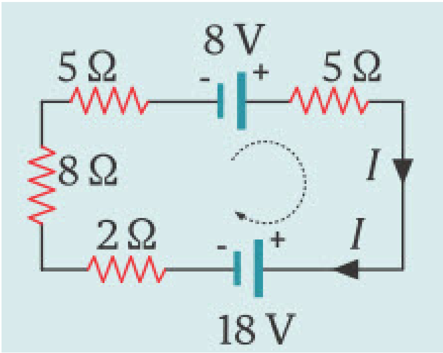


Figure 123

Example

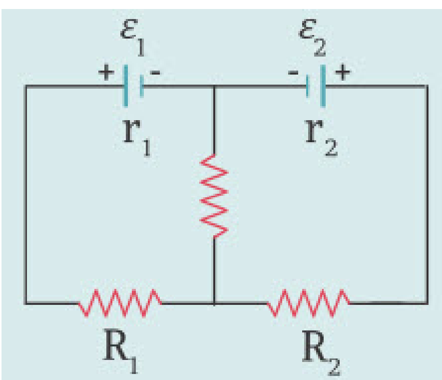
Consider the circuit in the figure. What is the magnitude and direction of the current in the circuit?

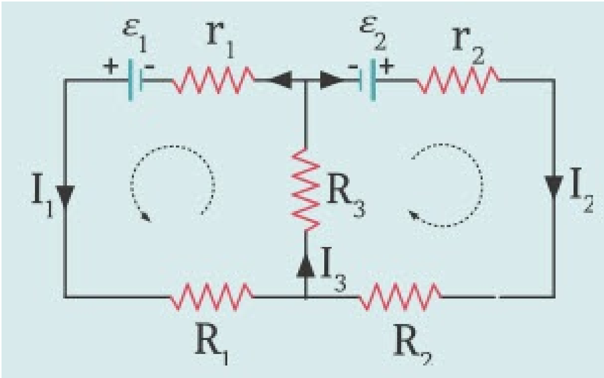


Given:	Calculations:
$\varepsilon_1 = 8\,V$	$\Sigma\varepsilon + \Sigma IR = 0$
$\varepsilon_2 = 18\,V$	$\Sigma\varepsilon = \varepsilon_1 + \varepsilon_2$
$R_1 = 2\,\Omega$	Let us choose clockwise direction for the loop.
$R_2 = 8\,\Omega$	$\Sigma\varepsilon = -18 + 8 = -10$
$R_3 = 5\,\Omega$	$\Sigma IR = IR_1 + IR_2 + IR_3 + IR_4$
$R_4 = 5\,\Omega$	$\Sigma IR = -2I - 8I - 5I - 5I = -20I$
$I = ?\ A$	$-10 - 20I = 0$
	$I = -0.5\,A$
Formulas:	Discussion:
$I_1 = I_2 + I_3$	When sign of current is minus that means current is opposite to direction of loop.
$\Sigma\varepsilon + \Sigma IR = 0$	

Example

Find the currents flowing through the resistors R_1=4 Ω,R_2=6 Ω ,R_3=4 Ω. EMF are ε_1=22 V and ε_1=19 V . Internal resistances are r_1=1 Ω and r_2=1 Ω.





Given:

$\varepsilon_1 = 22\,V$ $\quad r_1 = 1\,\Omega$

$\varepsilon_2 = 19\,V$ $\quad r_2 = 1\,\Omega$

$R_1 = 4\,\Omega$ $\quad I_1 = ?$

$R_2 = 6\,\Omega$ $\quad I_2 = ?$

$R_3 = 4\,\Omega$ $\quad I_3 = ?$

Formulas:

$I_3 = I_2 + I_1$

$\Sigma\varepsilon + \Sigma IR = 0$

Calculations:

Left loop:

$\Sigma\varepsilon + \Sigma IR = 0$

$\Sigma\varepsilon = \varepsilon_1 = 22$

$\Sigma IR = I_1 r_1 + I_1 R_1 + I_3 R_3$

$\Sigma IR = -I_1 - 4I_1 - 4I_3$

$22 = 5I_1 + 4I_3$

Right loop:

$$\Sigma\varepsilon + \Sigma IR = 0$$

$$\Sigma\varepsilon = \varepsilon_2 = 19$$

$$\Sigma IR = I_2 r_2 + I_2 R_2 + I_3 R_3$$

$$\Sigma IR = -I_2 - 6I_2 - 4I_3$$

$$19 = 7I_2 + 4I_3$$

Junction:

$$I_3 = I_2 + I_1$$

$$22 = 5I_1 + 4(I_2 + I_1)$$

$$22 = 9I_1 + 4I_2$$

$$19 = 7I_2 + 4(I_2 + I_1)$$

$$19 = 11I_2 + 4I_1$$

$$I_1 = \frac{22 - 4I_2}{9}$$

$$I_1 = \frac{19 - 11I_2}{4}$$

$$\frac{22 - 4I_2}{9} = \frac{19 - 11I_2}{4}$$

$$88 - 16I_2 = 171 - 99I_2$$

$$83I_2 = 83$$

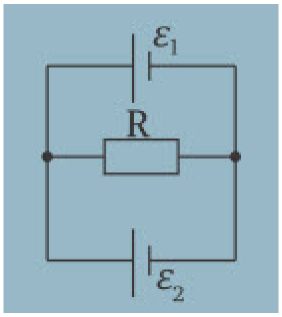
$$I_2 = 1\ A$$

$$I_1 = \frac{22 - 4I_2}{9} = \frac{22 - 4}{9} = 2\ A$$

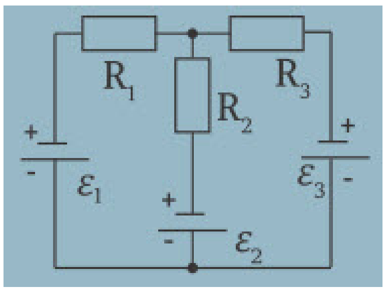
$$I_3 = I_2 + I_1 = 3\ A$$

Literacy

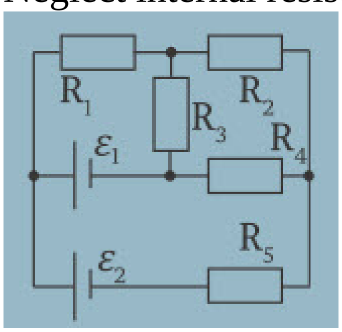
1. What is definition of Kirchhoff's first rule? What is its meaning?
2. What is definition of Kirchhoff's second rule? What is its meaning?
3. In the electric circuit shown in the figure: ε_1=2 V, ε_2=1 V, R=0.5 Ω, internal resistances are r_1=r_2=1 Ω. Calculate current through R.



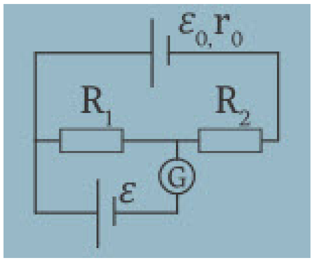
4. Calculate current in all branches of electric circuit. ε_1= 2 V, ε_2= 4 V, ε_3= 6 V,R_1= 4 Ω, R_2= 6 Ω, R_3= 8 Ω, r_1= 0.5 Ω, r_2= 1 Ω, r_3= 1.5 Ω.



5. In the electric circuit shown in the figure: ε_1=65 Volt, ε_2=39 Volt, R_1=20 Ω, R_2=R_3=R_4=R_5=10 Ω. Calculate currents in all branches of circuit. Neglect internal resistances.



6. Calculate ε of battery shown on the electric circuit. Parameters of circuit elements are ε_0=1.5 Volt, r_0=1.5 Ω, R_1=4 Ω, R_2=4.5 Ω. Galvanometer detects no current.



11.5 Work and power of electric current. Joule–Lenz law. Efficiency of source of current

You will

- apply formulas of electric work, electric power and efficiency of voltage source for problem solving.

Question

Which light bulb does consume more money: incandescent light bulb, fluorescent light bulb, or LED light bulb? Why?

Work

There are a lot of electrical heating elements such as iron, heaters, electric stove - all of them work on same principle - using motion of charges to produce heat energy.

Consider the simple circuit given in Figure 124. The battery produces an electric field along the wire, so electrons in the electric field transfer their energy to the molecules of the conductor by collisions with the atoms of the conductor. Since the resistance of wires is negligible compared to the resistance of a resistor component, the energy produced by the battery is converted into heat by the resistor alone. Work done to carry charges from one terminal to another terminal of a battery under a potential difference of V, is

$$W = \frac{V^2}{R}t = I^2Rt = IVt$$

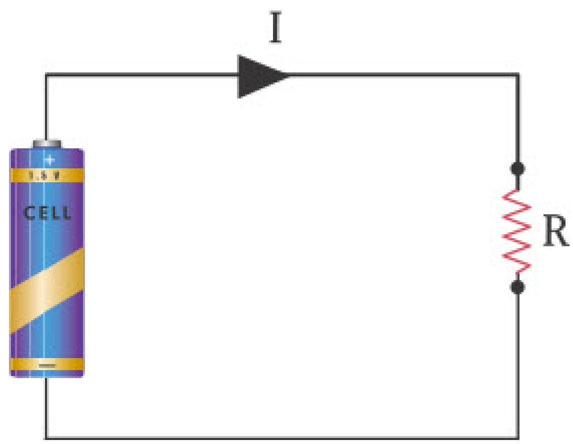


Figure 124

The last expression is called Joule's Law. Which states that, electrical energy produced by the battery is converted into heat by resistor R.

The SI unit of electrical work is the Joule (J).

Power

The electrical energy dissipated in a resistor per unit time is called the power dissipated by the resistor. Hence, power dissipated by the resistor is given as

$$Power = \frac{work}{time}$$

$$P = \frac{V^2}{R} = I^2R = IV$$

The SI unit of power is the Watt, W.

1 W = 1 J/s or 1 J = 1 V·A

In electric bills, a more convenient unit of electrical energy is used called the kilowatt-hour (kWh). In kWh, the unit of power is the kilowatt (kW) and the unit of time is the hour (h).

Since 1 kW = 10^3 W then

1 kWh = (10^3 W) (3600 s) = $3.6.10^6$ J.

Note that, the brightness of light bulbs is directly proportional to the power delivered by their resistors. If the lamps are similar then the lamps with greater currents are brighter.

Efficiency

The efficiency indicates how much of the energy given to a device is returned as useful energy. Formula of efficiency is

$$\eta = \frac{I^2R}{\varepsilon I} = \frac{V}{\varepsilon} = \frac{R}{R+r}$$

Example

An electric heater of resistance 100 Ohm is connected to a source of 220 Volt.

a) Find the current passing through the heater.
b) Find the power of the heater.
c) Find the electric energy dissipated in 10 min.

Given:	Formulas:
$R = 100\ \Omega$	$V = IR$
$V = 220\ V$	$P = \frac{V^2}{R}$
$t = 10\ min = 600\ s$	$W = \frac{V^2}{R}t$
$I = ?$	
$P = ?$	
$W = ?$	

Calculations:

a) $V = IR$

$220 = I \cdot 100$

$I = 2.2\ A$

b) $P = \dfrac{V^2}{R} = \dfrac{220^2}{100} = 484\ W$

c) $W = \dfrac{V^2}{R}t = \dfrac{220^2}{100} \cdot 600 = 290400\ J$

Activity

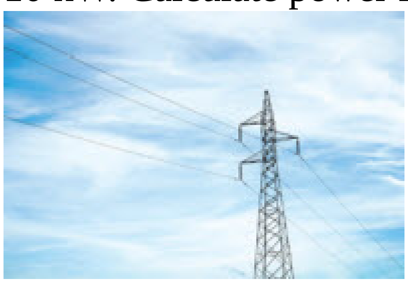
Draw a scheme of lamps in your class and find the power dissipated in each of them.

Literacy

1. What if all electrical devices in the world stop working? How would your life change? Write short essay answering these questions.
2. How does electricity change into heat, for example, in electric kettle? Answer by using such concepts as molecule, atom, proton, neutron, electron.
3. Duration of lightning is about 0.001 sec, voltage of lightning is 10^9 V, current of lightning is $2{\cdot}10^4$ Ampere. Calculate “price” of lightning. Assume 1 kWh costs 20 tenge.

4. What is work done by air fan in 30 sec if it consumes 0.1 A at 220 V?

5. Lead wire of 1 m length is connected to 10 V power source. What is the minimum time needed for melting of wire? Wire is at 20 °C initially. Use tables to find density, specific heat capacity, resistivity of lead and melting point .
6. Power is transmitted from 500 V generator to consumer who is 2.5 km away through copper wires that have diameter of 1.5 cm. Consumer power is
10 kW. Calculate power loss in wires.



Research time

Why do we use energy saving light bulbs? What is the difference between energy saving light bulb and normal bulb?

Physics in life

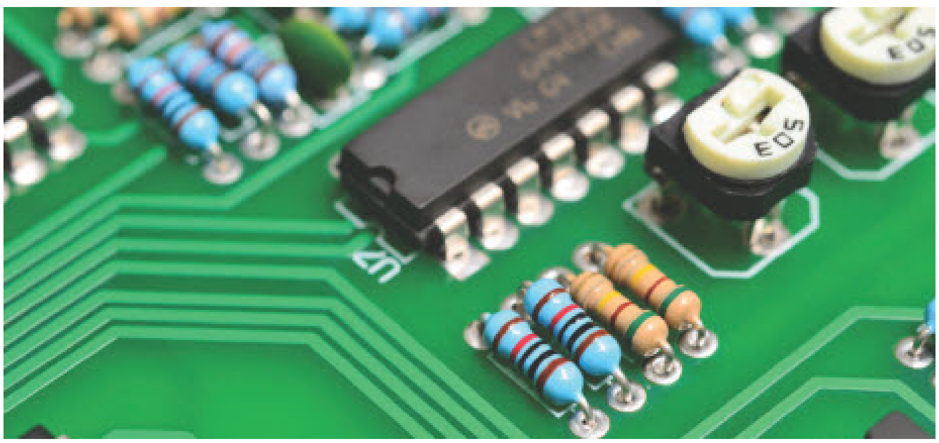
Electric power is distributed over large distances at high voltage 330000 Volts. Why such high value is used?

11.6 Problem Solving

You will

- apply formulas of electric work, electric power and efficiency of voltage source for problem solving.

Question



Why are there coloured strips on some of the elements of Printed Circuit Board (PCB)? What is the name of these elements?

Example

A 4 Ω resistor is connected across a battery. The current through the circuit is measured as 2 A. The internal resistance of the battery is 1 Ω. Find the emf of the battery.

Given:	Formulas:	Calculations:
$R = 4\,\Omega$	$I = \dfrac{\mathcal{E}}{R + r}$	$\mathcal{E} = I(R + r)$
$I = 2\,A$		$\mathcal{E} = 2 \cdot (4 + 1)$
$r = 1\,\Omega$		$\mathcal{E} = 10\,V$
$\mathcal{E} = ?$		

Example

EMF of a battery is 15 Volt. The internal resistance of the battery is 1 Ohm. An external resistance of 24 Ohm is connected to battery. Calculate the power dissipated by the external resistor, power dissipated by the internal resistor, and efficiency of battery.

Given:

$\mathcal{E} = 15\ V$
$r = 1\ \Omega$
$R = 24\ \Omega$
$P_R = ?$
$P_r = ?$
$\eta = ?$

Formulas:

$$I = \frac{\mathcal{E}}{R+r} \quad P_R = I^2 R \quad P_r = I^2 r \quad \eta = \frac{R}{R+r}$$

Calculations:

$$I = \frac{15}{24+1} = 0.6\ A$$

$$P_R = 0.6^2 \cdot 24 = 8.64\ W$$

$$P_r = 0.6^2 \cdot 1 = 0.36\ W$$

$$\eta = \frac{24}{24+1} = 0.96 = 96\%$$

Question

Why does battery heat up, swell and explode?

Activity

Open "Phet Circuit Construction Kit". Construct the simple circuit. Now reverse the terminals of batteries. What changes? Analyze and write your observations.

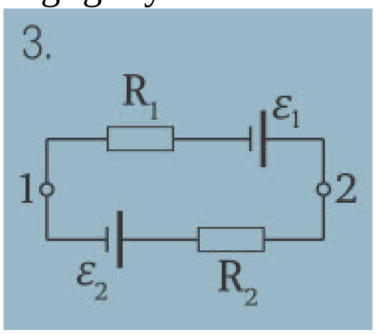
Literacy

1. What is definition of “electrical power”?
2. There are two electric irons, 800 W iron and 2000 W iron. Which one is better, why? Which one is more expensive, why?
3. Light bulb is connected to battery that has 10 V EMF. Voltage on light bulb is 8 V. Calculate efficiency of battery.
4. Resistor of 18 Ohm is connected to battery. Then 63 Ohm resistor is connected in series. As a result efficiency is doubled. Calculate internal resistance of battery.
5. Battery of 2.2 V EMF and 1 Ohm internal resistance is short circuited by 30.3 gram copper wire. Calculate final temperature of copper wire after 5 minutes if initial temperature of wire is 25 °C. Use tables to find resistivity and specific heat capacity of copper.
6. Electric circuit consists of 30 V EMF and 4 Ohm internal resistance battery and rheostat that has range from 0 Ohm to 10 Ohm. Plot P(I) graph, where P is power released on rheostat and I is current. What is current I_0 when power is maximum? What is maximum power? Plot η(I) graph, where η is efficiency of battery. Explain both graphs. Use table given below.

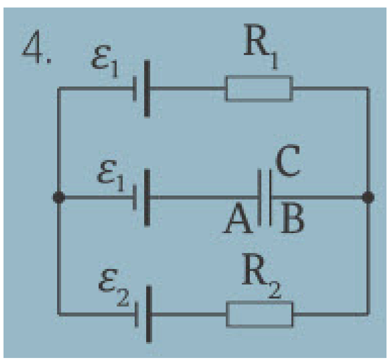
EMF (Volt)	30	30	30	30	30	30	30	30	30	30	30
r (Ohm)	4	4	4	4	4	4	4	4	4	4	4
R (Ohm)	0	1	2	3	4	5	6	7	8	9	10
I (Ampere)											
P (Watt)											
Efficiency (%)											

Literacy

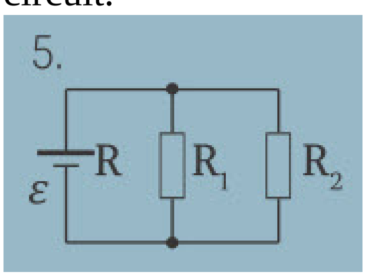
1. What is difference between Ohm’s law and Kirchhoff’s rules?
2. What do you use when there several batteries in complex circuit: Ohm’s law or Kirchhoff’s rules?
3. Calculate potential difference between points 1 and 2 and current in circuit if R_1=10 Ω, R_2=20 Ω, ε_1=5 Volt, ε_2=2 Volt, internal resistances are negligibly small.



4. Calculate voltage on capacitor if R_1=10 Ω, R_2=20 Ω, ε_1=1 Volt, ε_2=2.5 Volt. Internal resistances are negligibly small.

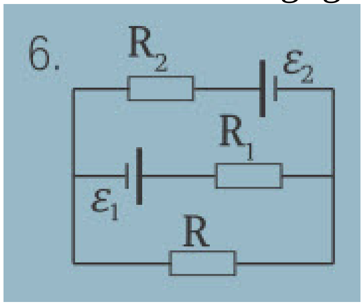


5. In the circuit shown on the figure ε=5 Volt, R_1=4 Ω, R_2=6 Ω, internal resistance of battery is R=0.1 Ω. Calculate currents in all branches of electric circuit.



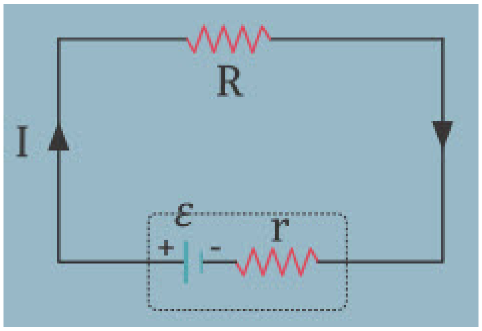
6. Calculate current through resistor R if parameters of circuit elements are given as ε_1=1.5 Volt, ε_2=3.7 Volt, R_1=10 Ω, R_2=20 Ω, R=5 Ω. Internal

resistances are negligibly small.



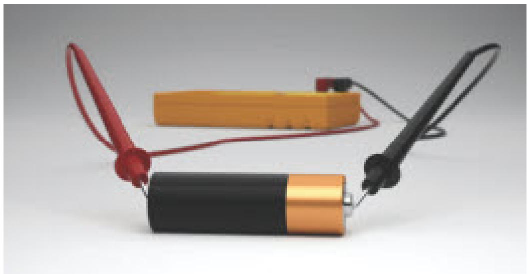
Literacy

1. What is “short circuit”? Why does short-circuit happen? What can you do to prevent short circuit?
2. Why do batteries (regular batteries, phone batteries, car batteries) explode? What can you do to prevent explosions?
3. Battery of 6 V EMF is connected to 11.5 Ohm external resistance. Calculate current, voltage between the terminals of the battery and voltage drop in battery if internal resistance is known to be 0.5 Ohm.
4. Rheostat of 5 Ohm resistance is connected to battery of 12 V EMF and 1 Ohm internal resistance. Calculate current in circuit and voltage between the terminals of the battery.
5. Light bulb is connected to battery of 4.5 V EMF. Voltage and current in light bulb are 4 V and 0.25 A. What is internal resistance of battery?
6. EMF of battery is 3.7 V, internal resistance of battery is 1.5 Ohm. External resistance of 11.7 Ohm is connected to battery. Calculate voltage between the terminals of the battery.



Activity

Connect multimeter or voltmeter to the battery and determine its internal resistance.



Research time

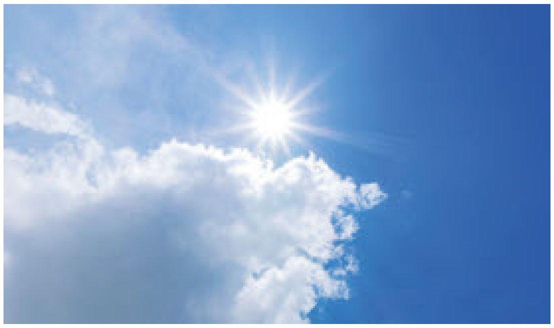
What is piezoelectricity? How and where it can be used?

Physics in life

A fuse has a metal strip with a low melting point that, when overheated by an excessive current, permanently breaks the connection of a circuit to a voltage source.

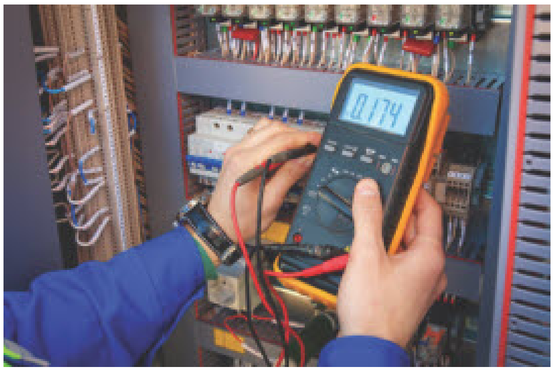
Physics in life

The Sun is 99.86% of the total mass of the Solar system and has power of four-hundred septillion watts! That's 400 trillion-trillion watts (or $4 \cdot 10^{26}$ Watts).



Is it true?

Multimeter is a device for measuring resistance.



LAB WORK #7

Title:

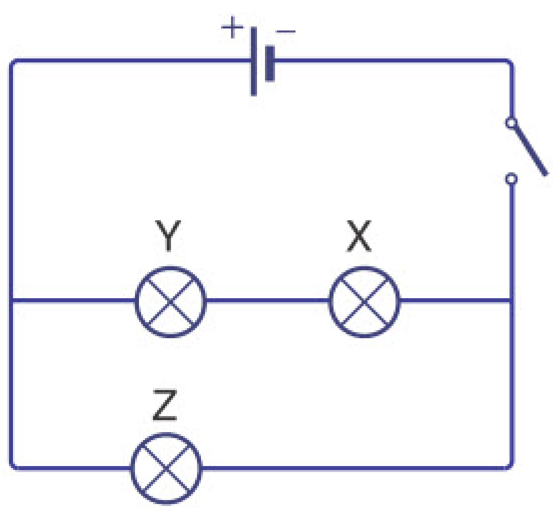
Complex combinations of resistors

You will

- investigate complex combination of resistors.

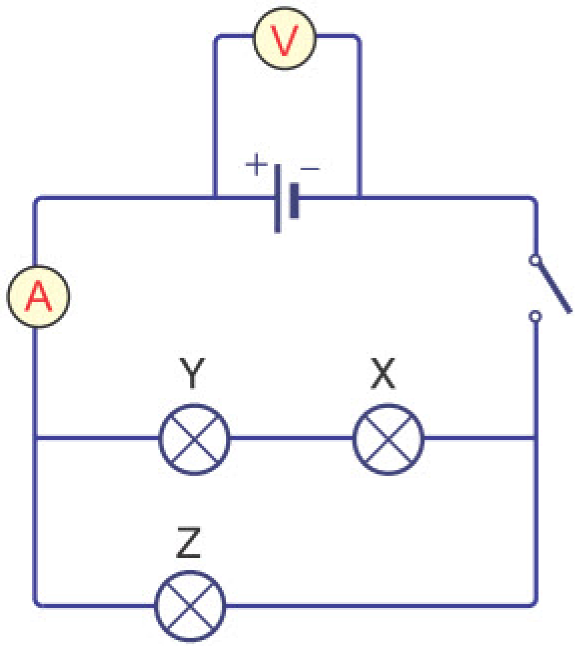
Theory:

In this experiment you will construct complex circuit shown on the figure.



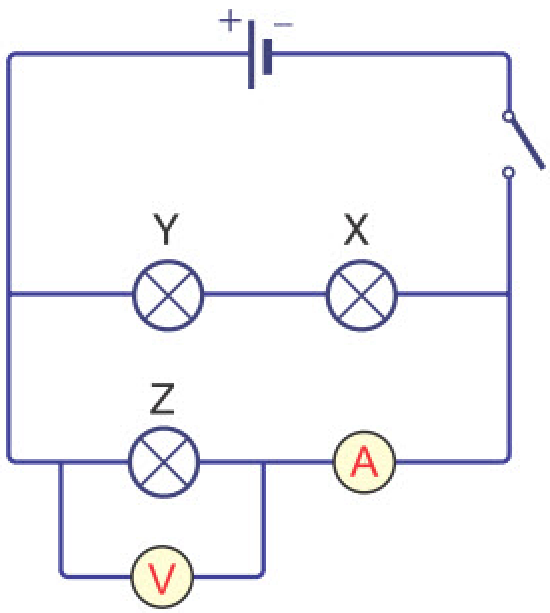
First of all, you will connect voltmeter and ammeter to power source and measure V and I to calculate experimental equivalent resistance

$$R_{experiment} = \frac{V}{I}$$

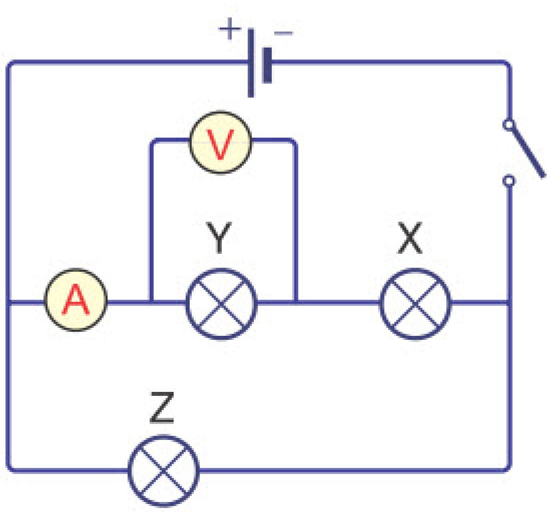


Then you will connect voltmeter and ammeter to lamps Z, Y and X, and measure V_Z, I_Z, V_Y, I_Y, V_X, I_X . By using these quantities you will calculate R_Z , R_Y ,R_X.

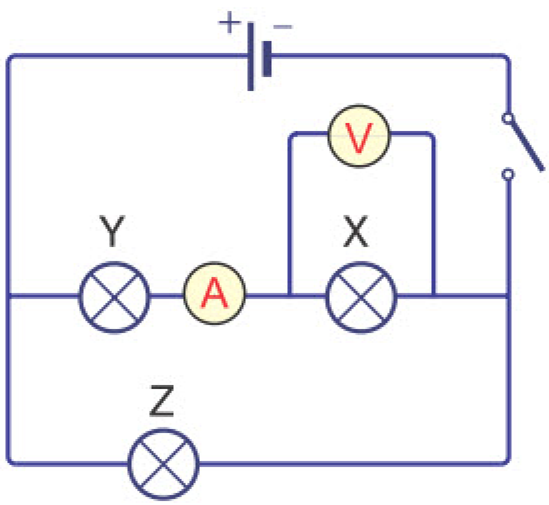
$$R_Z = \frac{V_Z}{I_Z}$$



$$R_Y = \frac{V_Y}{I_Y}$$



$$R_X = \frac{V_X}{I_X}$$



Finally, you will calculate theoretical value of equivalent resistance R_{theory} by using R_Z, R_Y, R_X.

$$R_{theory} = \frac{(R_X + R_Y)R_Z}{R_X + R_Y + R_Z}$$

Equipment:

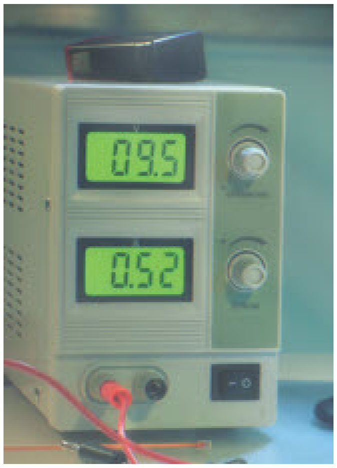
1. Safety glasses

2. Gloves

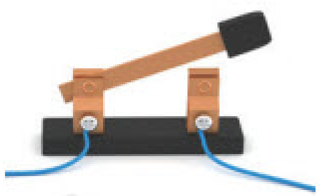
3. Three incandescent light bulbs or resistors

4. Voltmeter and ammeter (or multimeter)

5. Power source



6. Switch



7. Connecting wires

Procedure:

1. Construct circuit shown on the figure.

2. Connect voltmeter and ammeter to power source, lamp Z, lamp Y, lamp X, and fill the tables.

$V\ (V)$	$I\ (A)$	$V_Z\ (V)$	$I_Z\ (A)$

$V_Y\ (V)$	$I_Y\ (A)$	$V_X\ (V)$	$I_X\ (A)$

$R_X\ (\Omega)$	$R_Y\ (\Omega)$	$R_Z\ (\Omega)$

$R_{experiment}\ (\Omega)$	$R_{theory}\ (\Omega)$

Conclusion:

1. Which on is greater, $R_{experiment}$ or R_{theory}? Why?

2. Which one is greater V_X+V_Y, or V_Z? Why?

3. Show the derivation of

$$R_{theory} = \frac{(R_X + R_Y)R_Z}{R_X + R_Y + R_Z}$$

LAB WORK #8

Title:

Electromotive force and internal resistance

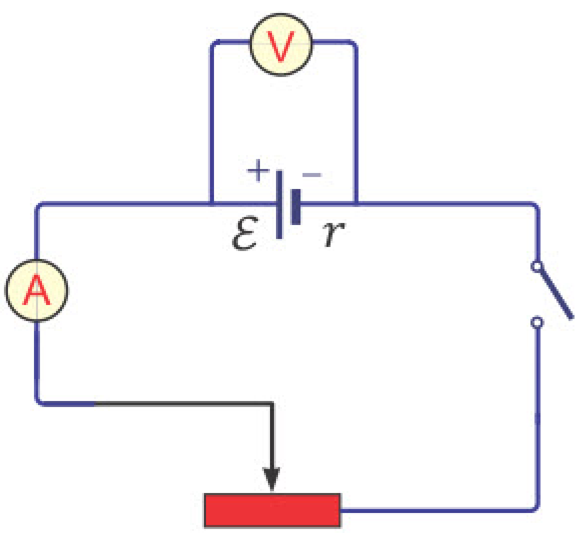
You will

- experimentally determine electromotive force and internal resistance of the battery

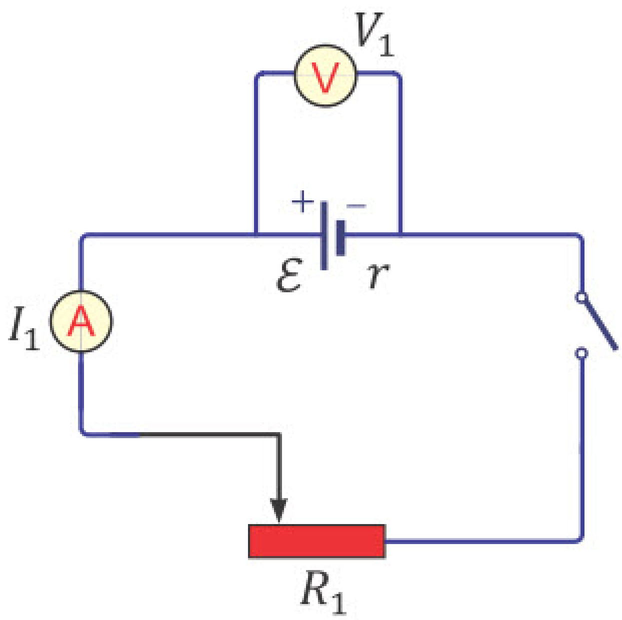
Theory:

In this experiment, you will determine electromotive force ε and internal resistance r of the battery.

First of all, you will use the battery, voltmeter, ammeter, rheostat, switch and connecting wires to construct electric circuit shown on the figure.



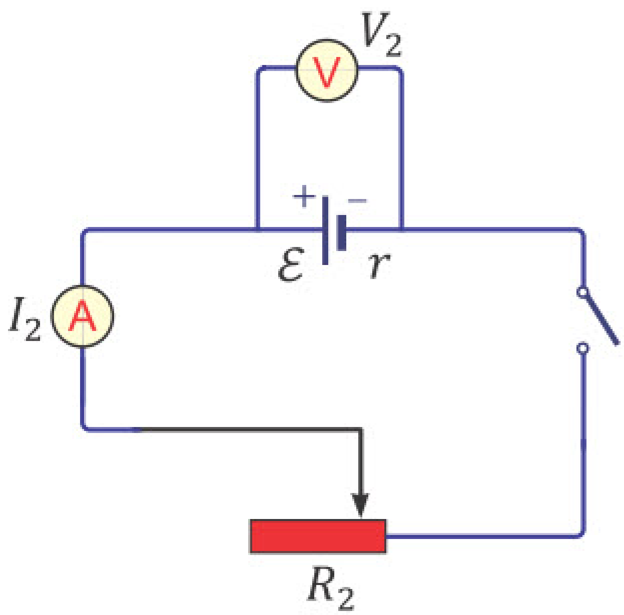
When you close the switch, current starts to flow through the circuit and voltmeter shows voltage .



$$I_1 = \frac{\mathcal{E}}{R_1 + r}$$

$$\mathcal{E} = I_1 R_1 + I_1 r$$

Then you change the resistance of the rheostat so that current starts to flow through the circuit and voltmeter shows voltage .



$$I_2 = \frac{\mathcal{E}}{R_2 + r}$$

$$\mathcal{E} = I_2R_2 + I_2r$$

Resistances R_1 and R_2 of the rheostat can be found by using Ohm's law.

$$I_1R_1 = V_1$$

$$I_2R_2 = V_2$$

By using these formulas we can derive expressions for ε and r.

$$V_1 + I_1 r = V_2 + I_2 r$$

$$I_1 r - I_2 r = V_2 - V_1$$

$$r = \frac{V_2 - V_1}{I_1 - I_2}$$

$$\mathcal{E} = V_1 + I_1 r$$

$$\mathcal{E} = V_1 + I_1 \cdot \frac{V_2 - V_1}{I_1 - I_2}$$

Equipment:

1. Safety glasses

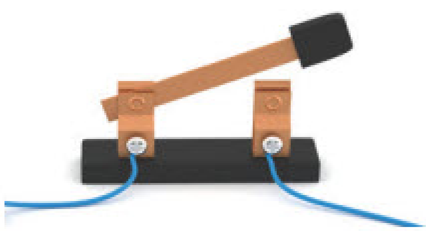
2. Gloves

3. Rheostat (Variable resistor)

4. Voltmeter and ammeter (or multimeter)

5. Electric battery (1.5 V or 9 V)

6. Switch



7. Connecting wires

Procedure:

1. Construct circuit shown on the figure.

2. Close the switch and measure I_1 , V_1 and record them in the table.

3. Change resistance of the rheostat and measure I_2,V_2 and record them in the table.

4. Calculate ε and r.

I_1 (A)	I_2 (A)	V_1 (V)	V_2 (V)	r (Ω)	$\mathcal{E}$ (V)

Conclusion:

1. Which one is greater: V_1, V_2 or ε ? Why?

2. Which one is greater: R_1, R_2 or r? Why?

3. What are the factors decreasing the accuracy of the experiment? Propose ways to improve the accuracy of the experiment.

CHECK YOURSELF

Use this table to answer questions 1-20. Voltage in electrical socket is 220 Volt. Assume resistances of heating elements do not depend on temperature. Heating elements have cylinder-like shape when stretched out.

Kettle	Power (Watt)	Resistivity (Ohm m)	Length of heating element (metre)
PHILIPS	2400	$2 \cdot 10^{-7}$	0.5
SAMSUNG	2000	$2 \cdot 10^{-7}$	0.2
TEFAL	2500	10^{-7}	0.4
UFO	1800	10^{-7}	0.6
XIAO	1500	$5 \cdot 10^{-7}$	0.3

1. Which one is true?
A) Rxiao >Rufo >Rsamsung >Rphilips >Rtefal
B) Rsamsung >Rphilips >Rtefal >Rxiao >Rufo
C) Rufo >Rsamsung >Rxiao > Rphilips =Rtefal
D) Rtefal > Rphilips > Rsamsung > Rufo >Rxiao
E) Rphilips >Rtefal= Rxiao >Rufo >Rsamsung

2. What is resistance of PHILIPS kettle?
A) 10 Ohm
B) 2 Ohm
C) 20 Ohm

D) 4 Ohm
E) 15 Ohm

3. What is ratio of resistances of SAMSUNG and TEFAL?
A) 1
B) 1.25
C) 1.5
D) 2
E) 1.75

4. What is ratio of cross-sectional areas of heating elements of TEFAL and SAMSUNG?
A) 1
B) 1.25
C) 1.5
D) 2
E) 1.75

5. What is ratio of volumes of heating elements of UFO and PHILIPS?
A) 1.65
B) 1.75
C) 1.85
D) 1.95
E) 1.55

6. Which heating element has the biggest volume?
A) SAMSUNG
B) PHILIPS
C) TEFAL
D) UFO
E) XIAO

7. What is volume of heating element of SAMSUNG kettle?

A) 0.33 mm^3

B) 1.33 mm^3

C) 2.33 mm^3

D) 3.33 mm^3

E) 4.33 mm^3

8. What is ratio of currents through heating elements of SAMSUNG and TEFAL?

A) 1
B) 0.8
C) 0.6
D) 2
E) 0.9

9. What is current through heating element of UFO kettle?

A) 12A
B) 1.2 A
C) 4 A
D) 8 A
E) 0.12 A

10. UFO kettle and PHILIPS kettle are both filled with 2 litre of water at 100 °C. Both kettles work until all water is evaporated. What is the ratio of times of evaporation?

A) 1.5
B) 1
C) 3
D) 2.5
E) 1.3

11. TEFAL kettle is filled with 2 litre of water at 100 °C. Kettle works until all water is evaporated. What is the time of evaporation? Specific latent heat of vapourisation of water is $22.5 \cdot 10^5$ J/kg.
A) 350 sec
B) 1400 sec
C) 25 min
D) 30 min
E) 1 hour

12. Assume that service time of kettle is directly proportional to surface area of heating element. Which kettle is going to work the longest time?
A) SAMSUNG
B) PHILIPS
C) TEFAL
D) UFO
E) XIAO

13. Which one is true about efficiencies of kettle? Assume that energy given by each kettle to water is same.
A) ufo >samsung >xiao > philips =tefal
B) samsung >philips >tefal >xiao >ufo
C) xiao >ufo >samsung >philips >tefal
D) tefal > philips > samsung > ufo >xiao
E) philips >tefal= xiao >ufo >samsung

14. What is efficiency of SAMSUNG kettle if power received by water is equal to 1000 Watt?
A) 200 %
B) 2 %
C) 100 %
D) 30 %
E) 50 %

15. What is the change of the temperature of the room when SAMSUNG kettle works 20 minutes? Heat capacity of the room is $3 \cdot 10^5$ J/°C.
A) Temperature does not change
B) 8 °C
C) 6 °C
D) 4 °C
E) 9 °C

16. Which kettle can heat 5 litre of water from 20 °C to 100 °C in exactly 14 minutes?
A) SAMSUNG
B) PHILIPS
C) TEFAL
D) UFO
E) XIAO

17. Let's say you make Carnot engine by using water boiled by kettle and air in room that has 20 °C temperature. What is efficiency of this Carnot engine?
A) 0.3
B) 0.5
C) 0.6
D) 0.2
E) 0.4

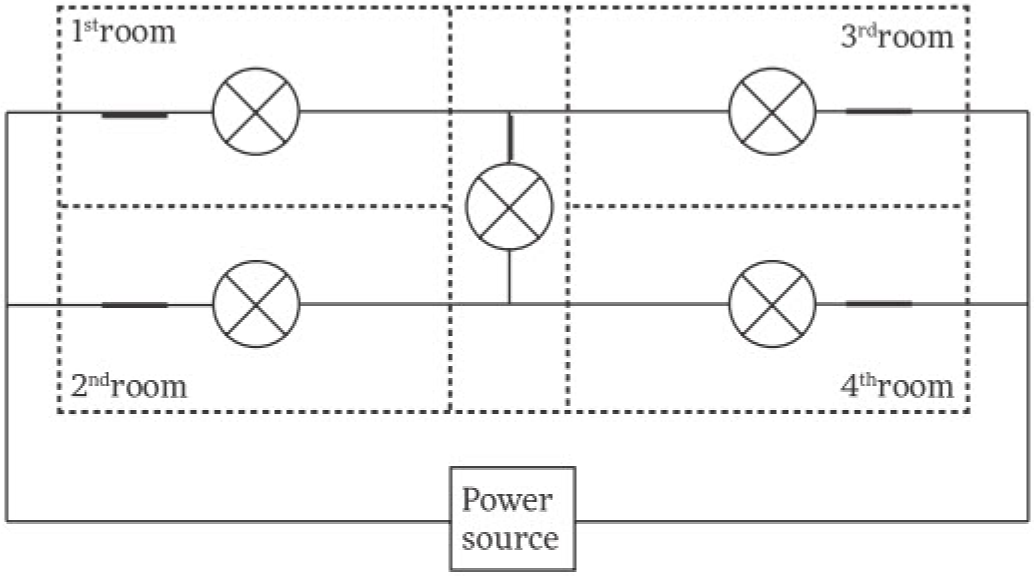
18. Let's say heat loss from kettle to air is 1.8 kJ per second. Which kettle can maintain constant temperature of water?
A) SAMSUNG
B) PHILIPS
C) TEFAL
D) UFO
E) XIAO

19. Price of electricity is 6 tenge per 1 kWh. How much more money does user of TEFAL pay compared to user of UFO? Assume time of usage is 24 hour.

A) 90 tenge
B) 100 tenge
C) 75 tenge
D) 83 tenge
E) 92 tenge

20. How much energy does power plant save if 1 million of users change their TEFAL kettles to XIAO kettles? Assume time of usage is 100 hours.
A) 10^{11} Joule
B) $36 \cdot 10^{5}$ Joule
C) $36 \cdot 10^{11}$ Joule
D) 10^{10} Joule
E) $3.6 \cdot 10^{14}$ Joule

Inexperienced electrician installed 5 light bulbs of 100 Ohm resistance and 170 W power in 4 rooms and hall of the office building. Office workers were not satisfied with the quality of work of electrician and asked you to correct his mistakes. Use plan of office building to correct mistakes of electrician and answer questions 21-40.



21. Which two rooms' light should be switched off so that all light in the building is switched off?
A) Room 1 and 3
B) Room 2 and 3
C) Room 1 and 4
D) Room 2 and 4
E) Room 3 and 4

22. Which light bulb is not going to work when all light bulbs are switched on?
A) Room 1
B) Room 2
C) Room 3
D) Room 4
E) Hall

23. Which light bulb can be switched off so that brightness of other light bulbs does not change?
A) Room 1
B) Room 2
C) Room 3

D) Room 4
E) Hall

24. Let’s switch off light in the 1^{st} room. Which light bulb is going to be the brightest?
A) Room 1
B) Room 2
C) Room 3
D) Room 4
E) Hall

25. Let’s switch off light bulb in the hall. What is the equivalent resistance of the remaining light bulbs?
A) 100 Ohm
B) 200 Ohm
C) 300 Ohm
D) 400 Ohm
E) 50 Ohm
26. Let’s switch off light bulbs in the rooms 1 and 4. What is the equivalent resistance of the remaining light bulbs?
A) 100 Ohm
B) 200 Ohm
C) 300 Ohm
D) 400 Ohm
E) 50 Ohm

27. Let’s switch off light bulbs in the rooms 2 and 3. What is the equivalent resistance of the remaining light bulbs?
A) 100 Ohm
B) 200 Ohm
C) 300 Ohm
D) 400 Ohm
E) 50 Ohm

28. Let's switch off light bulbs in the rooms 1 and 3. What is the equivalent resistance of the remaining light bulbs?
A) 100 Ohm
B) 200 Ohm
C) 300 Ohm
D) 400 Ohm
E) 50 Ohm

29. Let's switch off light bulbs in the rooms 2 and 4. What is the equivalent resistance of the remaining light bulbs?
A) 100 Ohm
B) 200 Ohm
C) 300 Ohm
D) 400 Ohm
E) 0 Ohm

30. Let's switch off light bulbs in the rooms 3 and 4. What is the equivalent resistance of the remaining light bulbs?
A) 100 Ohm
B) 200 Ohm
C) 300 Ohm
D) 400 Ohm
E) Circuit is open, resistance is infinity

31. What is the ratio of equivalent resistances of electric circuit when light bulb in the hall is switched on or switched off?
A) 0.5
B) 1
C) 2
D) 4
E) 3
32. Let's switch off light bulb in the room 3. What is the equivalent resistance of the remaining light bulbs?
A) 67 Ohm
B) 167 Ohm
C) 267 Ohm

D) 400 Ohm
E) 0 Ohm

33. Which light bulb should be switched off so that power of electric circuit does not change? Voltage of the power source is 110 Volt.
A) Room 1
B) Room 2
C) Room 3
D) Room 4
E) Hall

34. Let's switch on all light bulbs. What is power released on light bulb №3? Voltage of the power source is 110 Volt.
A) 110 Watt
B) 20 Watt
C) 30 Watt
D) 0 Watt
E) 100 Watt

35. Let's switch on only light bulbs in rooms 2 and 4, and light bulb in hall. What is power of light bulb №2 and light bulb in the hall? Voltage of the power source is 110 Volt.
A) 110 Watt and 110 Watt
B) 20 Watt and 20 Watt
C) 30 Watt and 10 Watt
D) 30 Watt and 0 Watt
E) 0 Watt and 30 Watt

36. Let's switch on all light bulbs except light bulb №3 and increase voltage of power source to 220 Volt. Which statement is false?
A) One light bulb will burn out
B) There will be no light in building

C) If light bulb №3 is switched on it will burn out too
D) All light bulbs will work except light bulb №3
E) Equivalent resistance of the electric circuit will increase

37. Let’s switch on only light bulbs in rooms 2 and 4, and light bulb in hall. What is power of light bulb №4? Voltage of the power source is 220 Volt.
A) 110 Watt
B) 120 Watt
C) 100 Watt
D) Light bulb will burn out
E) 220 Watt

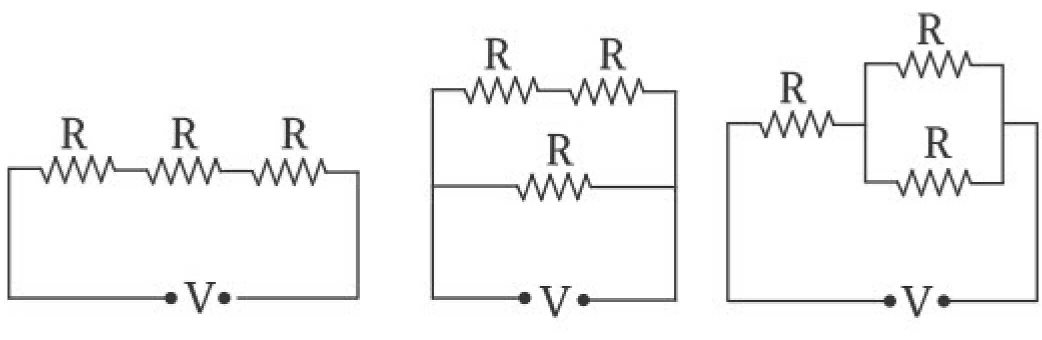
38. What should be power rating of light bulbs so that light bulbs do not burn out? Voltage of power source is 220 Volt and light bulb in Room 3 is switched off..
A) 110 Watt
B) 175 Watt
C) 12 Watt
D) No right answer
E) 110 Watt

39. How would power of light bulb №1 change if light bulb in the hall is switched off? Voltage of power source is 110 Volt.
A) Increases by 20 Watt
B) Decreases by 20 Watt
C) Increases by 10 Watt
D) Decreases by 10 Watt
E) Does not change

40. What type of corrective action would you advice to inexperienced electrician?
A) series connection of all light bulbs
B) parallel connection of all light bulbs
C) remove light bulb in the hall
D) remove light bulb in the room 1
E) change power source

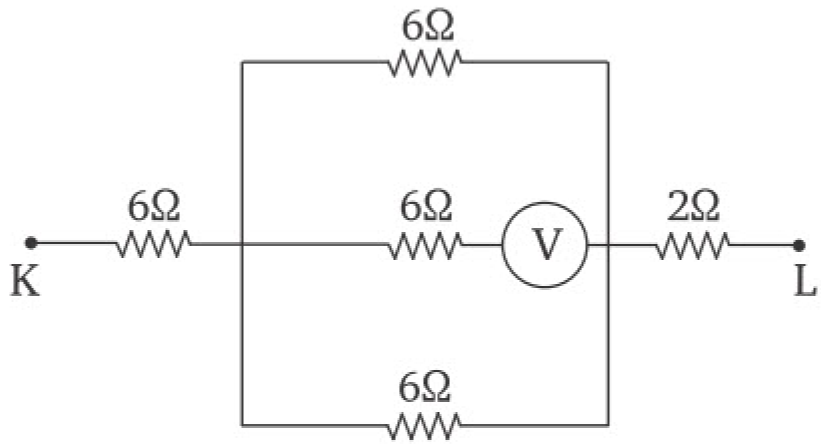
Test Problems

1. The circuits K, L and M are constructed from identical resistors. What is the relationship between the currents IK, IL and IM, in the main arm of the circuits?



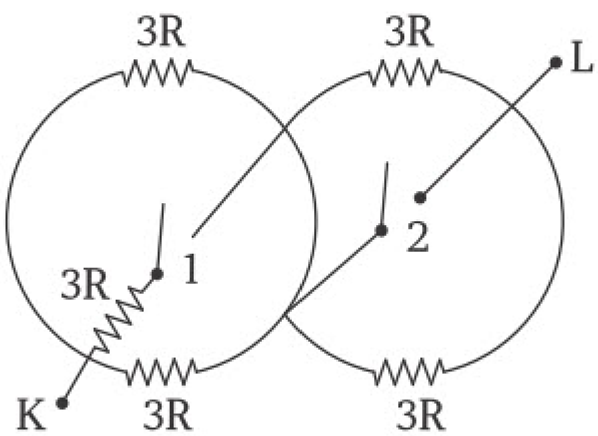
A) $I_K = I_L = I_M$
B) $I_K > I_L = I_M$
C) $I_K > I_L > I_M$
D) $I_L > I_M > I_K$
E) $I_L > I_K > I_M$

2. In the network shown in the figure, the potential difference between points K and L, in the circuit shown in the figure, is 44 V. What is the reading on the voltmeter, in volts?



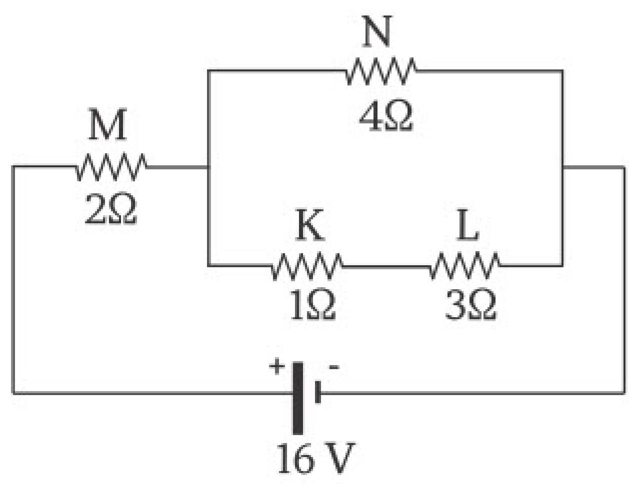
A) 4.4
B) 8.8
C) 10
D) 12
E) 12.2

3. In the network shown in the figure, what is the equivalent resistance, in ohms, between points K and L, in terms of R, after switches 1 and 2 are closed?



A) 1
B) 2
C) 4
D) 5
E) 3

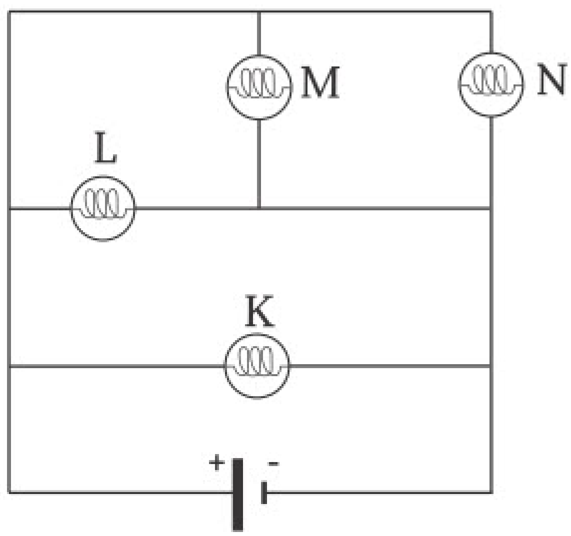
4. In the circuit shown in the figure, which two resistors have the same potential difference?



A) K and M
B) M and N

C) L and M
D) K and N
E) K and L

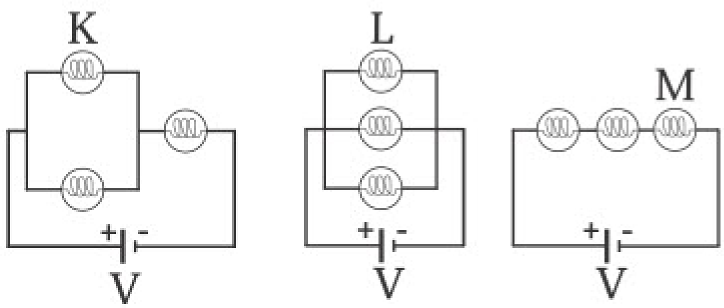
5. The circuit shown in the figure is constructed from identical lamps. Which of the following statements concerning the brightness of the lamps is/are correct?
I. The brightest lamp is K.
II. The brightness of the lamps are equal.
III. Lamps M and N have the same brightness and lamp L is brighter than both of them.



A) I only

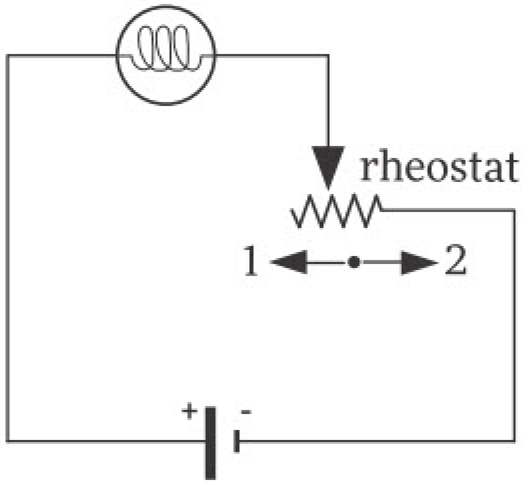
B) II only
C) III only
D) I and III
E) I, II and III

6. The electric circuits, shown in the figure, are constructed from identical lamps. What is the relationship between the brightnesses of lamps K, L and M?



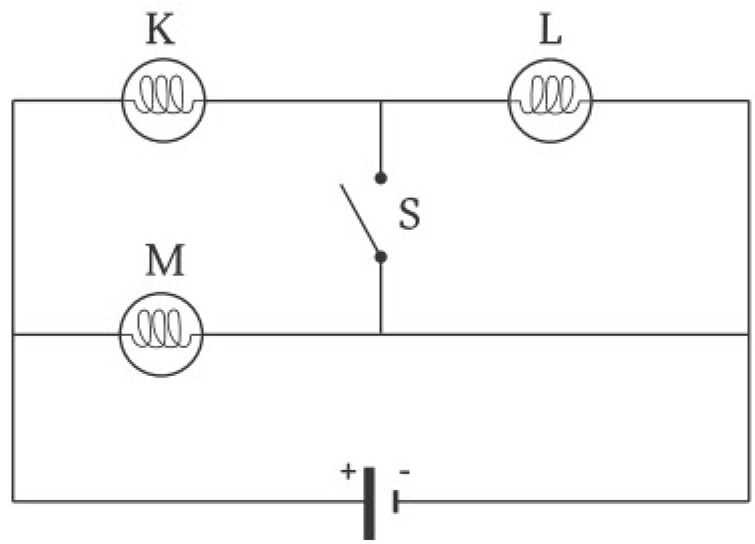
A) K=L=M
B) M=L>K
C) L>K=M
D) L>K>M
E) L>M>K

7. The position of the sliding bar of the rheostat in a circuit is as shown in the figure. Which of the following statements is incorrect?



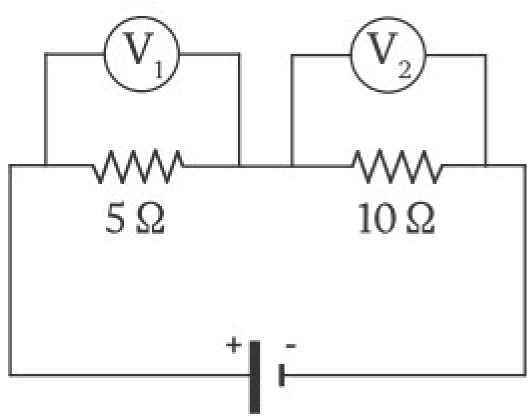
A) The brightness of the lamp decreases if the sliding bar is moved in direction 1.
B) The brightness of the lamp increases if the sliding bar is moved in direction 2.
C) The equivalent resistance decreases if the sliding bar is moved in direction 2.
D) The equivalent resistance increases if the sliding bar is moved in direction 2.
E) The voltage of the lamp decreases if the sliding bar is moved in direction 1.

8. In the circuit shown in the figure, constructed from identical lamps, switch S is closed. Which of the following statements is/are correct?
I. The brightness of lamp M doesn't change.
II. The voltage across lamp K increases.
III. Lamp L is extinguished.



A) II only B) III only
C) I and II D) II and III
E) I, II and III

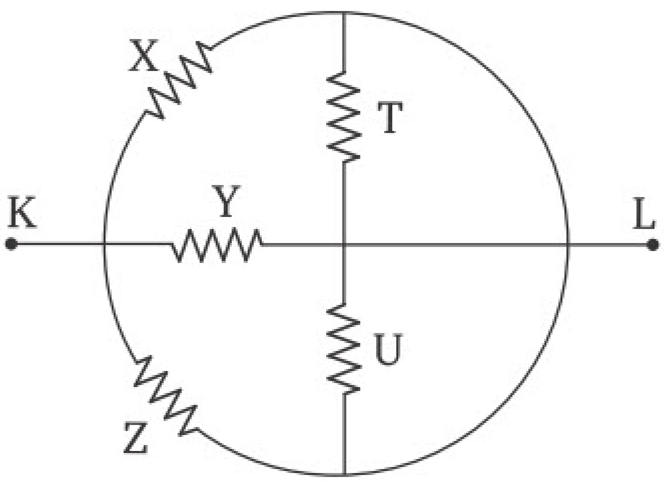
9. In the circuit shown in the figure, what is the ratio of the voltages V_1/V_2, on voltmeters V_1 and V_2, respectively?



A) 1/2 B) 1

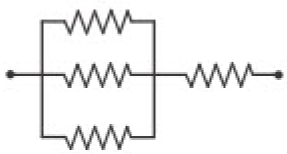
C) 2 D) 3
E) 4

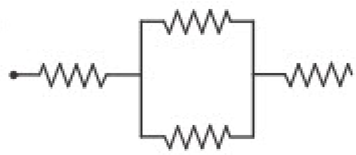
10. In the circuit shown in the figure, in order to find the equivalent resistance between points K and L, which resistor values is not required?

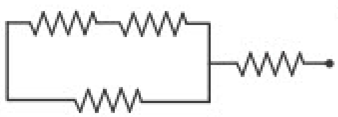


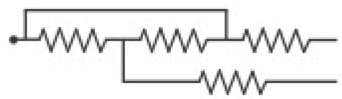
A) X only
B) T only
C) U only
D) T and U
E) X, Y and Z

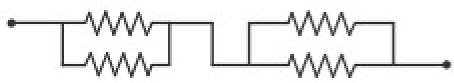
11. The following circuits are constructed from identical resistors. Which of the following circuits has the lowest equivalent resistance?

A) 

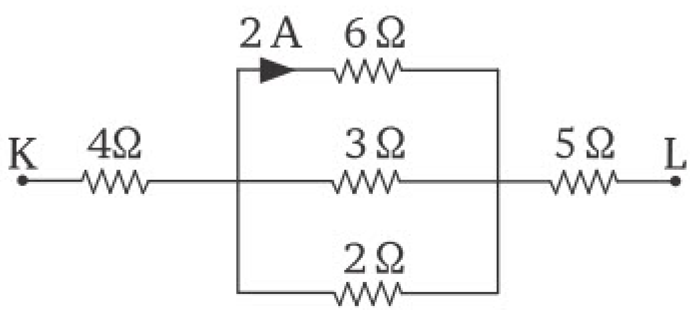
B) 

C) 

D) 

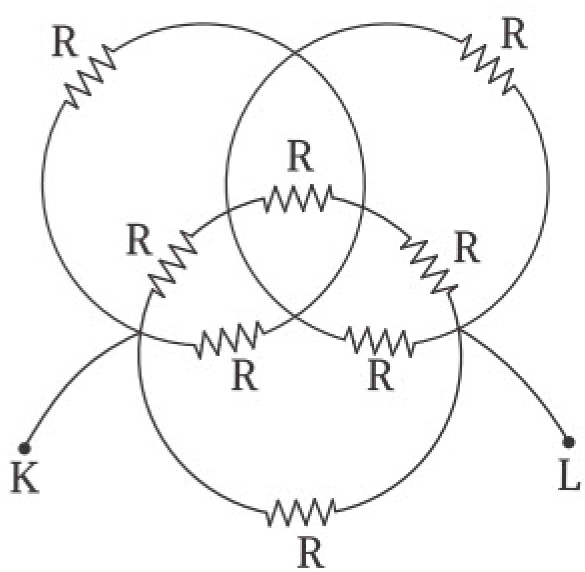
E) 

12. In the network shown in the figure, what is the potential difference between points K and L, in volts?

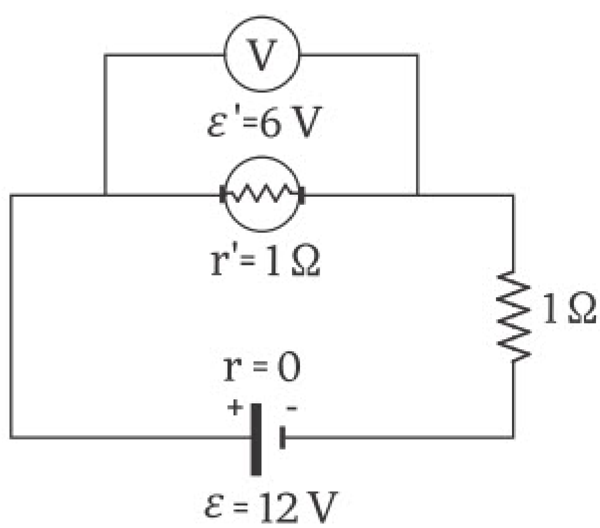


A) 24
B) 120
C) 132
D) 186
E) 220

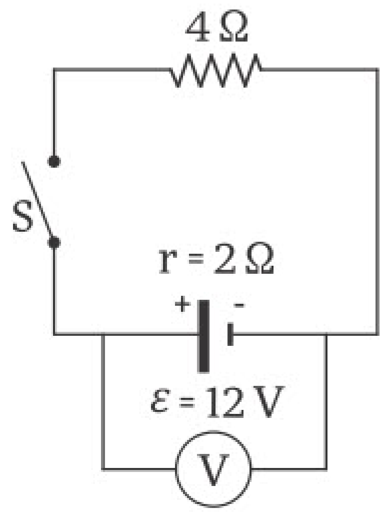
13. In the network shown in the figure, what is the equivalent resistance between points K and L, in terms of R?



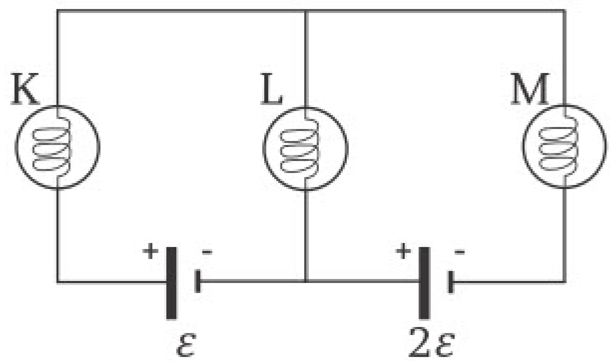
14. In the circuit shown in the figure, the voltmeter reads V_1 when the motor runs and V_2 when it is disabled. What is the ratio V_1/V_2 ?



15. In the circuit shown in the figure, the voltmeter reads V_1 when switch S is open and V_2 when switch S is closed. What is the ratio V_1/V_2 ?



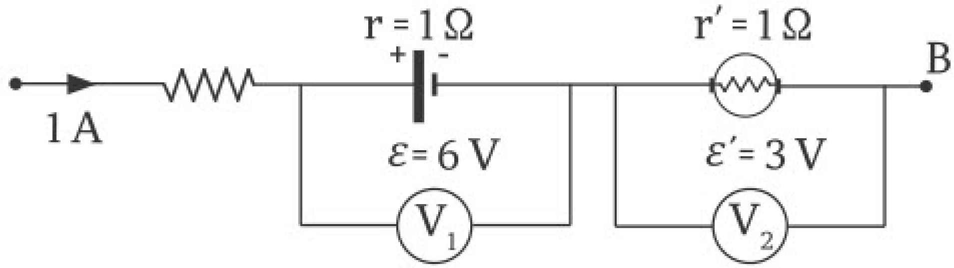
16. In the circuit shown in the figure, what is the relationship between the brightnesses of identical lamps K, L and M? (The internal resistance of the batteries is neglected.)



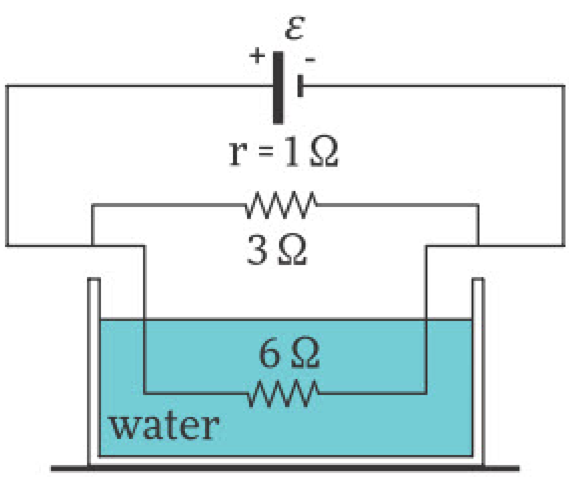
A) K>L>M
B) K=M>L
C) M>K>L

D) K=L=M
E) L>M>K

17. In the circuit shown in the figure, the readings on voltmeters are V_1 and V_2, respectively, what is the ratio V_1/V_2?

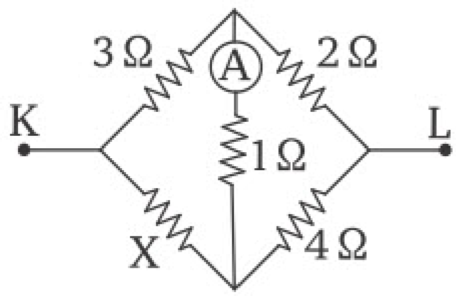


18. In the circuit shown in the figure, the temperature of 300 g of water increases from 0 °C to 20 °C in 160 s. What is the emf of the battery, in volts? (cwater=1 cal/g°C; 1 cal=4 J)



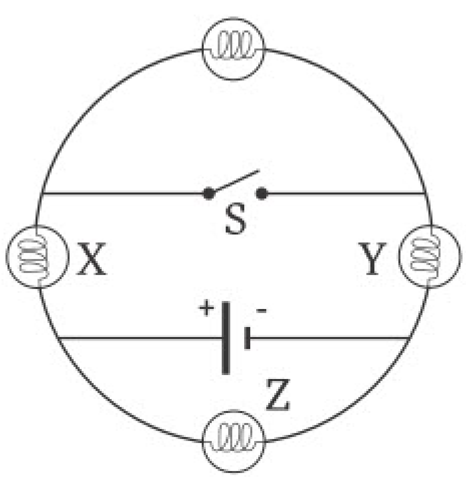
A) 10
B) 12
C) 18
D) 24
E) 45

19. In the circuit shown in the figure, no current passes through the ammeter. What is the value of resistor X, in ohms?



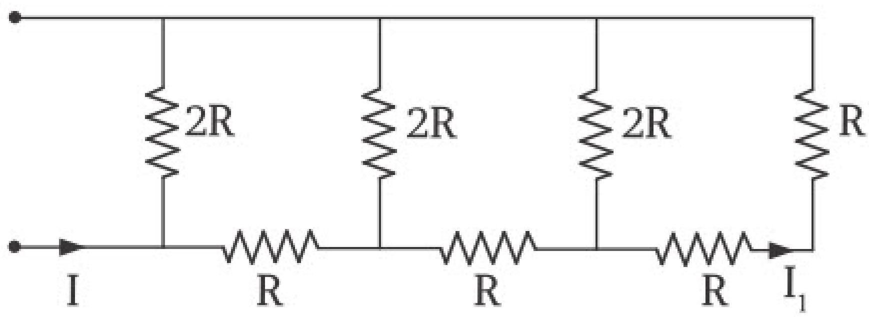
A) 1
B) 3
C) 4
D) 6
E) 12

20. The circuit shown in the figure consists of identical lamps. If switch S is closed, how do the brightnesses of lamps X, Y and Z change? (The internal resistance of the battery is neglected.)



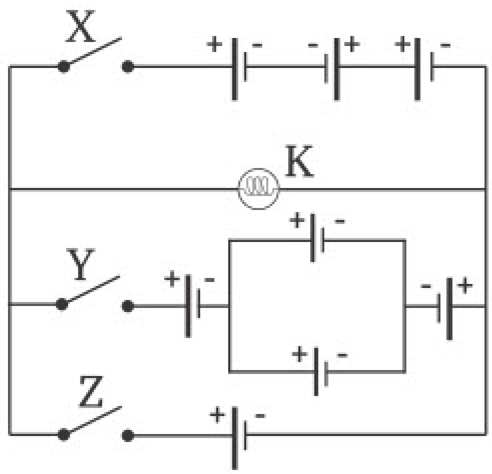
	X	Y	Z
A)	increases	increases	decreases
B)	increases	increases	no change
C)	increases	decreases	decreases
D)	decreases	decreases	no change
E)	decreases	increases	decreases

21. In the circuit shown in the figure, what is the ratio I/I_1?



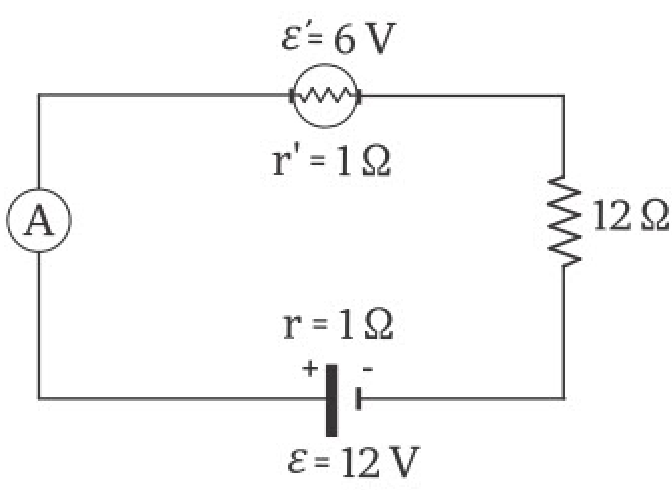
A) 1
B) 2
C) 4
D) 6
E) 8

22. The circuit shown in the figure consists of identical batteries. When switches X, Y and Z are closed one after the other, lamp K switches on, having brightnesses which change in sequence with the close of each switch of P_X, P_Y and P_Z, respectively. What is the relationship between P_X, P_Y and P_Z? (The internal resistance of the batteries is neglected.)

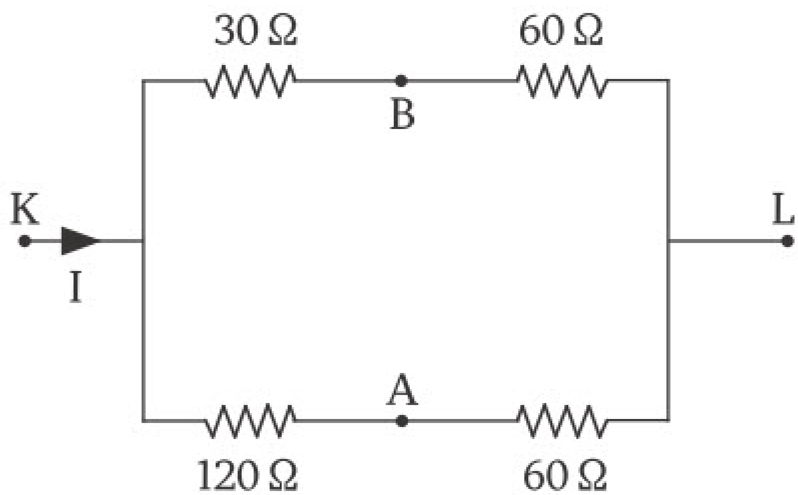


A) $P_X > P_Y > P_Z$
B) $P_X = P_Y > P_Z$
C) $P_Y > P_X > P_Z$
D) $P_X = P_Y = P_Z$
E) $P_X > P_Z > P_Y$

23. In the circuit shown in the figure, the ammeter reads I_1 when the motor runs and I_2 when the motor does not run. What is the ratio I_1 / I_2?



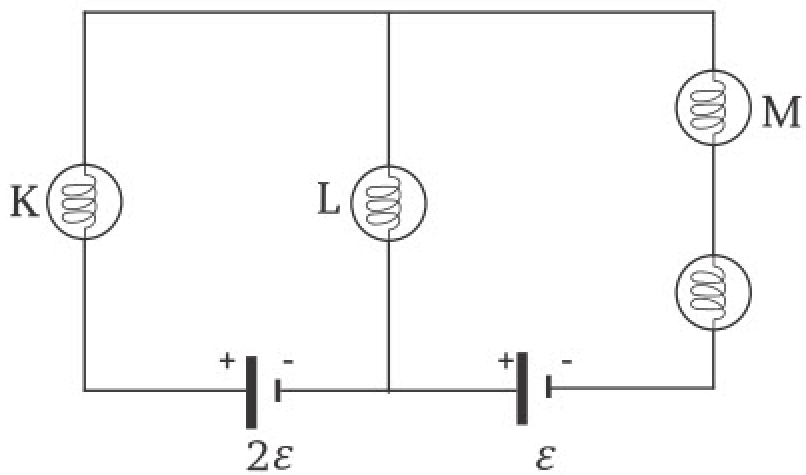
24. In the network shown in the figure, I=0.3 A. What is the potential difference across points A and B, U_{AB}, in volts?



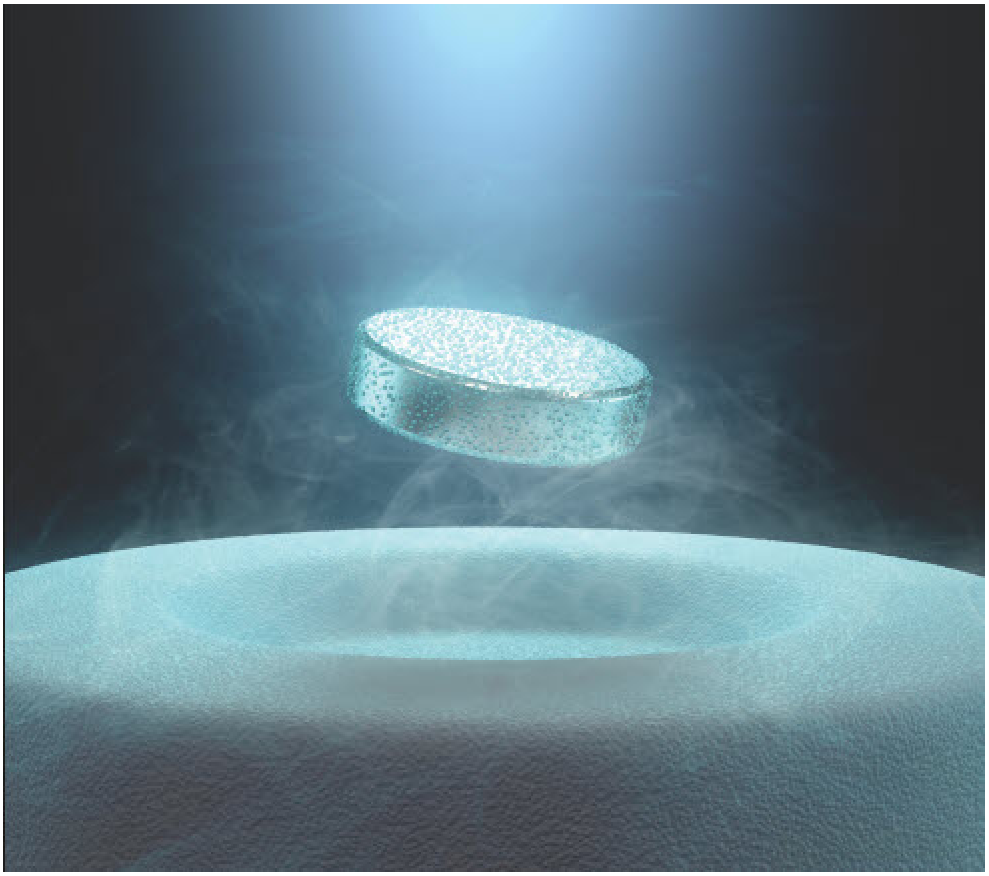
A) 6
B) 12
C) 18
D) 24
E) 30

-

25. The circuit shown in the figure consists of identical lamps. What is the relationship between the brightnesses of lamps K, L and M? (The internal resistance of the batteries is neglected.)



A) L=M>K
B) K>L=M
C) K>M>L
D) M>L>K
E) K>L>M



CHAPTER 12: ELECTRIC CURRENT IN SOLIDS, LIQUIDS AND GASES

12.1 CURRENT IN METALS. SUPERCONDUCTIVITY.

You will

- describe electric current in metals and analyse relationship between resistance and temperature of conductor.
- discuss perspectives of high temperature superconductors.

Question

Why does this object levitate? Why is there smoke (or vapour)?

Resistance and temperature

Electric current is formed by the motion of electrons through a conductor. If we apply a voltage across a steel wire and then heat it, as in Figure 125, we see that the current passing through it decreases. This indicates that the current in a conductor changes with temperature.

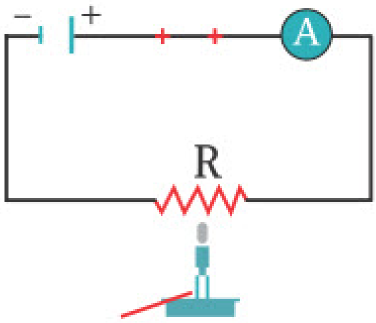


Figure 125

Let the resistance of a conductor at an initial temperature, T_0 be R_0 and at a final temperature, T be R. The relationship between these resistances and temperatures is given by

$$R = R_0(1 + \alpha\Delta T)$$

where the proportionality constant, α, is called the temperature coefficient of the substance of which the resistor is made.

The resistance of all metals increases with increasing temperature ($\alpha > 0$), but the resistance of some alloys, i.e, manganin and constantan does not change at all with temperature. The resistance of some electrolytes, carbon, porcelain and glass decreases ($\alpha < 0$). The temperature coefficient of resistivity for various materials is given in Table 9.

MATERIAL	RESISTIVITY, ρ (Ωm)	TEMPERATURE COEFFICIENT α (1/C°)
Silver	$1.59 \cdot 10^{-8}$	$3.8 \cdot 10^{-3}$
Copper	$1.7 \cdot 10^{-8}$	$3.9 \cdot 10^{-3}$
Gold	$2.44 \cdot 10^{-8}$	$3.4 \cdot 10^{-3}$
Aliminum	$2.82 \cdot 10^{-8}$	$3.9 \cdot 10^{-3}$
Tungsten	$5.6 \cdot 10^{-8}$	$4.5 \cdot 10^{-3}$
Iron	$10 \cdot 10^{-8}$	$5.0 \cdot 10^{-3}$
Platinum	$11 \cdot 10^{-8}$	$3.92 \cdot 10^{-3}$
Lead	$22 \cdot 10^{-8}$	$3.9 \cdot 10^{-3}$
Nichrome	$1.5 \cdot 10^{-8}$	$0.4 \cdot 10^{-3}$
Carbon	$3.5 \cdot 10^{-8}$	$-0.5 \cdot 10^{-3}$
Germanium	0.46	$-48 \cdot 10^{-3}$
Silicon	640	$-75 \cdot 10^{-3}$
Glass	10^{10}-10^{14}	

Table 9

The temperature coefficient of resistivity also changes slightly with temperature, but this change is negligible for moderate temperature changes.

We must use real materials to construct measuring devices such as voltmeters and ammeters, so materials of constant resistance must be used. Materials whose resistance varies with temperature, such as platinum, are used to construct resistance thermometers. These thermometers are used to measure very low and very high temperatures, in temperature ranges where liquid thermometers cannot work.

Superconductivity

Superconductivity is when resistance of conductor drops to zero. Some substances and alloys display superconductivity below a certain, very low temperature called the transition temperature, Tc, Table 10.

Substance	T_c(K)
$YBa_2Cu_3O_7$	92
TI-Ba-Ca-Cu-O	125
$HgBa_2Ca_2Cu_3O_8$	134
Pb	7.18
Hg	4.2
Su	3.7
Zn	0.9

Table 10

What happens when a substance becomes a superconductor? When a potential difference is applied across a closed loop, some current flows. When the source of potential difference is removed the current stops flowing. If this loop is made of a superconductor material, and the source of potential difference removed, the current would be maintained for a long time. Almost no energy would be lost as heat in the wires. Scientists are presently carrying out research to find substances which become superconductors at higher transition temperatures.

Superconductors which work at room temperatures would be useful in many areas of technology. Motors, and generators would be four or five times smaller than those of today, computers would be much faster, electric energy would be transferred more easily and cheaply since no energy would be lost as heat in transmission lines. Much stronger electromagnets would be constructed by superconductors, as they can store much more energy than ordinary electromagnets.

Another application of superconductivity is magnetic quantum levitation, Figure 126. When superconductor is cooled with liquid nitrogen it starts to expel magnetic field from itself. That means it becomes "locked" above magnet at its initial height. This effect can be used to make frictionless vehicles.

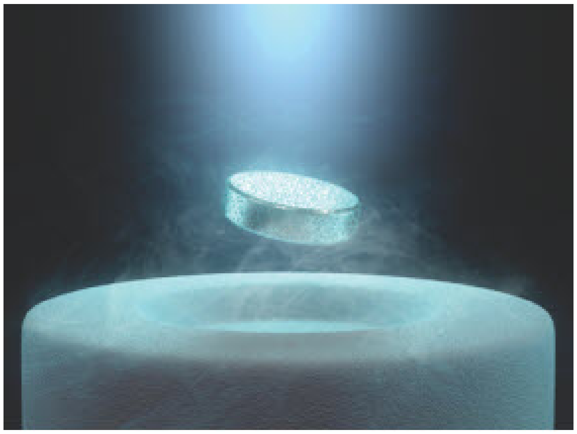


Figure 126

Activity

Open "Phet Conductivity". Observe how metal conducts electricity. Write down your conclusion.

Research time

Why superconductors are important? What would change if all wires acted like superconductors?

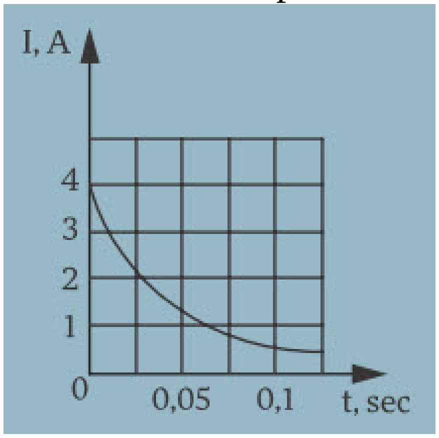
Example

Digital thermometers contain device called a thermistor. Thermistor has $\alpha = -0.06\ °C^{-1}$. At 37 °C resistance of thermistor is 1 Ω. What is a patient's temperature if the thermistor's resistance at that temperature is 0.82 Ω?

Given:	Formulas:	Calculations:
$\alpha = -0.06°C^{-1}$ $T_0 = 37°C$ $R_0 = 1\ \Omega$ $R = 0.82\ \Omega$ $T = ?$	$R = R_0(1 + \alpha\Delta T)$ $\Delta T = T - T_0$	$T = T_0 + \frac{R - R_0}{\alpha R_0}$ $T = 37 + \frac{0.82 - 1}{(-0.06) \cdot 1}$ $T = 40°C$

Literacy

1. What is definition of superconductivity? Why does resistance of metal decreases when temperature decreases?
2. Where superconductors are used? How can you make superconductor? How can you make superconductor at room temperature?
3. There is current-time graph of incandescent lamp that is plugged to 220 V electric socket. Explain graph. Why does current decrease? What is resistance of incandescent lamp in cold state? What is resistance of incandescent lamp in hot state?



4. Aluminum wire at 0 °C has resistance of 4.25 Ohm. What is resistance of wire at 200°C?
5. What should be the temperature of silver wire so that its resistance doubles? Initial temperature of silver wire is 0 °C.
6. You should design electroheating device that has resistance of 48 Ohm at 800 °C. Temperature coefficient of wire is 0.00021 K^{-1}, diameter is 0.5 mm, resistivity is 0.4 μΩ·m. What length of wire should you take?

Physics in life

Superconductor cables are used in LHC (Large Hadron Collider). They can transfer a current of 12500 Ampere. Why are they used?

12.2 ELECTRIC CURRENT IN SEMICONDUCTORS. SEMICONDUCTOR DEVICES.

You will

- describe electric current in semiconductors and explain semiconductor devices.

Question

Why does LED allows current to pass only in one direction?

Electric current in semiconductors

Semiconductors are materials whose electrical properties are between conductors and insulators. Semiconductors are the basis of electronics. Silicon (Si) and germanium (Ge) are the most commonly used semiconductors in electronic circuits. The resistivity of a semiconductor decreases quickly as its temperature increases. They behave just like an insulator at very low temperatures.

A semiconductor contains four valence electrons in its outermost shell, their crystalline structure is shown in Figure 127.

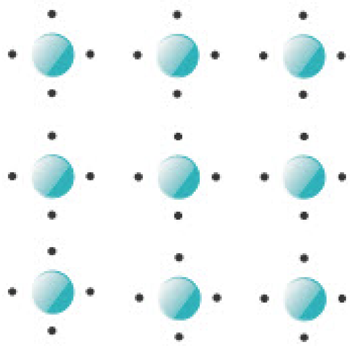


Figure 127

When energy is transferred to a semiconductor (when it is heated), some valence electrons begin to move from one atom to a neighbour atom, like free electrons moving in a metal, Figure 128a. Since the kinetic energy of electrons increase, they can break their bond with the nucleus. Thus, when an electric field is applied, an electric current is formed. When an electron escapes from its own atom and moves toward another atom it leaves a hole (space) behind for an electron which comes from another neighbour atom, this process continues, Figure 128b. Whenever an electron leaves, it creates a new hole, this hole (deficiency of electron in the site) can be thought of as a positive charge, +e, and acts as a charge carrier. Thus, as the negative electrons move in one direction, the positive holes move in the opposite direction through the semiconductor. In a pure semiconductor there are equal numbers of electrons and holes, so it is neutral. The holes (because they are positive) move in the direction of the electric field and the electrons move in the opposite direction to the field. This electron-hole conduction of current in a semiconductor can be represented as in Figure 128c.

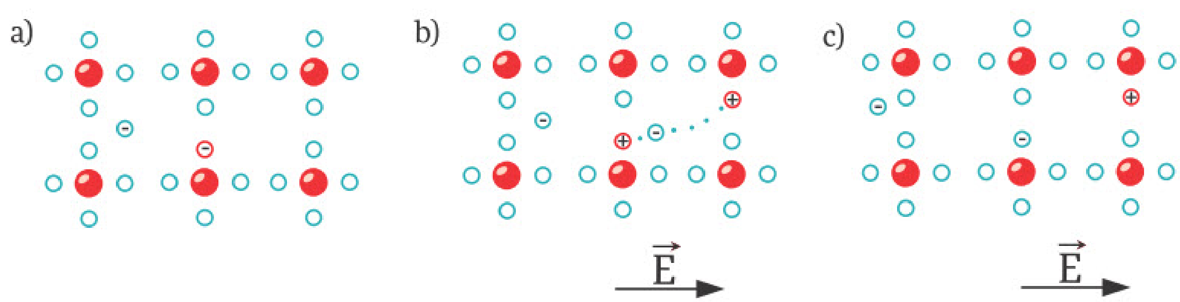


Figure 128

N-type semiconductors

If the impurity added to the semiconductor is an element with five valence electrons (such as arsenic), only four electrons from the arsenic atom will fit into the structure.The fifth electron cannot fit and thus, moves freely, just like the free electrons in a metal. This process is shown in Figure 129. In n-type semiconductor current is carried by free electrons (negative charges).

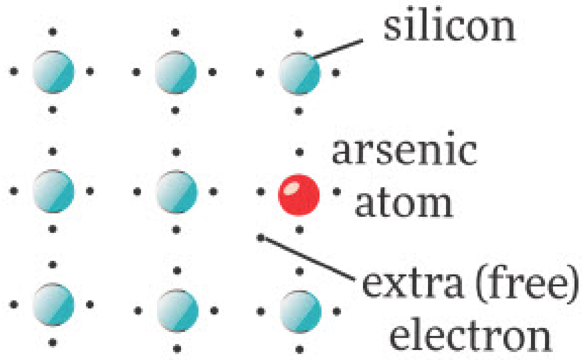


Figure 129

P-type semiconductors

If we add impurity having three valence electrons (gallium or aluminum) three electrons of an atom (aluminum) will fit into the structure, Figure 130. However, there is a hole near the impurity, which will be filled by an electron from a nearby silicon atom, which again leaves behind a hole. This hole will be filled by another electron from a neighbouring silicon atom, and so on. In p-type semiconductor current is carried by holes (positive charges).

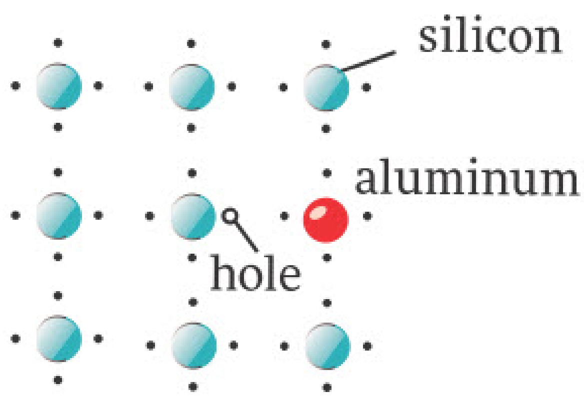


Figure 130

Semiconductors devices

An important application of p-type and n-type semiconductors are diodes. A diode is an electronic device that allows electric current to pass only in one direction. A symbol for a diode in an electric circuit diagram is

 .

Diodes are used to rectify alternating current into direct current.

A light-emitting diode (LED) is a two-lead semiconductor light source. It is a p–n junction diode that emits light when activated. When a suitable voltage is applied to the leads, electrons are able to recombine with electron holes within the device, releasing energy in the form of photons.

Transistors are semiconductor devices that control large output signals with tiny input signals, that is, they can amplify weak input signals. Transistors are the basic circuit elements of electronic amplifiers.

Modern electronics is built on semiconductors. All smartphones, tablets, computers, consumer electronics, electronics in cars, planes, trains have semiconductor devices, Figure 131.

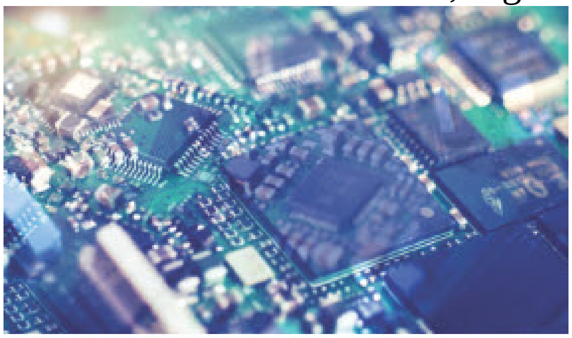


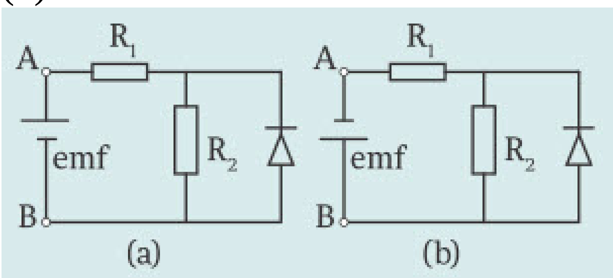
Figure 131

Reserach time

State the differences and similarities between semiconductors and superconductors.

Example

EMF, two resistors and ideal diode are connected as shown in Figure (a) and (b).



Ideal diode has zero resistance when it is forward biased and infinite resistance when it is reverse biased. Current in (a) is 2 Ampere and in (b) it is 5 Ampere. Determine R_2 if R_1=2 Ω. Neglect internal resistance of EMF.

Given:

$I_a = 2\ A$

$I_b = 5\ A$

$R_1 = 2\ \Omega$

$r = 0$

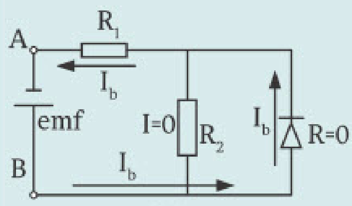
$\varepsilon = ?$

$R_2 = ?$

Formulas:

$$I = \frac{\mathcal{E}}{R + r}$$

Calculations:



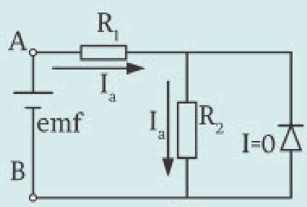
(b)

In (b) diode is forward biased so its resistance is zero. That means current does not pass through R_2.

$$\mathcal{E} = I_b(R + r)$$

$$\mathcal{E} = 5 \cdot (2 + 0)$$

$$\mathcal{E} = 10\ V$$



(a)

In (a) diode is reverse biased so its resistance is infinite. That means current does not pass through diode.

$$I_a = \frac{\mathcal{E}}{R_1 + R_2} \qquad R_2 = \frac{\mathcal{E}}{I_a} - R_1$$

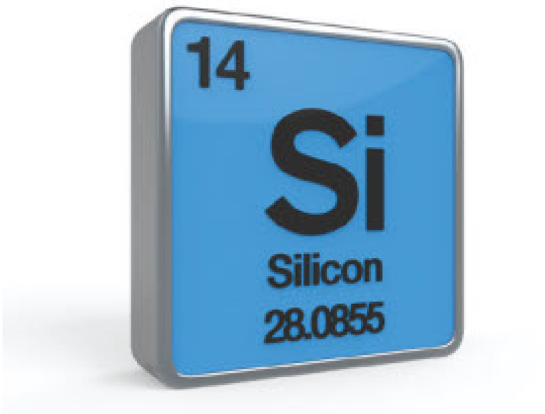
$$R_2 = \frac{10}{2} - 2 \qquad R_2 = 3\ \Omega$$

Activity

Open "Phet Semiconductor". Observe the process and write down your conclusions.

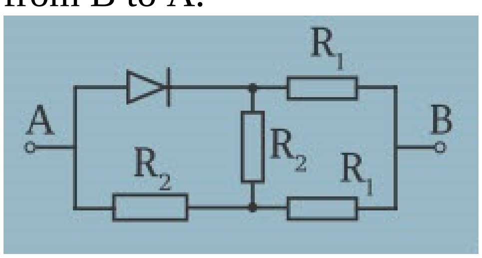
Physics in life

Silicon valley (in California) gets its name from semiconductor element silicon. Big tech companies such as Apple, Google and Microsoft are located there.

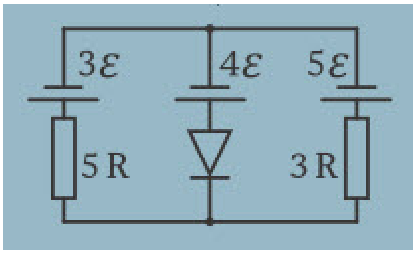


Literacy

1. What is definition of semiconductor? How semiconductors are made? Where semiconductors are used?
2. What would happen if all semiconductor devices in the world stop working? How would your life change?
3. Calculate resistance of semiconductor diode in forward biased mode and reverse biased mode if at
0.5 V current is 5 mA, and at -10 V current is 0.1 mA.
4. What area should semiconductor solar panel have to generate 100 W power? Efficiency of solar panel is 20%. Solar irradiance that reaches Earth's surface is 8.34 Joule/(cm^2·min).
5. There is electric circuit that consists of ideal diode and two resistors R_1=30 Ω, R_2=60 Ω. First, calculate equivalent resistance when current flows from A to B. Next, calculate equivalent resistance when current flows from B to A.



6. There is electric circuit that consists of one ideal diode, two resistors and three batteries. Calculate voltage and current through ideal diode. Neglect internal resistances of batteries and assume ε=10 V, R=2 Ω.

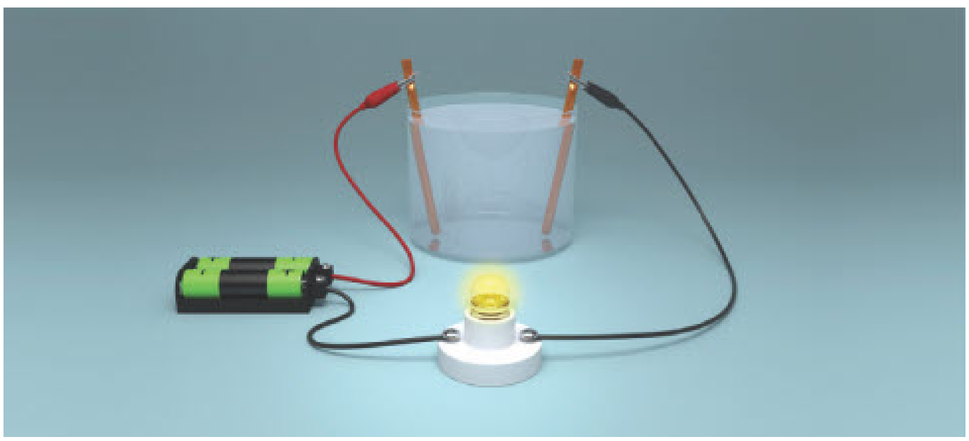

3ε
4ε
5ε
5 R
3 R

12.3 ELECTRIC CURRENT IN ELECTROLYTES. FARADAY'S LAWS OF ELECTROLYSIS

You will

- describe electric current in electrolytes and apply Faraday's laws of electrolysis for problem solving.

Question



In which case light bulb is going to emit light: distilled water or salty water in the container? Why?

Electric current in liquids

Experiment shows that pure water does not conduct electric current. This means, there are no charge carriers in pure water. Table salt (sodium chloride) doesn't conduct electric current either. However, when we add some table salt to pure water, the salt molecules split into Na^+ and Cl^- ions. If a battery is applied across this solution, as shown in Figure 1, the ions begin to move under the influence of the electric field produced by the

battery, towards the electrodes A and C. Thus, in salty water electric current is caused by the flow of positive and negative ions, instead of the flow of electrons as in metals.
The solutions in which electric currents can flow are called electrolytes. Salty water, sugary water or solutions of silver nitrate $AgNO_3$, are some common electrolytes.

The conducting rods submerged into an electrolyte (rods A and C in Figure 132) are called electrodes. The electrode connected to the positive terminal of the battery is called the anode and the other electrode is called the cathode. This process of charge flow through an electrolyte is known as electrolysis.

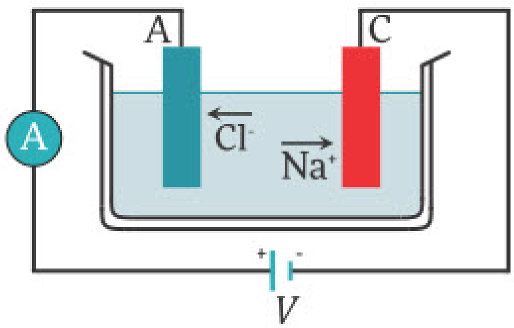


Figure 132

Faraday's law for Electrolysis

Consider two electrodes of different metals, such as silver and copper submerged in water and connected to the terminals of a battery. When some silver nitrate (AgNO3) is added into the water, the Ag^+ and NO_3^- ions dissolve in the water, as shown in Figure 133. The Ag+ ions begin to move to the cathode (which is made of copper) and accepts one electron from the cathode. As a result, it becomes neutral. Contrary to this, the NO_3^- ions move to the anode and are neutralised there. An electric current flows and the copper electrode is plated by the silver atoms. This process is called electroplating, and it is used to protect metals from oxidation or for decoration.

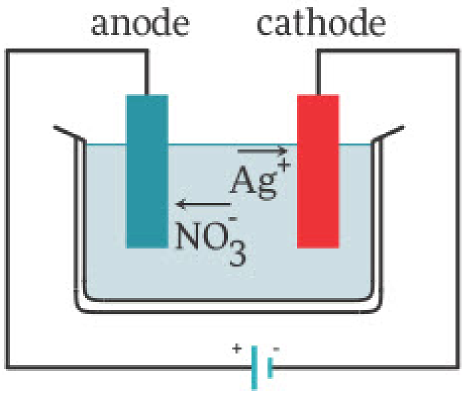


Figure 133

Michael Faraday developed an equation showing the relationship between the amount of substance which is decomposed at the anode or deposited at the cathode and the current passing through the electrolyte. Thus, the amount of substance, decomposed or deposited on the electrodes in electrolysis is proportional to the electric charge that passes through the system.

$$m = k\Delta q = kIt$$

where k is the electrochemical constant of the element in units of kg/C or kg/A·s, I is current and t is the time period in seconds.

In electrolysis, water can be separated into its elements, oxygen and hydrogen, as shown in Figure 134. To increase the conductivity of water, we can add either some acid or salt. The chemical reaction that occurs in the electrolysis of water is

$$2H_2O \rightarrow 2H_2 + O_2$$

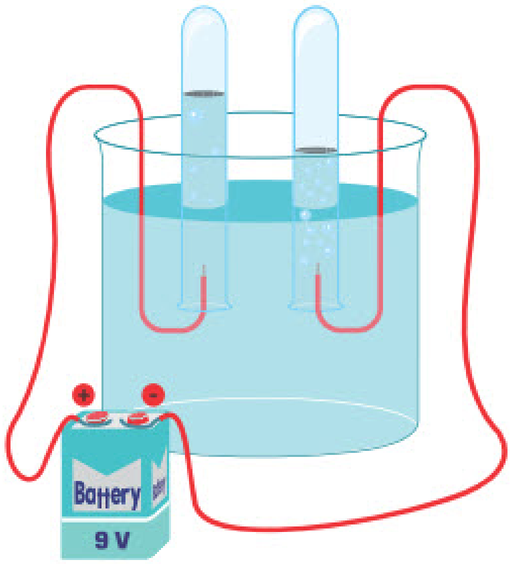


Figure 134

Hence, the volume of hydrogen collected in the tube over the cathode is twice the volume of oxygen collected in its tube over the anode. Experimentally it has been found that when a charge of 1 Coulomb passes through the water electrolysis circuit the volume of hydrogen collected is 0.12 cm^3, and the volume of oxygen is 0.06 cm^3.

Activity

Open Phet Sugar and Salt Solutions. Pour salt and sugar into water. Which one is electrolyte? How does the amount of solute affect the transfer?

Example

What mass of aluminum is deposited in an electrolysis experiment in t = 30 min, if the current is 2 Ampere? (Take k=0.093 mg/C)

Given:

$t = 30\ min = 1800\ s$

$I = 2\ A$

$k = 0.093\ mg/C = 0.093 \cdot 10^{-3}\ g/C = 0.093 \cdot 10^{-6}\ kg/C$

$m = ?$

Formulas:

$m = kIt$

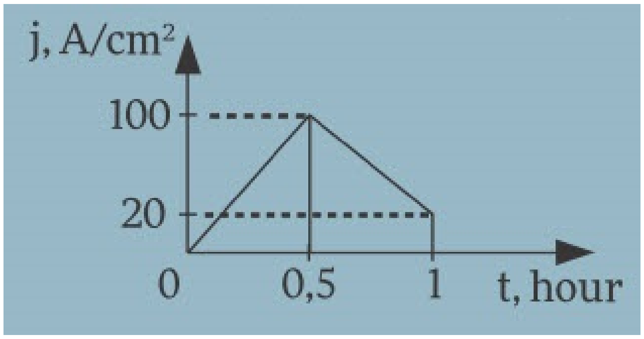
Calculations:

$m = kIt = 0.093 \cdot 10^{-6} \cdot 2 \cdot 1800 = 3.348 \cdot 10^{-4}\ kg$

$m = 0.3348\ g$

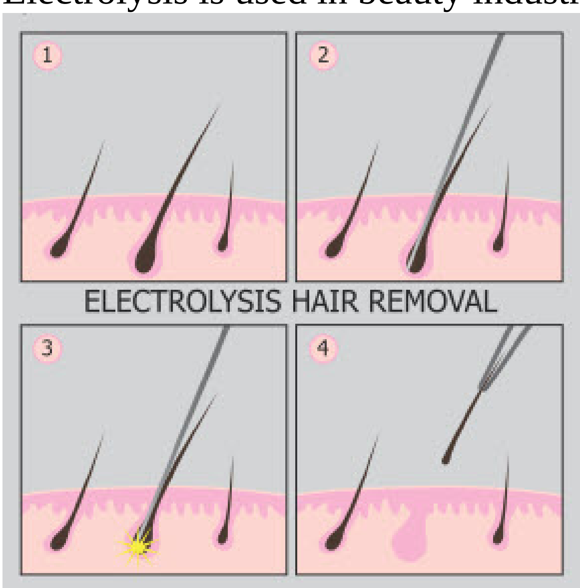
Literacy

1. What is definition of electrolysis? How can you make electrolysis? Where electrolysis is used?
2. Describe movement of ions, protons, neutrons, electrons during electrolysis. Give several examples with different electrolytes. Use drawings to clarify your answer.
3. Silver of mass of 0.67 gram was deposited in electroplating bath in 10 minutes. Ammeter that is connected in series with bath showed 0.90 Ampere.
Is reading of ammeter true?
4. There was experiment that was designed to find electrochemical equivalent of copper. Duration of experiment was 20 minutes, current was 0.5 Ampere, initial mass of cathode was 70.4 gram, final mass of cathode was 70.52 gram. Calculate electrochemical equivalent of copper.
5. Calculate amount of energy needed to obtain 1 kg of copper from $CuSO_4$ solution at voltage of 10 Volt.
6. Electrolysis of copper sulfate solution (blue vitriol, look at figure) lasts 1 hour. Current-time graph of process is shown on the figure. Area of each electrode is 75 cm^2. How much copper will be deposited on electrode?



Is it true?

Electrolysis is used in beauty industry in hair removal process.



Research time

Some vegetables and fruit also conduct electricity. How it works? Write your opinion.

Career

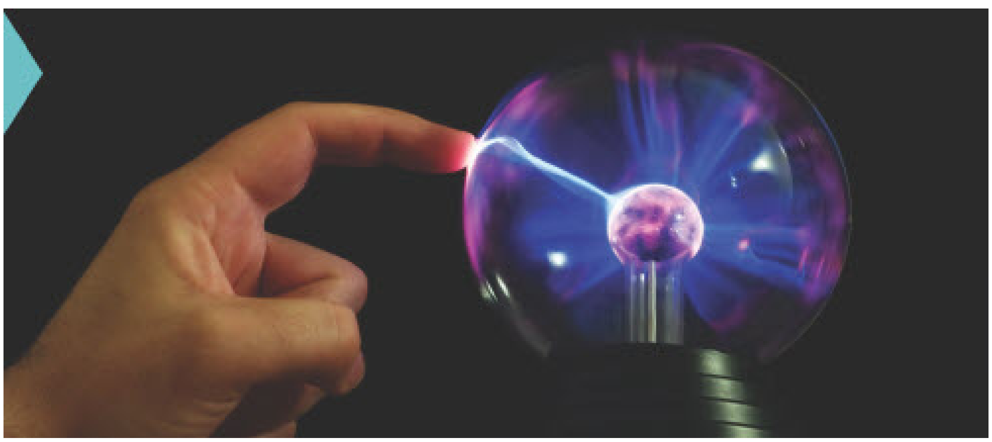
Aluminium factory workers use electrolysis to extract aluminium from its ore.

12.4 ELECTRIC CURRENT IN GASES. ELECTRIC CURRENT IN VACUUM. CATHODE-RAY TUBES

You will

- describe electric current in gases and vacuum.
- explain working principles and areas of application of cathode-ray tubes.

Question



Why do you see ‘light filament’ between centre of glass sphere and finger? What is inside of glass sphere? How does it work?

Electric current in gases

Gases are insulators. They do not conduct electric current because they do not contain ions under normal conditions. A gas can become a conductor when its atoms become positively or negatively charged ions in a given process, for example by heating it, as shown in Figure 135.

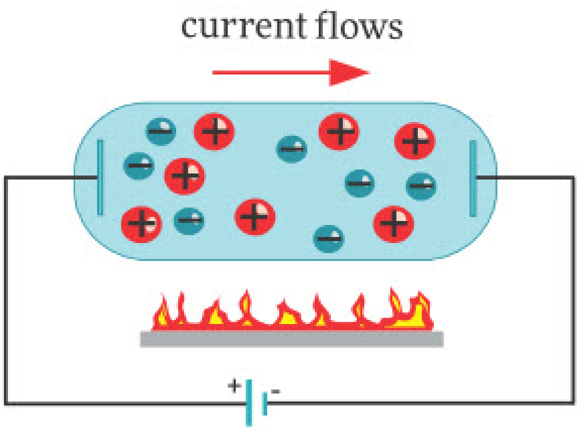


Figure 135

As we heat the gas, the kinetic energy of the atoms increases and when the kinetic energy of an atom exceeds the binding energy with its electrons, they begin to ionise. If the temperature of the gas is large enough, all atoms ionise and the gas becomes a mixture of ions and electrons. This state of a substance is called a plasma. A substance in a plasma state is a good conductor of electric current.

Gas atoms can also be ionised by the effects of electromagnetic radiation and charged particles as indicated in Figure 136. Ionisation by an external source, such as heating or electromagnetic radiation is called the discharge of a gas by external ionisers.

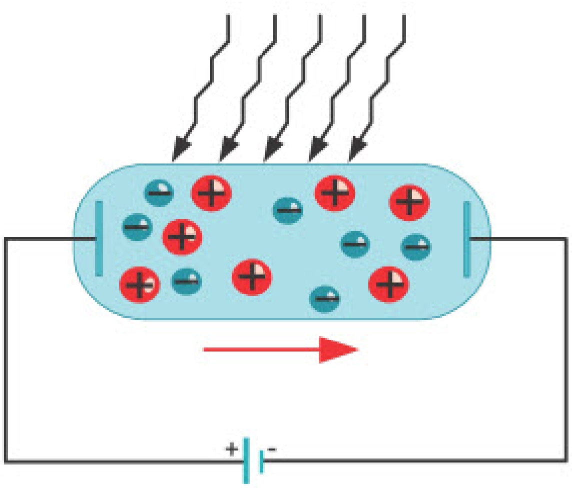


Figure 136

An electric current can flow through a gas without employing an external ioniser. This occurs when the electric field inside the gas is very high, due to the presence of a high voltage. An electron is accelerated by this electric field and gains a high enough kinetic energy over a small distance, that when it strikes an atom, it knocks out an electron and the atom becomes an ion. These, two electrons then have high enough kinetic energy to strike other atoms, ionise them also, and so on. The number of electrons and ions increases in the gas and an electric current begins to flow through the gas, as shown in Figure 137. This kind of ionisation is called discharge by self-ionisers.

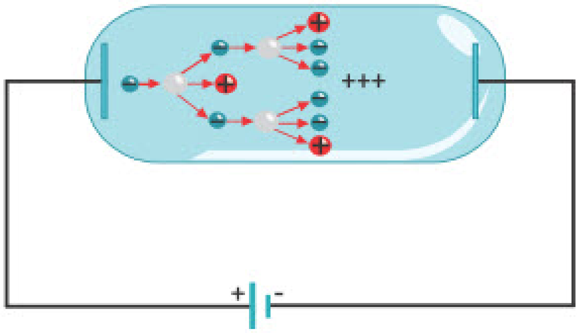


Figure 137

The phenomenon of gaseous discharge is used to construct light bulbs and tubes containing gas, especially for advertising as shown in Figure 138.

Figure 138

Electric field and voltage inside of discharge tubes are related like this:

$$E = \frac{V}{d}$$

E – electric field between two points [Volt/metre]
V– voltage between two points [Volt]
d– distance between two points [metre]

Electric currents in vacuum

Vacuum contains no charged particles, so it behaves as an insulator. However, metal electrode surfaces can cause a region of the vacuum to become conductive by injecting free electrons or ions through either field electron emission or thermionic emission.

Vacuum tube (or vacuum diode) is a device that controls electric current between electrodes in an evacuated container, Figure 139.

Figure 139

The cathode ray tube (CRT) is a vacuum tube that contains one or more electron guns and a phosphorescent screen, and is used to display images, Figure 140. It modulates, accelerates, and deflects electron beam onto the screen to create the images. The images may represent electrical waveforms (oscilloscope), pictures (television, computer monitor), radar targets, or others, Figure 141.

Figure 140

Figure 141

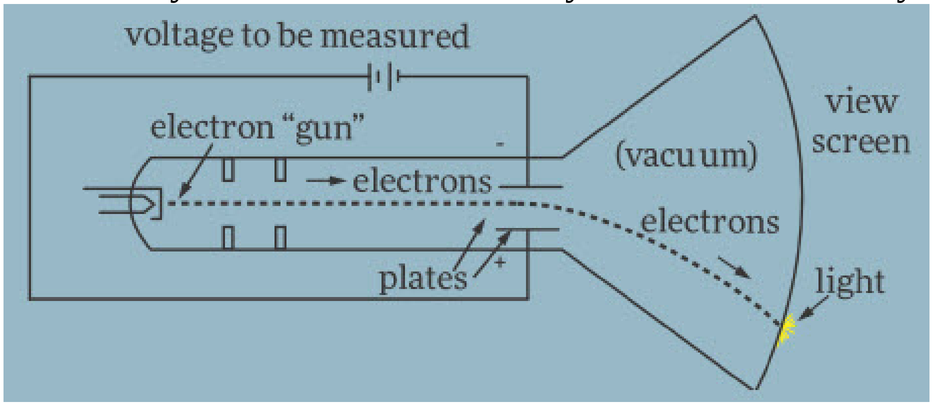
Example

Breakdown voltage of air is 30 kV/cm. Tesla coil can produce sparks of length of 3.5 metre. What is voltage of Tesla coil?

Given:	Formulas:	Calculations:
$E = 30 \cdot 10^5\ V/m$ $d = 3.5\ m$ $V = ?$	$E = \frac{V}{d}$	$V = Ed$ $V = 30 \cdot 10^5 \cdot 3.5$ $V = 10.5 \cdot 10^6\ V$

Literacy

1. What is cathode-ray tube? How does cathode-ray tube work? Where cathode-ray tube is used? How can you make cathode-ray tube?



2. Why does lightning strike? How many Volts and Amperes are there in lightning? How can you use energy of lightning?
3. Parallel plate capacitor is connected to 6 kV voltage source. What is the separation between the plates during dielectric breakdown? Dielectric strength of air is 3 MV/m.
4. Maximum current on anode of vacuum diode is 50 mA. How many electrons are emitted each second from cathode?
5. Voltage of CRT (cathode ray tube) is 16 kV. Distance between anode and phosphorescent screen is 30 cm. How many seconds do electrons travel from anode to phosphorescent screen?
6. Electrons of 8 keV energy are moving between the plates of capacitor in CRT (cathode ray tube). Length of capacitor is 4 cm, separation between the plates of capacitor is 2 cm. What voltage should you apply to capacitor to deflect electron beam by 0.8 cm?

Activity

How does lightning happen? Illustrate and explain the process.

Research time

Open "Phet Discharge Lamps". How does the colour change? Observe and write down your conclusion.

Is it true?

Cathode ray tube was the first gaming device.

Physics in life

The most common example of plasma is lightning. Why?

LAB WORK #9

Title:

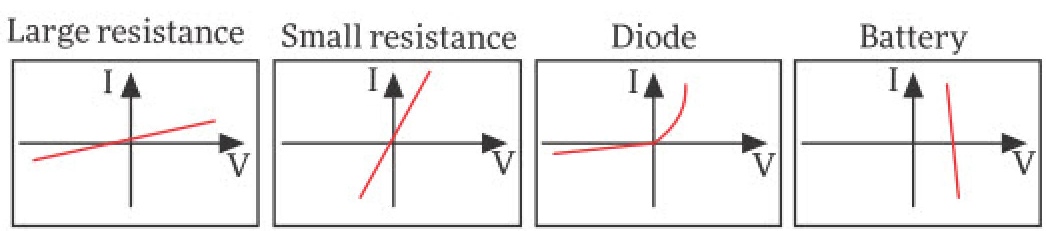
Current-voltage characteristic of incandescent light bulb, resistor and semiconductor diode.

You will

- investigate current-voltage characteristic of incandescent light bulb, resistor and semiconductor diode.

Theory:

On the figure you can see current-voltage characteristic of some circuit elements.



To plot current-voltage characteristic of device you need to change voltage and current applied to device and record them in table. Then you plot the graph by using data in the table.

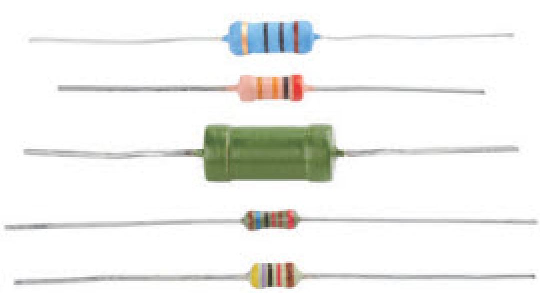
Equipment:

1. Safety glasses

2. Gloves

3. Incandescent light bulb

4. Resistor



5. LED (or semiconductor diode)

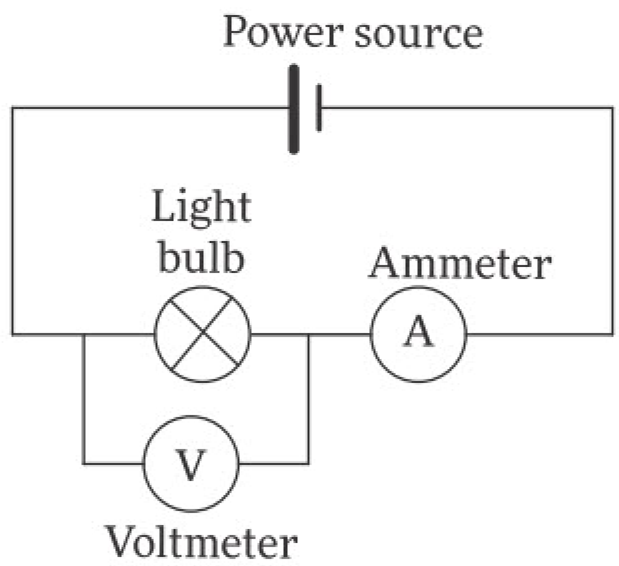
6. Voltmeter and ammeter (or multimeter)

7. Power source

8. Connecting wires

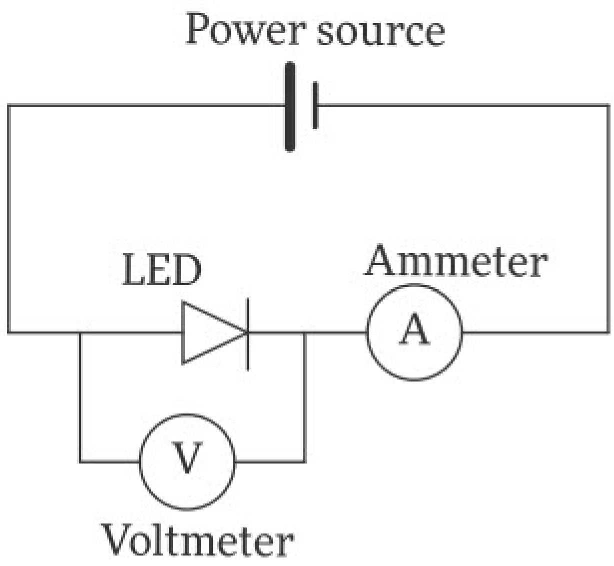
Procedure:

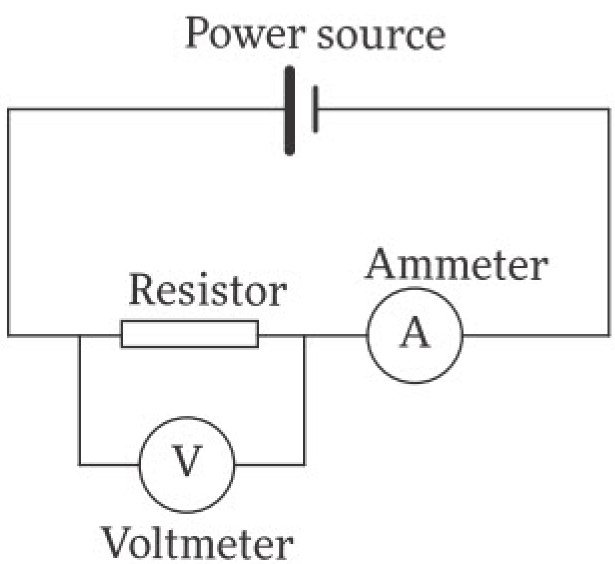
1. Use connecting wires to connect power source, incandescent light bulb and ammeter in series as shown in the figure.



2. Connect voltmeter in parallel to incandescent light bulb.
3. Turn on power source and arrange voltage to be 10 Volt.
4. Write down value of current in table.
5. Decrease voltage by 1 Volt.
6. Repeat steps 4 and 5 until voltage becomes zero.
7. Change polarity of power source (plus-minus wires). That means voltage becomes negative (minus) so you write current values in lower half of table.

8. Repeat steps 3, 4, 5, 6.
9. Repeat steps 1-8 for resistor and LED.





10. Use table to plot I-V graphs of incandescent light bulb, resistor, and LED.

Conclusion:

1. What is the difference between I-V graphs of light bulb, resistor and LED? Why are they different (or same)?

Incandescent light bulb		Resistor		LED	
Voltage (Volt)	Current (Ampere)	Voltage (Volt)	Current (Ampere)	Voltage (Volt)	Current (Ampere)
10		10		10	
9		9		9	
8		8		8	
7		7		7	
6		6		6	
5		5		5	
4		4		4	
3		3		3	
2		2		2	
1		1		1	
0		0		0	
-1		-1		-1	
-2		-2		-2	
-3		-3		-3	
-4		-4		-4	
-5		-5		-5	
-6		-6		-6	
-7		-7		-7	
-8		-8		-8	
-9		-9		-9	
-10		-10		-10	

LAB WORK #10

Title:

Charge of monovalent ion.

You will

- experimentally determine elementary charge during electrolysis.

Theory:

From previous topics you know this formulas:

$$\frac{m}{M} = \frac{N}{N_A}$$

$$I = \frac{q}{t}$$

$$q = N(ze)$$

m: mass of substance deposited during electrolysis, kg
M: molar mass of substance, kg/mole
N: Number of ions deposited during electrolysis
$N_A = 6.02 \cdot 10^{23}$ Avogadro's number
I: current during electrolysis, Ampere
q: charge traveled during electrolysis, Coulomb
t: time of electrolysis, second
z: valence
e: charge of monovalent ion (elementary charge).

Now we use these formulas to obtain formula for e.

m_1: mass of electrode before electrolysis, kg
m_2: mass of electrode after electrolysis, kg

$$q = Nze$$
$$It = Nze$$
$$It = \frac{mN_A}{M} ze$$
$$e = \frac{MIt}{zmN_A}$$
$$e = \frac{MIt}{(m_2 - m_1)zN_A}$$

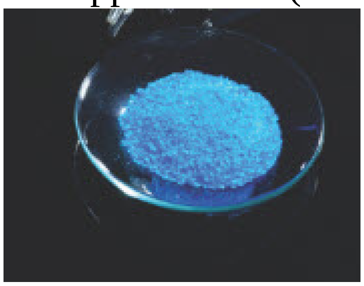
Equipment:

1. Safety glasses

2. Gloves

3. Protective mask

4. Copper sulfate (blue vitriol)

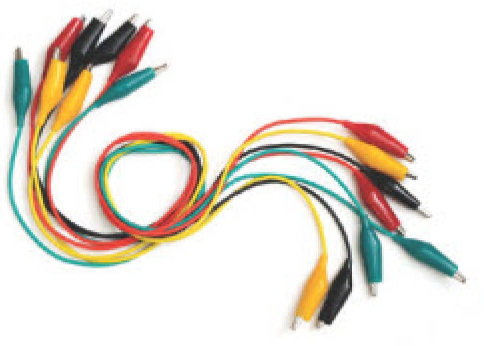


5. Beaker

6. Water

7. Copper electrodes (or graphite electrodes)

8. Connecting wires



9. Scale

10. Ammeter

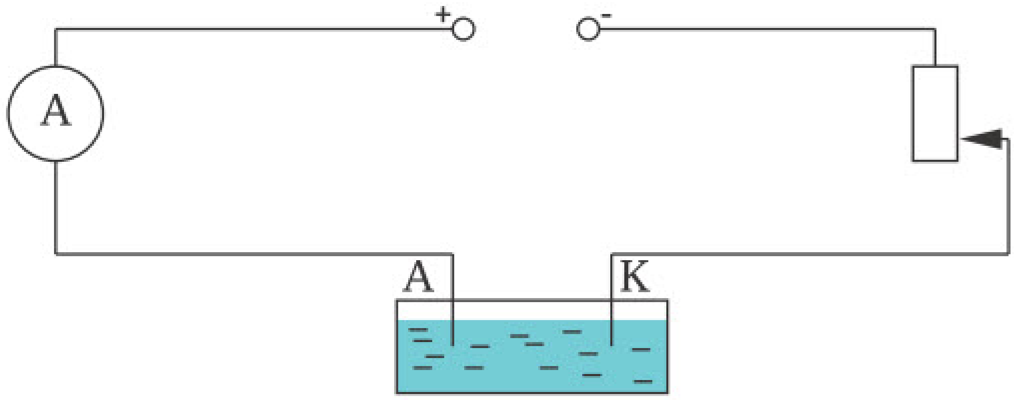
11. Stopwatch

12. Hair dryer or electric heater

13. Power source

Procedure:

1. Dry electrode (cathode) by using hair dryer or electric heater and measure its mass m_1.
2. Prepare solution of copper sulfate $CuSO_4$ in beaker. Use connecting wires and construct circuit shown on the figure.



3. Turn on power source and start stopwatch. Record current I and time t of electrolysis.
4. Turn off power source and stop stopwatch. Dry electrode (cathode) by using hair dryer or electric heater and measure its mass m_2.
5. Write all data in table and calculate charge of monovalent ion e. Valence of copper is 2, molar mass of copper is $63.5 \cdot 10^{-3}$ kg/mole.

Conclusion:

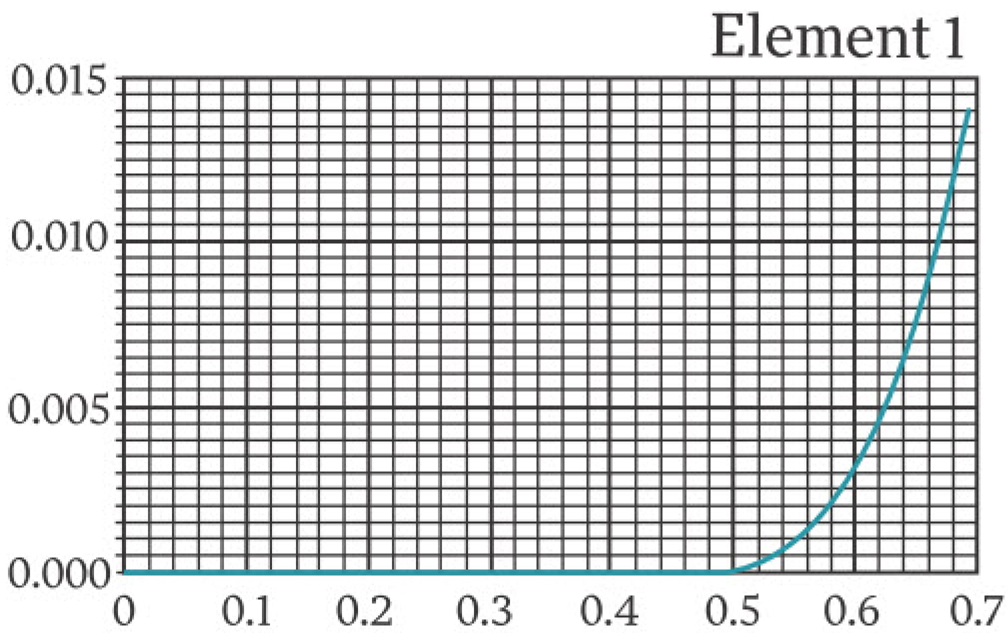
1. Is your answer larger or smaller than $e = 1.6 \cdot 10^{-19}$ C?

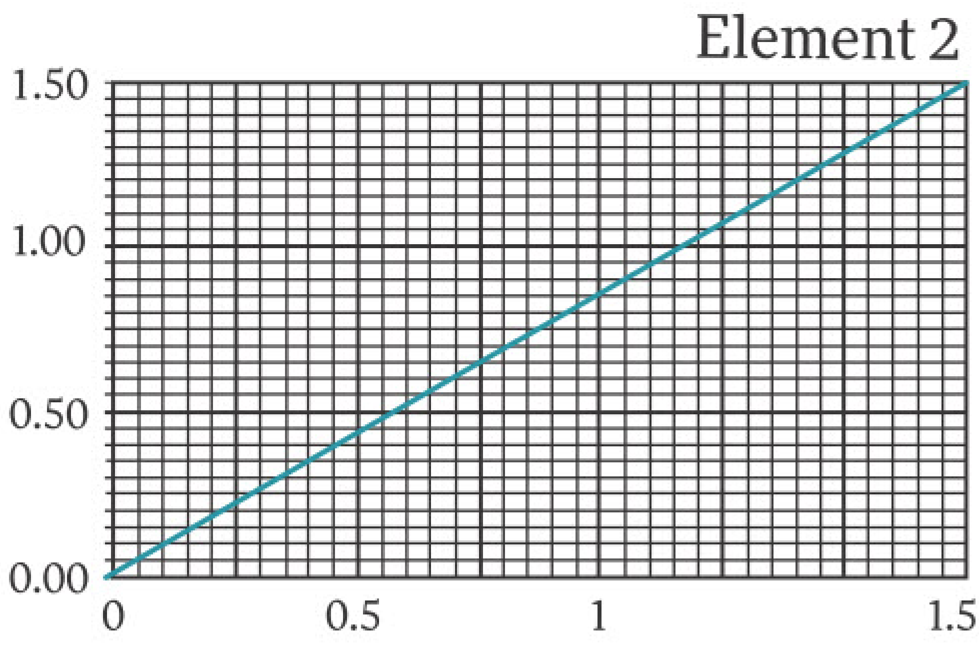
2. What is percent error of your answer compared to $e = 1.6 \cdot 10^{-19}$ C?

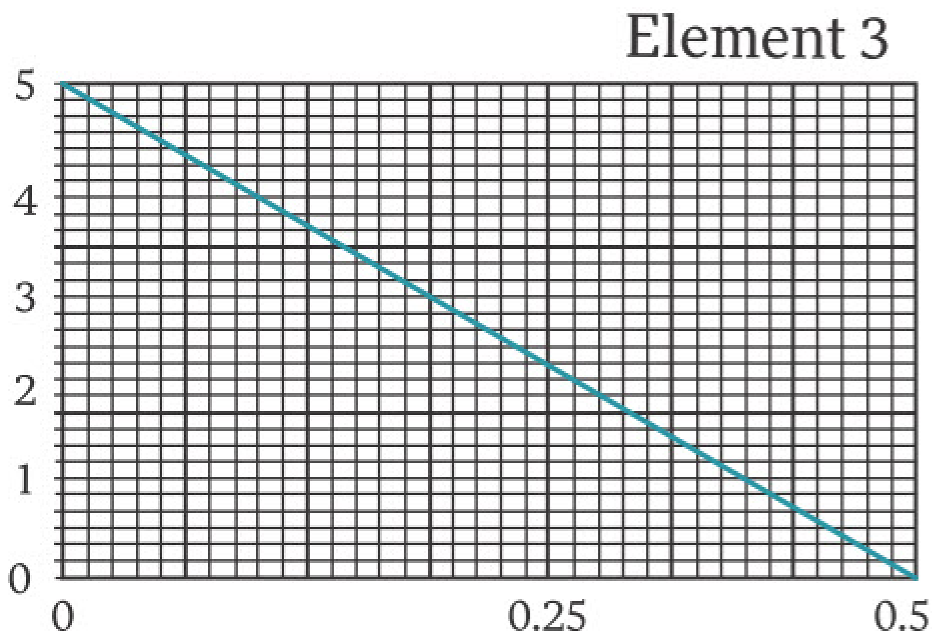
3. What are other experimental ways to determine $e = 1.6 \cdot 10^{-19}$ C ?

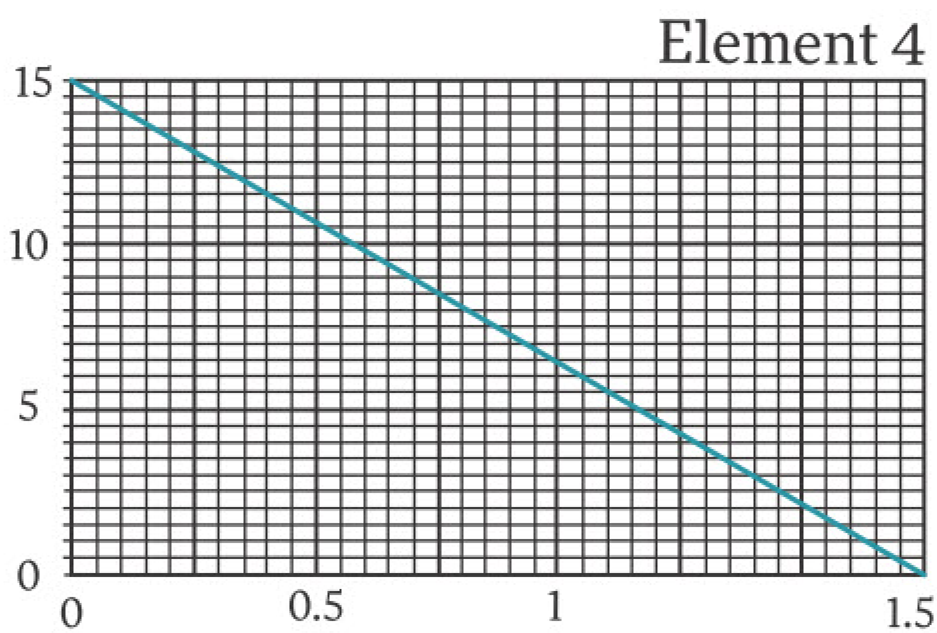
4. What is the meaning of $e = 1.6 \cdot 10^{-19}$ C?

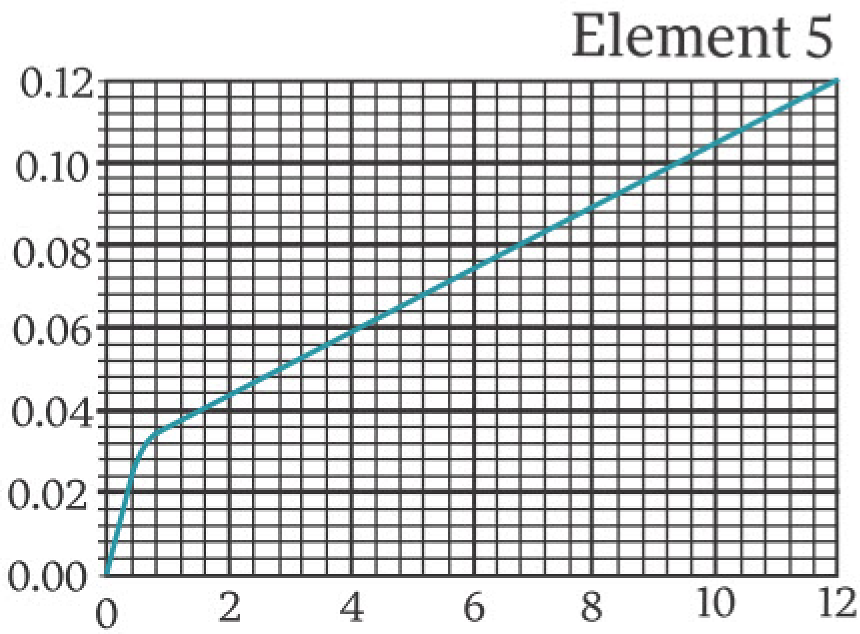
CHECK YOURSELF

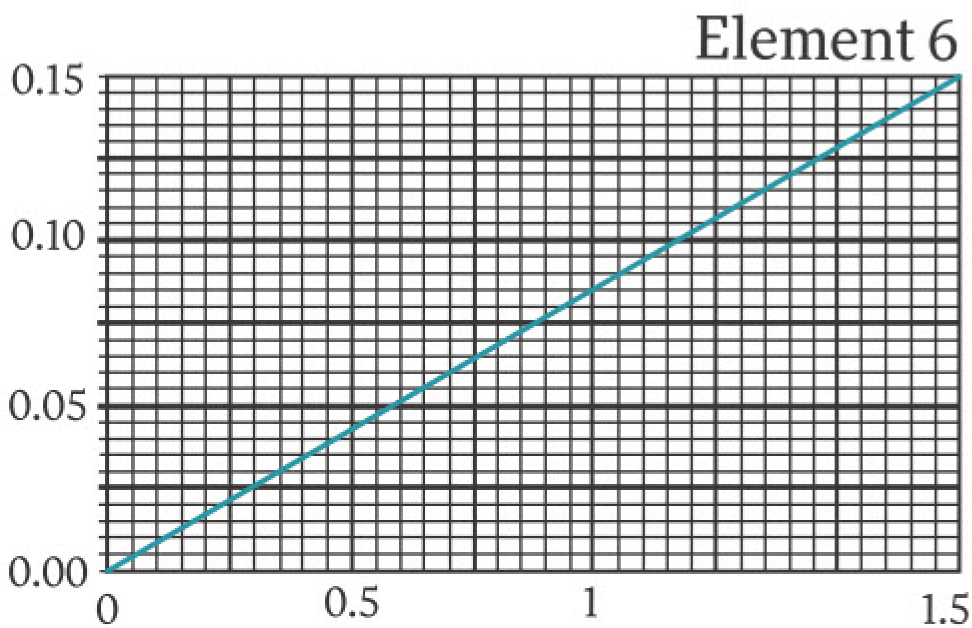





Element 3
5
4
3
2
1
0
0
0.25
0.5


Element 4
15
10
5
0
0
0.5
1
1.5





There are six I-V curves of different circuit elements. Use I-V curves to answer questions 1-45.

1. What parameter is represented by vertical axis of the graphs?
A) Power (Watt)
B) Voltage (Volt)
C) Resistance (Ohm)
D) Current (Ampere)

E) There is no right answer

2. What parameter is represented by horizontal axis of the graphs?
A) Power (Watt)
B) Voltage (Volt)
C) Resistance (Ohm)
D) Current (Ampere)
E) There is no right answer

3. What is name of the Element 1?
A) Resistor
B) Battery
C) Diode
D) Incandescent light bulb
E) There is no right answer
4. What is name of the Element 2?
A) Resistor
B) Battery
C) Diode
D) Incandescent light bulb
E) There is no right answer

5. What is name of the Element 3?
A) Resistor
B) Battery
C) Diode
D) Incandescent light bulb
E) There is no right answer

6. What is name of the Element 4?
A) Resistor

B) Battery
C) Diode
D) Incandescent light bulb
E) There is no right answer

7. What is name of the Element 5?
A) Resistor
B) Battery
C) Diode
D) Incandescent light bulb
E) There is no right answer

8. What is name of the Element 6?
A) Resistor
B) Battery
C) Diode
D) Incandescent light bulb
E) There is no right answer

9. How does resistance of Element 1 change when voltage increases?
A) Increases
B) Decreases
C) Stays constant
D) It is impossible to determine
E) There is no right answer

10. How does resistance of Element 2 change when voltage increases?
A) Increases
B) Decreases
C) Stays constant

D) It is impossible to determine
E) There is no right answer
11. How does resistance of Element 5 change when voltage increases?
A) Increases
B) Decreases
C) Stays constant
D) It is impossible to determine
E) There is no right answer

12. How does resistance of Element 6 change when voltage increases?
A) Increases
B) Decreases
C) Stays constant
D) It is impossible to determine
E) There is no right answer

13. What is resistance of Element 2?
A) 0.1 Ohm
B) 1 Ohm
C) 10 Ohm
D) 140 Ohm
E) There is no right answer

14. What is resistance of Element 5 in range between 6 Volt and 10 Volt?
A) 0.1 Ohm
B) 1 Ohm
C) 10 Ohm
D) 140 Ohm

E) There is no right answer

15. What is resistance of Element 6?
A) 0.1 Ohm
B) 1 Ohm
C) 10 Ohm
D) 140 Ohm
E) There is no right answer

16. What is “threshold voltage” of semiconductor diode?
A) 0.07 Volt
B) 0.7 Volt
C) 7 Volt
D) 70 Volt
E) There is no right answer

17. Among six elements shown on the graphs there are two batteries. One of them has large EMF, second one has small EMF. What is EMF of large battery?
A) 0.5 Volt
B) 1.0 Volt
C) 1.5 Volt
D) 2.0 Volt
E) There is no right answer

18. Among six elements shown on the graphs there are two batteries. One of them has large EMF, second one has small EMF. What is EMF of small battery?
A) 0.5 Volt
B) 1.0 Volt

C) 1.5 Volt
D) 2.0 Volt
E) There is no right answer

19. Among six elements shown on the graphs there are two batteries. One of them has large EMF, second one has small EMF. What is internal resistance of large battery?
A) 0.1 Ohm
B) 1 Ohm
C) 10 Ohm
D) 140 Ohm
E) There is no right answer

20. Among six elements shown on the graphs there are two batteries. One of them has large EMF, second one has small EMF. What is internal resistance of small battery?
A) 0.1 Ohm
B) 1 Ohm
C) 10 Ohm
D) 140 Ohm
E) There is no right answer

21. What is short-circuit current of large battery?
A) 20 A
B) 15 A
C) 10 A
D) 5 A
E) There is no right answer

22. What is short-circuit current of small battery?

A) 20 A
B) 15 A
C) 10 A
D) 5 A
E) There is no right answer

23. Element 1 and Element 2 are connected in circuit. What is the current in the circuit?
A) 148.51 mA
B) 15 A
C) 1.36 A
D) 0
E) 49.50 mA

24. Element 1 and Element 4 are connected in circuit. What is the current in the circuit?
A) 148.51 mA
B) 9 A
C) 1.36 A
D) 0
E) 49.50 mA

25. Element 1 and Element 3 are connected in circuit. What is the current in the circuit?
A) 148.51 mA
B) 15 A
C) 1.36 A
D) 0
E) 49.50 mA

26. Element 1 and Element 5 are connected in circuit. What is the current in the circuit?
A) 148.51 mA
B) 15 A
C) 1.36 A

D) 0
E) 49.50 mA

27. Element 1 and Element 6 are connected in circuit. What is the current in the circuit?
A) 148.51 mA
B) 15 A
C) 1.36 A
D) 0
E) 49.50 mA

28. Element 2 and Element 3 are connected in circuit. What is the current in the circuit?
A) 148.51 mA
B) 454.55 mA
C) 1.36 A
D) 0
E) 49.50 mA

29. Element 2 and Element 4 are connected in circuit. What is the current in the circuit?
A) 148.51 mA
B) 454.55 mA
C) 1.36 A
D) 0
E) 49.50 mA

30. Element 2 and Element 5 are connected in circuit. What is the current in the circuit?
A) 148.51 mA
B) 454.55 mA
C) 1.36 A
D) 0
E) 49.50 mA

31. Element 2 and Element 6 are connected in circuit. What is the current in the circuit?
A) 148.51 mA
B) 454.55 mA
C) 1.36 A
D) 0
E) 49.50 mA

32. Element 3 and Element 4 are connected in circuit. What is the current in the circuit?
A) 0
B) 5 A
C) 10 A
D) 15 A
E) There is no right answer

33. Element 3 and Element 5 are connected in circuit. What is the current in the circuit?
A) 6.87 mA
B) 26.87 mA
C) 46.87 mA
D) 66.87 mA
E) 86.87 mA

34. Element 3 and Element 6 are connected in circuit. What is the current in the circuit?
A) 148.51 mA
B) 454.55 mA
C) 1.36 A
D) 0
E) 49.50 mA

35. Element 4 and Element 5 are connected in circuit. What is the current in the circuit?
A) 0.44 mA
B) 20.44 mA
C) 40.44 mA
D) 60.44 mA
E) 80.44 mA

36. Element 4 and Element 6 are connected in circuit. What is the current in the circuit?
A) 148.51 mA
B) 454.55 mA
C) 1.36 A
D) 0
E) 49.50 mA
37. Element 2 and Element 6 are connected in series. What is equivalent resistance of the circuit?
A) 9 Ohm
B) 100 Ohm
C) 0.91 Ohm
D) 11 Ohm
E) There is no right answer

38. Element 2 and Element 6 are connected in parallel. What is equivalent resistance of the circuit?
A) 9 Ohm
B) 100 Ohm
C) 0.91 Ohm
D) 11 Ohm
E) There is no right answer

39. Element 6, Element 2, and Element 3 are connected in circuit. What is the current in the circuit?
A) 15.05 mA
B) 25.05 mA
C) 35.05 mA
D) 45.05 mA
E) 55.05 mA

40. Element 6, Element 2, and Element 4 are connected in circuit. What is the current in the circuit?
A) 35.14 mA
B) 135.14 mA
C) 235.14 mA
D) 335.14 mA
E) 435.14 mA

41. Element 6 and Element 2 are connected in parallel. Then Element 3 is connected to them in series. What is the current in the circuit?
A) 695.5 mA
B) 595.5 mA
C) 495.5 mA
D) 395.5 mA
E) 295.5 mA

42. Element 6 and Element 2 are connected in parallel. Then Element 4 is connected to them in series. What is the current in the circuit?
A) 4.49 A
B) 3.49 A
C) 2.49 A
D) 1.49 A
E) 0.49 A
43. Element 6, Element 3, and Element 1 are connected in circuit. What is the current in the circuit?

A) 49.5 mA
B) 39.5 mA
C) 29.5 mA
D) 19.5 mA
E) 0

44. Element 2, Element 3, and Element 1 are connected in circuit. What is the current in the circuit?
A) 454.55 mA
B) 354.55 mA
C) 254.55 mA
D) 154.55 mA
E) 0

45. Which element does have the largest resistance?
A) Element 1
B) Element 2
C) Element 3
D) Element 4
E) Element 5

Electric Current in Various Media

1. Which substances are intermediate to conductors and insulators in their ability to conduct electric charge?
A) metals
B) semiconductors
C) nonconductors
D) superconductors
E) none of above

2. A light bulb whose filament is made of tungsten has a resistance of 20 Ω at 20 ºC. What is its resistance when its temperature reaches 1020 ºC? (The temperature coefficient of resistance for tungsten is $4.5.10^{-3}$ $(^{\circ}C)^{-1}$)
A) 10Ω
B) 100Ω
C) 110Ω
D) 120Ω
E) 1000Ω

3. What is a superconductor?
A) A material having a very strong structure.

B) A material having a very small electrical resistance.
C) A material having a use in high speed racing cars.
D) A material having zero electrical resistance.
E) A material at absolute zero temperature.

4. What are the charge carriers in semiconductors?
A) electrons
B) protons
C) ions
D) electrons and ions
E) electrons and holes

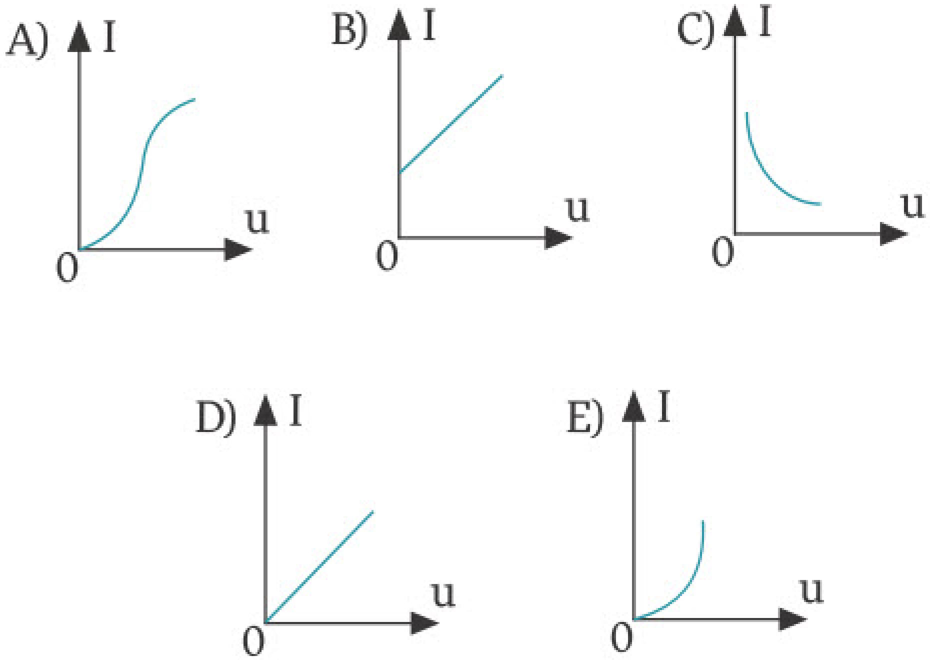
5. When a semiconductor is doped with an impurity containing three valence electrons, the semiconductor is called a/an ....
A) n-type
B) p-type
C) pn junction
D) npn
E) pnp

6. An impurity with five valence electrons is added to semiconductors. The impurity is called a/an ....
A) donor
B) acceptor
C) diode
D) hole
E) silicon
7. A circuit element represented by

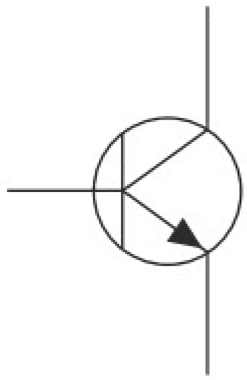
is called a ....
A) transistor
B) capacitor
C) diode
D) switch

E) fuse

8. Which of the following graphs represents the U-I relationship of a diode?



9. The figure shown to the right represents a circuit element that is called a/an ___________________



A) diode
B) npn transistor
C) pnp transistor
D) transformer
E) digital receiver

10. What is the main circuit element in an amplifier?
A) transformer
B) diode
C) transistor
D) capacitor
E) microphone

11. What are the charge carriers in an electric current flowing through a liquid?
I. Electrons
II. Holes
III. Ions
A) I
B) II
C) I, II
D) I, III
E) I, II, III

12. What is the time required to obtain 3.3 kg copper by electrolysis if the current is 100 A? ($k=3.3\cdot10^{-7}$ kg/A ·t)
A) 10 s
B) 102 s
C) 103 s
D) 105 s
E) 107 s

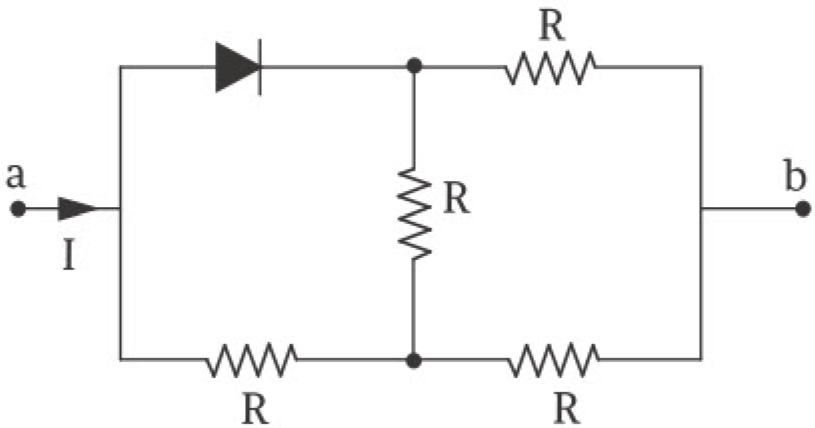
13. Which particles cause a gas to discharge by self ionisation?
A) protons
B) nucleus
C) electrons
D) ions

E) gas molecules

14. Metals which have relatively high resistivities are better to use in the manufacture of __________
A) Wires
B) Heaters
C) Solenoids
D) High voltage cables
E) None of the above

15. When the temperature of a metal wire decreases, the resistance of the wire also decreases because _________
A) Energy of the wire decreases.
B) Cross-sectional area of the wire decreases.
C) Number of electrons in the wire decreases.
D) Number of electrons colliding with atoms in the wire decreases.
E) Number of atoms in the wire decreases.

16. Which of the following should be added to silicon to obtain an n-type semiconductor?
A) Germanium (4)
B) Tin (4)
C) Aluminum (3)
D) Arsenic (5)
E) None of the above
17. What is the equivalent resistance of the circuit shown in the figure if point “a” is connected to the “-” and point “b” to the “+” terminal of a source?



A) R/2
B) 5R/3
C) 2R/3
D) 9R/4
E) 2R

18. The ratio of the mass deposited in an electrolysis process to the charge passing through the circuit is the __________
A) Molar mass
B) Avagadro’s number
C) Faraday’s constant
D) Electrochemical constant
E) Boltzman’s contant

19. Which of the following circuit elements permits electric current to pass in one direction?
A) Transistor
B) Capacitor
C) Diode
D) Resistance
E) Battery

20. Does potassium become a superconductor if it is cooled to nearly absolute zero?

21. How does the resistance of semiconductors change with temperature?

22. Two kinds of impurity are added to germanium (a) arsenic having 5 valence electrons (b) indium having 3 valence electrons. What kind of semiconductor do we obtain? What will the charge carriers be in each case?

23. What happens when we connect a p-type and an n-type semiconductor to each other?

24. Why do diodes allow electric current to pass through in only one direction? Write down the names of the connections on a diode.

25. For what purposes can a diode be used?

26. Can a diode be used to amplify signals?

27. In a pnp or npn junction the middle layer must be very thin? Why?

28. What mass of aluminum is deposited in an electrolysis experiment in t = 30 min, if the current is 2 A. (Take k=0.093 mg/ C)

29. Copper can be deposited from a copper sulphate solution ($CuSO_4$) when a voltage of 10 V is applied across it. Find the energy required to deposit 1 kg of copper (Take k=0.329 mg/C)

30. In the electrolysis of water, a current of 0.2 A is maintained for 10 min. Determine the volume of hydrogen and oxygen gases collected in the tubes.

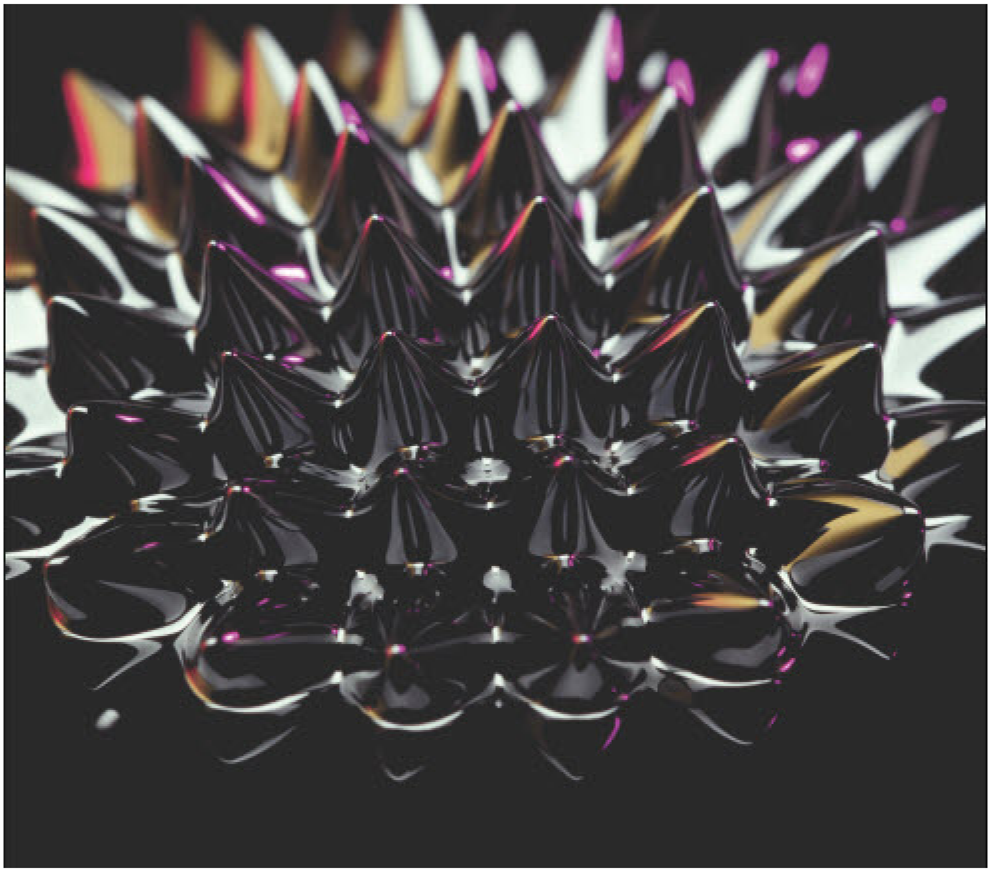
31. Explain the plasma state of matter. Is a substance in the plasma state a good conductor of electric current?

32. What external ionizers can discharge a gas? Explain this process.

33. How is a gas discharged by self-ionizers?

34. Find the magnitude of the electric field across a gas if electrons accelerating over a distance, $d=0.5$ μm can ionise gas atoms with an ionisation energy of $E=2.4\cdot 10^{-18}$ J.

35. A parallel plate capacitor is connected to a source of voltage, $U = 6$ kV. What is the minimum distance between the plates if the air begins to ionise when the electric field strength is 3 MV/m?



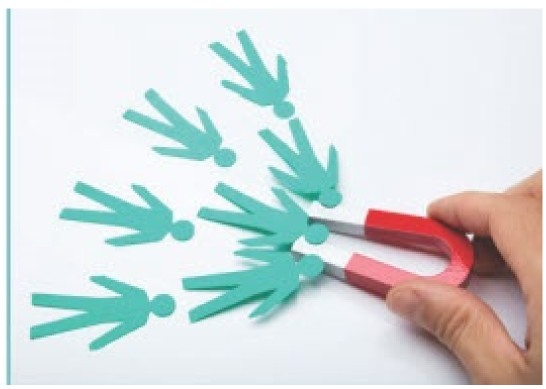
CHAPTER 13: MAGNETISM

13.1 MAGNETIC FIELD (B-FIELD)

You will

- explain physical meaning of magnetic field by using problem solving and modern technology (MagLev trains, etc.)

Question

Which picture is true and which picture is false? Why?

Nature of magnetism

Magnetism plays an important role in our daily lives. In industry, powerful electromagnets are used for lifting and transporting steel plates, scrap iron and other metals, Figure 142. Magnets are also used in various instruments such as miniature electric motors, loud speakers, computer memory (Figure 143).

Figure 142

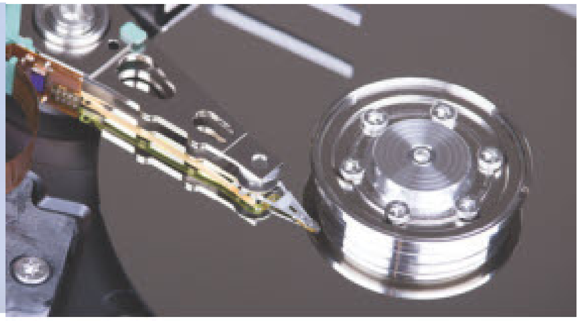


Figure 143

The magnetism of materials depends on domains inside them. A domain is a group of atoms lined up together in a small region, Figure 144.

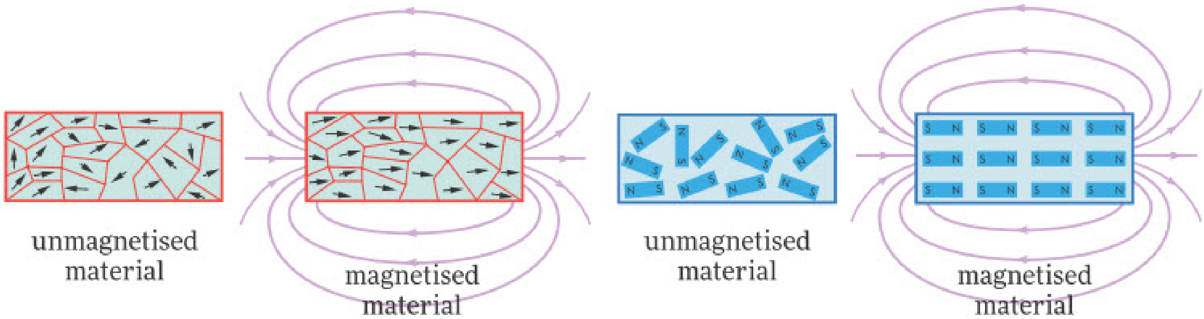


Figure 144

Each domain behaves as a tiny magnet because it includes billions of atoms aligned in the same direction. In an unmagnetised material, domains are not aligned. Each domain points in a different direction so that each domain cancels out the magnetic force of another. For this reason, an unmagnetised iron nail can not display magnetism.

Magnetic field

A magnetic field is defined as a region in which a magnetic force acts. The force one magnet exerts upon another can then be described as the interaction between a magnet and the magnetic field of another magnet.

A magnetic field can be described by its magnitude and direction. The number of magnetic field lines is proportional to the magnitude of the magnetic field.

The direction of the magnetic field at any point surrounding a magnet can be mapped out by placing compass needles in various positions around it, as shown in Figure 145. A compass needle is a permanent magnet and is represented by an arrow. The head of the arrow represents the north pole.

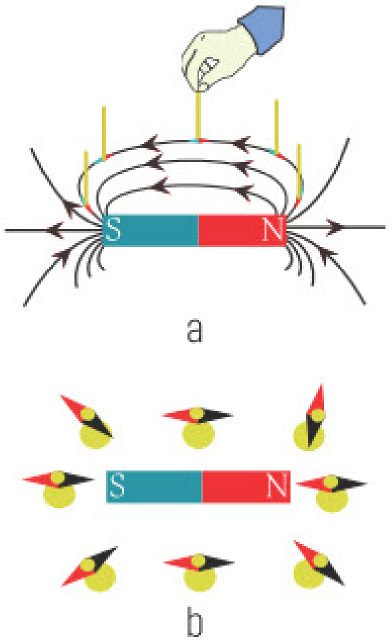


Figure 145

Magnetic field patterns can also be displayed with the help of iron filings, as shown in Figure 146.

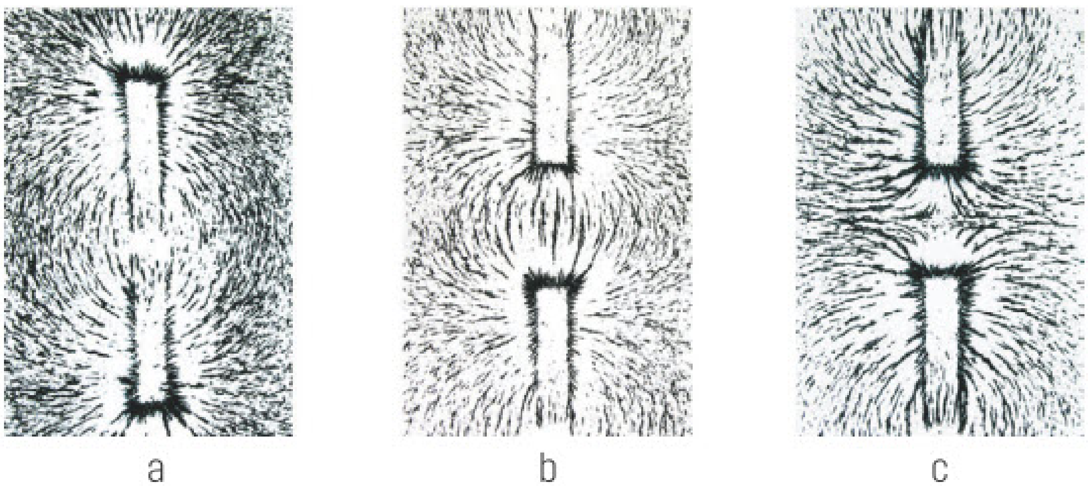


Figure 146

As the compass needles and iron filings indicate, the direction of the magnetic field lines begin at the north pole and go towards the south pole of a magnet, Figure 147.

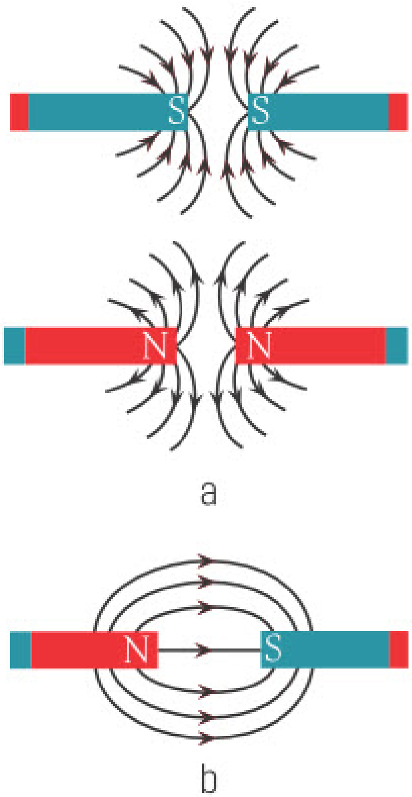


Figure 147

The magnetic field lines do not cross each other and the direction of the magnetic field at a given point is a tangent to that point (a line touching just this single point) and indicates the direction of the magnetic field lines. Magnetic field is represented by the symbol B and the SI unit of magnetic field is the Tesla (T).

Magnetic field of the Earth

The Earth's magnetic field is similar to that of an imaginary bar magnet centred inside the Earth, with the S pole of the magnet in the northern hemisphere and the N pole in the southern hemisphere. Declination between geographical and magnetic pole is approximately 10° .The magnetic field lines of the Earth are nearly parallel to the Earth's surface at the equator, but at the poles they point downward into the Earth. Magnetosphere of the Earth exists at distances more than 70-80 thousands kilometers. The magnetosphere has great importance for life on Earth. It acts like an umbrella, protecting the Earth from hazardous cosmic rays coming from the Sun, Figure 148.

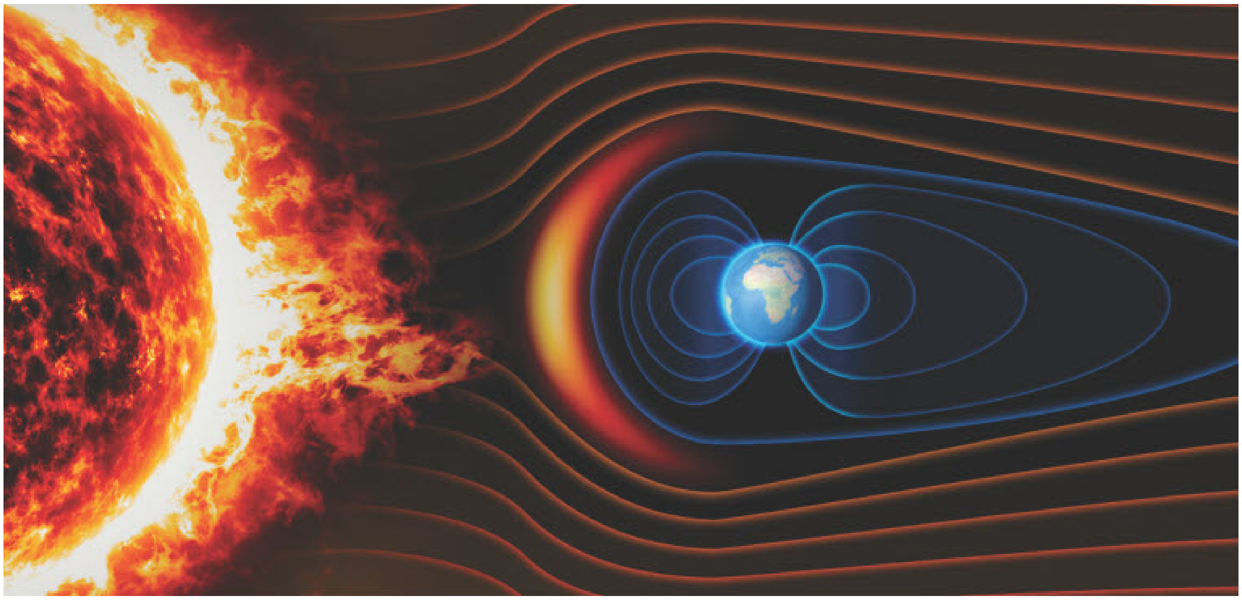
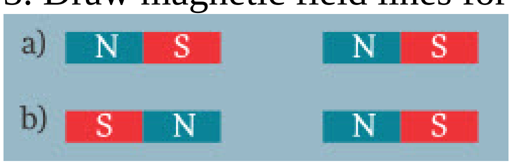


Figure 148

In the absence of the magnetosphere these cosmic rays may cause cancer in humans and animals. Under these circumstances, life on the Earth would end.

Literacy

1. What is definition of “magnet”? How can you make magnet? Where magnets are used?
2. What is definition of “magnetic field”? How can you generate magnetic field? What are applications of magnetic field? Does atom have magnetic field? Do proton, neutron, electron have magnetic field?
3. Draw magnetic field lines for pair of magnets.



4. Draw position of compass that is put in points A, B, C shown on the figure.
5. Why outer casing of compass is made of copper, aluminum, plastics and other materials but it is never made of iron?
6. Show poles of each magnet.

Is it true?

Magnetic field of neutron star is 10^5 stronger than Earth’s magnetic field.

Activity

Open "Phet Magnets and Electromagnets". What are differences between magnet and electromagnet?

Research time

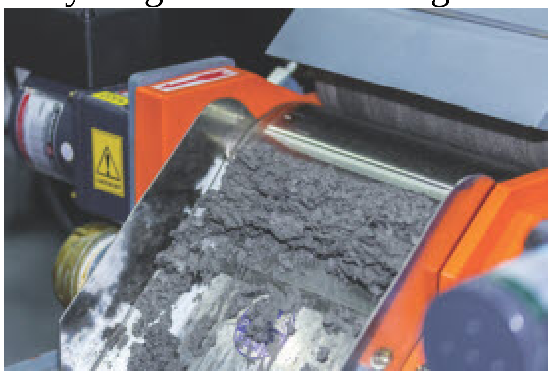
Download an application on your mobile phone that can detect metal. How does it work?

Career

Doctors use Magnetic Resonance Imaging (MRI) to diagnose diseases.

Physics in life

Recycling facilities use magnets to separate iron from other garbage.



13.2 MAGNETIC FIELD OF STRAIGHT WIRE, CIRCULAR LOOP, SOLENOID. RIGHT-HAND RULE FOR MAGNETIC FIELD.

You will

- explain physical meaning of magnetic field by using problem solving and modern technology (MagLev trains, etc.)

Question

Why these compasses don’t show same direction?

In 1820, Hans Christian Oersted (1777 - 1851) discovered that moving electric charges produce magnetism similar to that of a permanent magnet. Oersted’s discovery marked the beginning of an important discipline called electromagnetism.

The Magnetic Field of a Long, Straight Wire

When a current passes through a wire as shown in Figure 149, the compass needles will align in a circular pattern around the wire. The direction of the magnetic field lines can be determined by a simple method called the 'right hand rule-1' (RHR-1): curl the fingers of your right hand into the shape of a half-circle, point your thumb in the direction of the current, the tips of your fingers will point in the direction of the magnetic field, Figure 149.

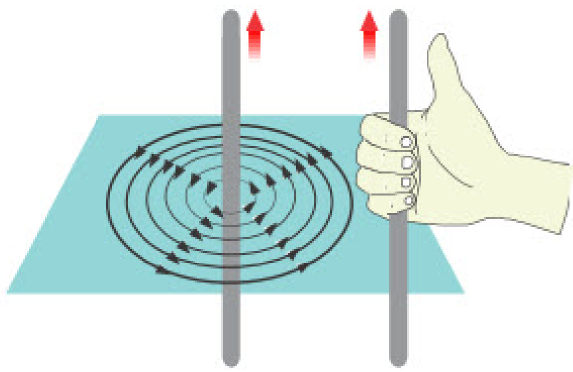


Figure 149

Magnitude of the magnetic field of straight wire at any point is given by:

$$B = \frac{\mu_0 I}{2\pi r}$$

μ_0 is magnetic permeability of free space (vacuum) and has a value $4 \cdot 10^{-7}$ N/A^2.

The directions perpendicular to the page are indicated by the symbols $\otimes$ and $\odot$,

where $\otimes$ – the direction into the page, $\odot$ – the direction out of the page, as shown in Figure 150.

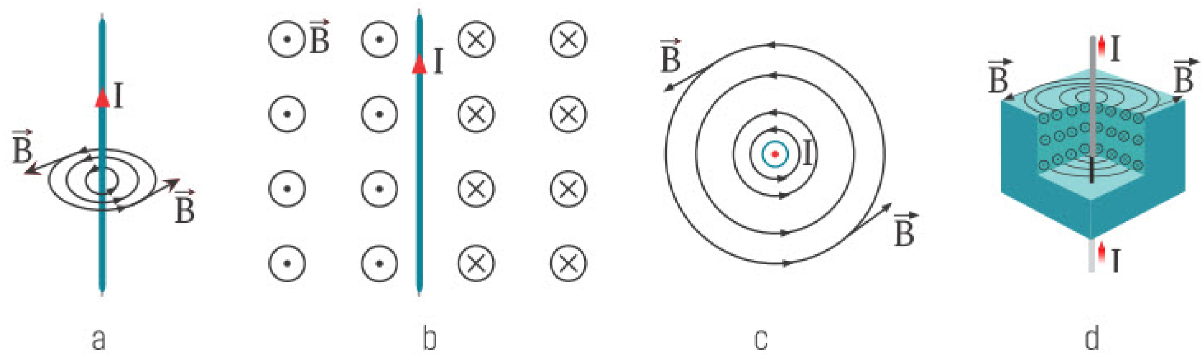


Figure 150

The Magnetic Field of a Current Carrying Loop

If a current-carrying wire is wound in the form of a circular loop, the magnetic field lines are formed at the centre and around the wire as in Figure 151a. For a circular loop, the right hand rule is used in the following way, as shown in Figure 151b.

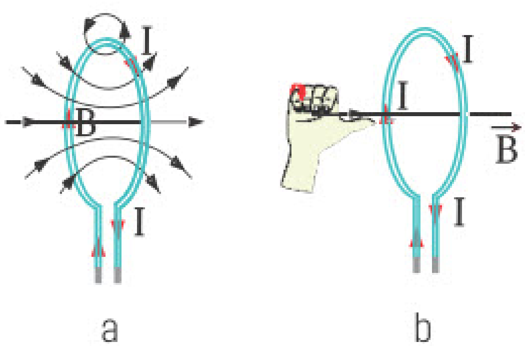


Figure 151

At the centre of a loop of radius r, the magnetic field is perpendicular to the plane of the loop and is represented as:

$$B = \frac{\mu_0 I}{2r}$$

Often the loop consists of N turns of wire, as shown in Figure 152.

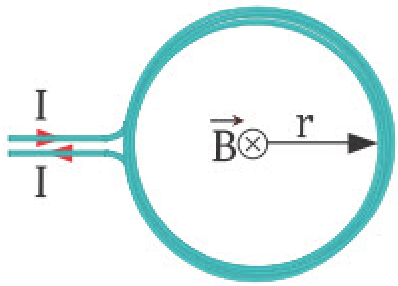


Figure 152

For such a coil the magnetic field at the centre of the circular loop is

$$B = N\frac{\mu_0 I}{2r}$$

The Magnetic Field of a Solenoid

The direction of the field inside the solenoid can be determined using the RHR-1, as shown in Figure 153a. One end of the solenoid behaves like magnet with a north pole and the other as a south pole, as shown in Figure 153b.

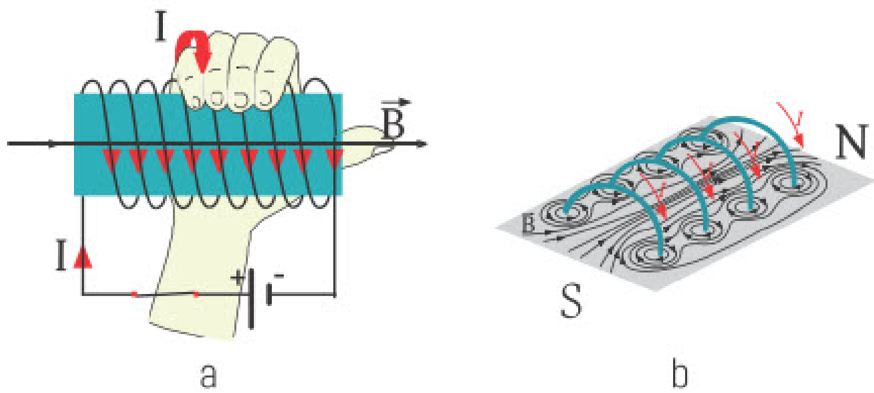


Figure 153

The magnitude of the magnetic field in the interior region of a solenoid is calculated using the relationship

$$B = \frac{\mu_0 N I}{l}$$

where N is the number of turns, l is the length of the solenoid and I is the current in the solenoid.

N/l is the number of turns per unit length, and can be represented by 'n'. So the relationship can be expressed as

$$B = \mu_0 n I$$

Example

What is the magnetic field strength at a distance of 0.05 m from a long, straight wire carrying a current of 5 A?

Given:

$r = 0.05\ m$

$I = 5\ A$

$\mu_0 = 4\pi \cdot 10^{-7}\ T \cdot m/A$

$B = ?$

Formulas:

$$B = \frac{\mu_0 I}{2\pi r}$$

Calculations:

$$B = \frac{\mu_0 I}{2\pi r} = \frac{4\pi \cdot 10^{-7} \cdot 5}{2\pi \cdot 0.05} = 2 \cdot 10^{-5}\ T$$

Example

The magnetic field at the centre of a circular loop of 50 turns of wire carrying a current of 2 A is $6 \cdot 10^{-4}$ T. What is the radius of the loop?

Given:

$N = 50\ turns$

$I = 2\ A$

$B = 6 \cdot 10^{-4}\ T$

$\mu_0 = 4\pi \cdot 10^{-7}\ T \cdot m/A$

$r = ?$

Formulas:

$$B = N\frac{\mu_0 I}{2r}$$

Calculations:

$$r = \frac{\mu_0 N I}{2B}$$

$$r = \frac{4 \cdot 3.14 \cdot 10^{-7} \cdot 50 \cdot 2}{2 \cdot 6 \cdot 10^{-4}}$$

$$r = 0.1047\ m = 10.47\ cm$$

Activity

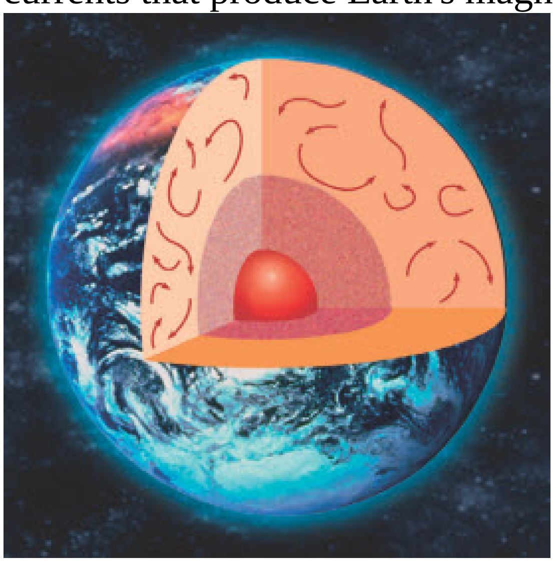
Open "Phet Faraday's law". What is the relationship between magnetic field and current?

Research time

How does metal detector work? Make simple homemade metal detector.

Physics in life

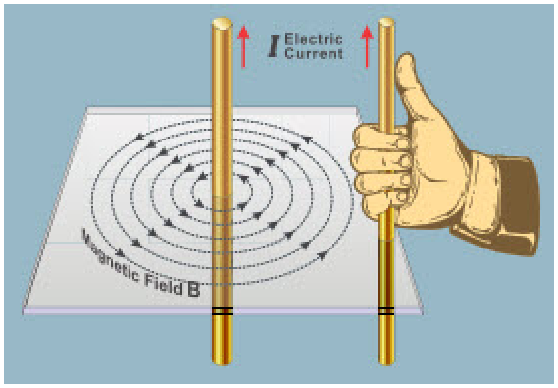
Convection currents in the molten interior of the Earth may cause the electric currents that produce Earth's magnetic field.



Literacy

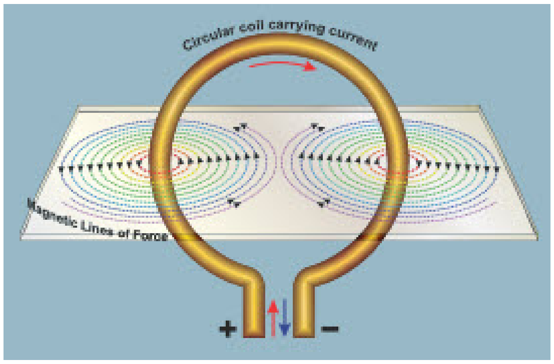
1. What is cause of magnetic field? Why does current generate magnetic field? Can magnetic field generate current? If yes, how?
2. What are “magnetic field lines”? How can you find direction of magnetic field lines of permanent magnet, straight wire, circular loop, solenoid?

3. Calculate magnetic field at point 5 cm away from straight wire that carries 50 A current.

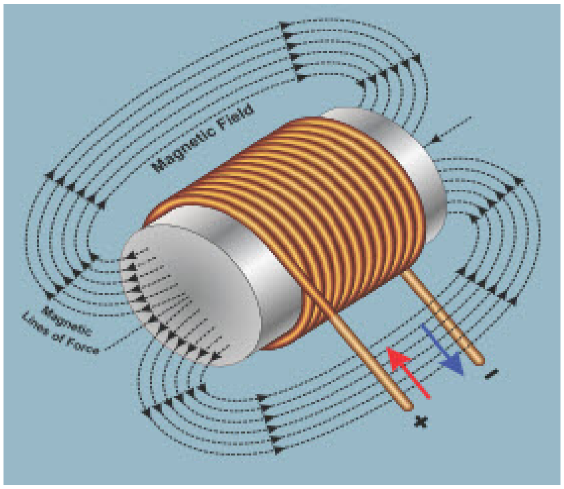


4. There are two long straight parallel wires at a distance of 5 cm from each other that carry 10 A current in same direction. Calculate magnetic field at point located 3 cm away from each wire.

5. Calculate magnetic field in the centre of circular loop of 1 cm radius that carries 1 A current.



6. Iron core (μ=183) is placed inside of 40 cm long solenoid that has 400 turns of wire and carries 8 A current. Calculate magnetic field inside of solenoid.


Magnetic Field
Magnetic
Lines of Force
+
-

13.3 AMPÈRE'S FORCE LAW. RIGHT-HAND RULE FOR AMPERE'S FORCE

You will

- explain working principles of electrical measuring equipment and electric motors.

Question

How does mixer convert electric energy into mechanical energy?

In previous chapter you understood that electric current may act like a magnet, so using this knowledge we could put a magnet near this wire and use energy of repulsion. This principle used in various electric motors which are placed, for example in mixers, vacuum cleaner, electric cars and etc.

The magnetic force on a current carrying conductor

If a current starts to flow through the rod, a magnetic field will be formed around it, Figure 154a. The magnetic field strength on the left side of the wire will increase and on the right side it will decrease due to the wire's magnetic field. Magnetic force acts towards the weaker regions of the magnetic field. So wire will experience a force due to the static magnetic field as shown in Figure 154b.

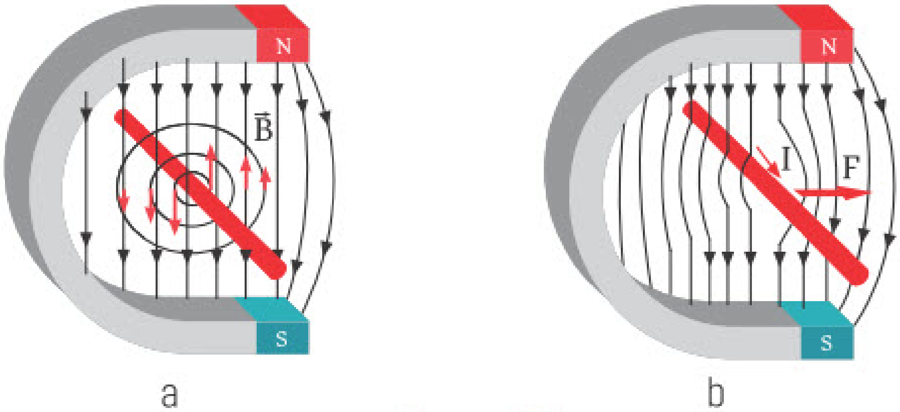


Figure 154

The direction of the magnetic force is given by the right hand rule-2 (RHR-2). The rule is shown in Figure 155. Your fingers indicate the direction of the magnetic field, your thumb indicates the direction of current and your palm indicates the direction of the magnetic force. This describes the direction of the magnetic force. What about its magnitude? Experiments have shown that, the magnitude of the magnetic force is directly proportional to the current I in the wire, the length L of the wire in the magnetic field, and the magnetic field B. The force is strongest when the wire is perpendicular to the field lines.

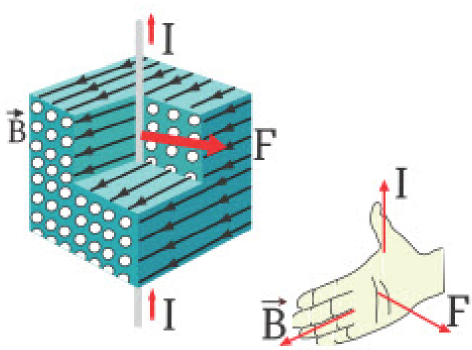


Figure 155

Figure 156 shows the variation of force with angle α. When the field lines and wire are parallel to each other, the wire experiences no force. At other angles the force is proportional to sinα . Thus we have

$$F = BILsin\alpha$$

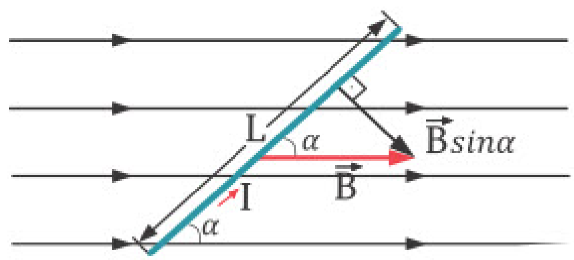


Figure 156

Magnetic force between current carrying parallel conuctors

When a current carrying conductor is placed in a magnetic field, a force will act on the conductor. Since a current in a conductor produces its own magnetic field, two conductors are placed near to each other, each wire will exert a force on the other one.

Consider two long, straight, parallel wires separated by a distance d, having lengths of L_1 and L_2, and carrying currents of I_1 and I_2 respectively, in the same direction, as shown in Figure 157. The force on one of the wires is created by the magnetic field produced by the other wire. Let us use the notation of F_{12} for the force on wire 1 due to wire 2, and F_{21} for the force on wire 2 due to wire 1.

Wire 1, which carries a current of I_1 produces a magnetic field of B_1 at the position of wire 2, the direction of B_1 is perpendicular to wire 2. The magnitude of B_1 is calculated from,

$$B_1 = \frac{\mu_0 I_1}{2\pi d}$$

So the magnetic force on wire 2 is calculated from,

$$F_{21} = B_1 I_2 L_2 \quad \Longrightarrow F_{21} = \left(\frac{\mu_0 I_1}{2\pi d}\right) I_2 L_2 \Longrightarrow F_{21} = \frac{\mu_0 I_1 I_2}{2\pi d} L_2$$

Likewise, the magnetic force on wire 1 is caused by the magnetic field of wire 2. The force on wire 1 is calculated as,

$$F_{12} = B_2 I_1 L_1 \quad \Longrightarrow F_{12} = \left(\frac{\mu_0 I_2}{2\pi d}\right) I_1 L_1 \Longrightarrow F_{12} = \frac{\mu_0 I_1 I_2}{2\pi d} L_1$$

It is obvious the magnitude of F_{12} and F_{21} are equal if L_1=L_2.These forces have the same magnitude but opposite directions, this fits in with

Newton's third law of action and reaction.

Using right hand rule-2, it can be seen that the magnetic forces are repulsive if the currents are in the opposite directions, and the magnetic forces are attractive if the currents are in the same direction, Figure 157.

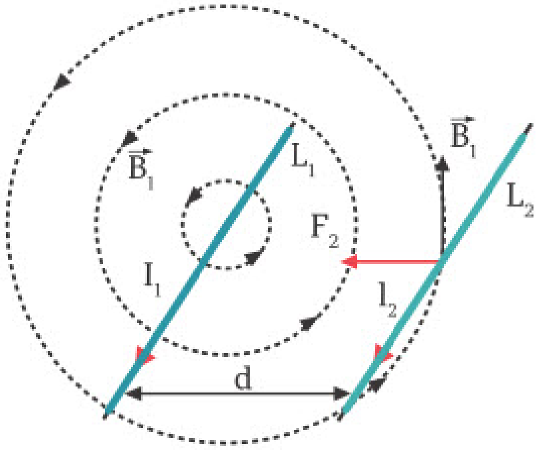
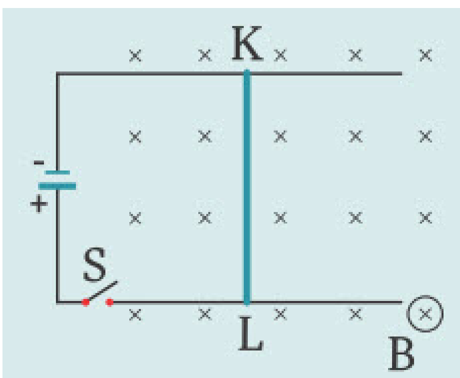


Figure 157

Example

The system shown in the figure is placed in a magnetic field of $4 \cdot 10^{-4}$ Tesla that is perpendicular to the plane of the page. When the switch S is closed, a current of 0.5 A is obtained in the 0.1 m long rod.



What is the magnitude of the force acting on the conducting rod KL, and in which direction does the rod move ?

Given:	Formulas:
$B = 4 \cdot 10^{-4}\ T$	$F = BILsin\alpha$
$I = 0.5\ A$	
$L = 0.1\ m$	Calculations:
$\alpha = 90°$	$F = BILsin\alpha = 4 \cdot 10^{-4} \cdot 0.5 \cdot 0.1 \cdot sin\ 90°$
$F = ?$	$F = 2 \cdot 10^{-5}\ N$

Example

The wires carry currents of 1 A and 2 A in opposite directions. If the lengths of the wires are 50 cm, and they are separated by 10 cm, what is the magnetic force between them? Do wires attract or repel each other?

Given:	Formulas:
$I_1 = 1\ A$	$F = \frac{\mu_0 I_1 I_2}{2\pi d} L$
$I_2 = 2\ A$	
$L = 50\ cm = 0.5\ m$	Calculations:
$d = 10\ cm = 0.1\ m$	
$\mu_0 = 4\pi \cdot 10^{-7}\ T \cdot m/A$	$F = \frac{\mu_0 I_1 I_2}{2\pi d} L = \frac{4\pi \cdot 10^{-7} \cdot 1 \cdot 2}{2\pi \cdot 0.1} \cdot 0.5$
$F = ?\ N$	$F = 2 \cdot 10^{-6}\ N = 2\ \mu N$

Wires repel each other because currents are in opposite directions.

Activity

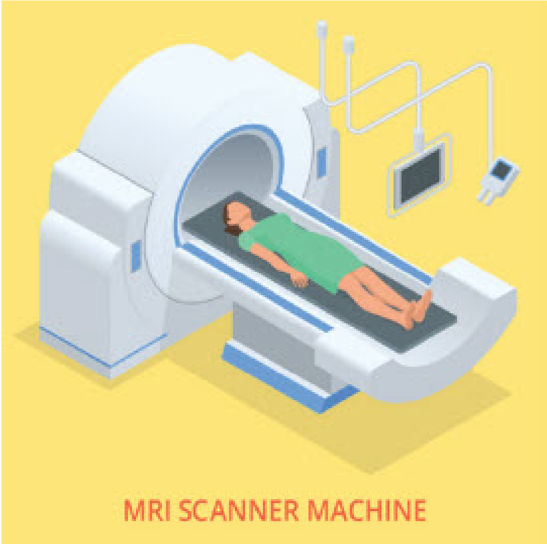
Make such homopolar motor (or search and watch video). Why does this wire rotate?

Research time

How does voltmeter work? What is inside of voltmeter?

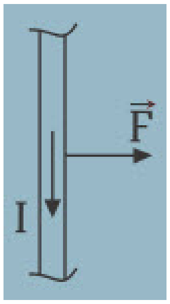
Physics in life

Magnetic field of MRI machine is so powerful that it is 40000 times stronger than Earth's magnetic field and it is only 2 Tesla.

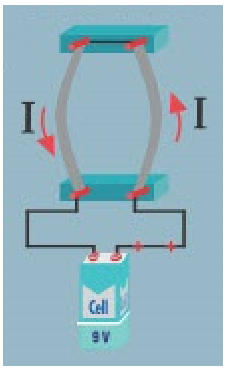


Literacy

1. What is “Ampere’s force”? Why does current-carrying wire feel force from magnet?
2. How does Ampere’s force change when magnetic field and current are doubled?
3. Straight wire of 5 m length carries 1 A current. Determine magnitude and direction of uniform magnetic field if Ampere’s force is 2 N.



4. Straight wire of 10 cm length carries 20 A current in 0.01 T uniform magnetic field. Force acting on the wire by magnetic field is 0.01 N. Calculate angle between magnetic field and current.
5. Wire of 23.7 gram mass is in equilibrium in uniform horizontal magnetic field of 48 mT. Current in the wire is 23 A, angle between current and magnetic field is 60o. Calculate length of the wire.
6. There two parallel wires that act with a force of 4 mN on each other. Currents in the wires are 20 A and 30 A, length of each wire is 1 metre. Calculate distance between the wires.



13.4 LORENTZ FORCE

You will

- analyse working principles of cyclotron, magnetic trap, tokamak, hadron collider, explain nature of aurora borealis and aurora australis.

Question

Why night sky is red and green in Northern and Southern poles?

Magnetic force on moving charges

A current is the motion of charged particles, and a wire carrying a current experiences a force in a magnetic field. Is it really necessary to confine the charges in a wire to obtain magnetic force? It is obvious that a beam of charge would also experience a force due to a magnetic field even if it doesn't move in a conductor.

To find the force on each charge in a conductor, we must divide the total magnetic force by the number of charge carriers in that certain length, L, as shown in Figure 158.

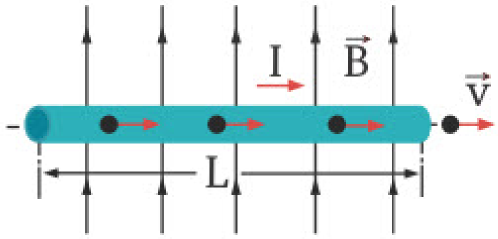


Figure 158

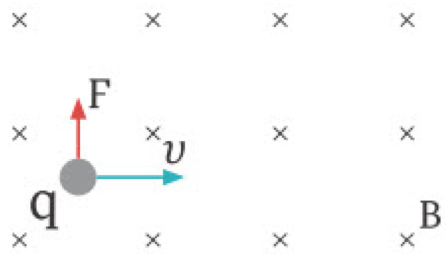
$$F_m = \frac{F_{tot}}{n} = \frac{BIL}{n} = \frac{B\frac{\Delta q}{\Delta t}L}{n}$$

$$\Delta q = nq$$
$$L = v\Delta t$$

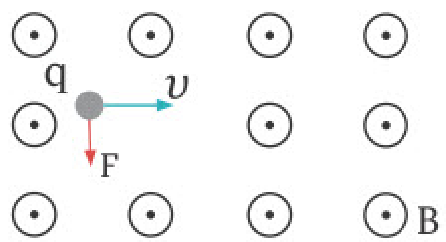
$$F = \frac{B\left(\frac{nq}{\Delta t}\right)(v\Delta t)}{n} \qquad F = qBv$$

where n is the number of charges, q is the charge of each particle, and is the average velocity of the charges.

The direction of the magnetic force for positive charges can be found using the right hand rule-2. In this case thumb will show the direction of velocity, fingers will show direction of magnetic field and the palm will show direction of magnetic force, Figure 159a. If we change the direction of the magnetic field, the direction of the force will also change, as shown in Figure 159b. The direction of magnetic force for negative charges is in the opposite direction to the force for positive charges, as shown in Figure 160.



a



b

Figure 159

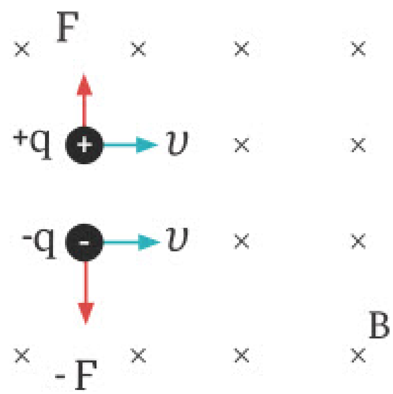
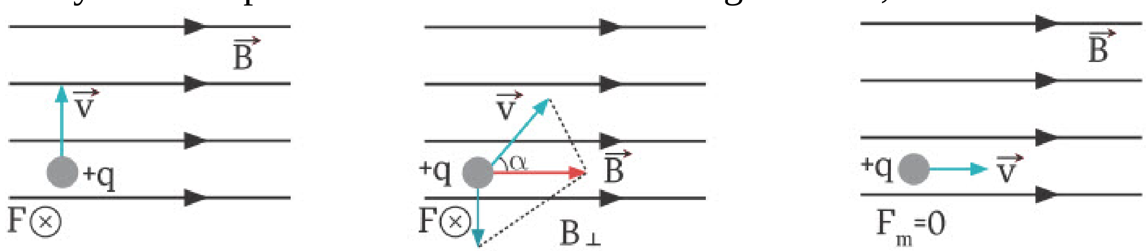


Figure 160

If the magnetic field direction makes an 90° with the direction of the velocity the field produces maximum force shown in Figure 161a, because sin 90°=1.

If the magnetic field direction makes an angle with the direction of the velocity the perpendicular component of the field produces the force shown in Figure 161b.

If the magnetic field direction makes an 0° with the direction of the velocity the field produces no force shown in Figure 161c, because sin 0°=0.



a b c

Figure 161

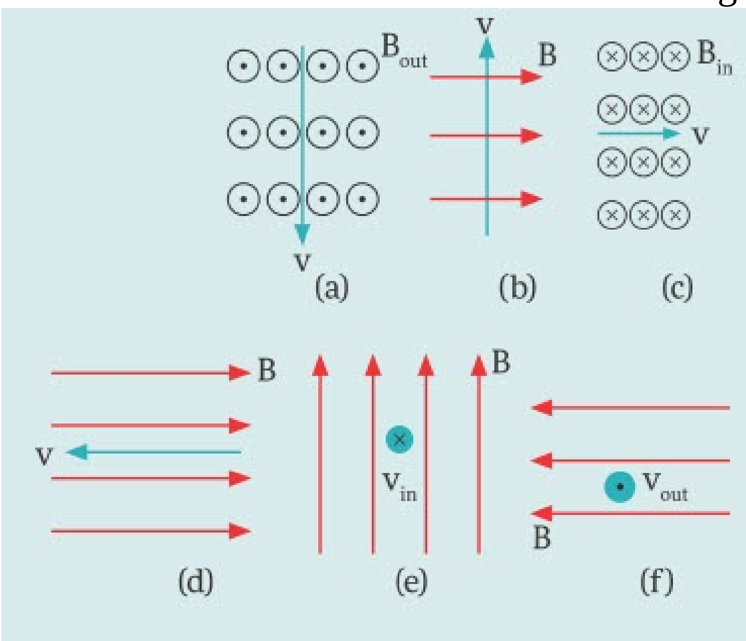
The magnetic force can be calculated using the following relationship

$$F = qBv \cdot sin\alpha$$

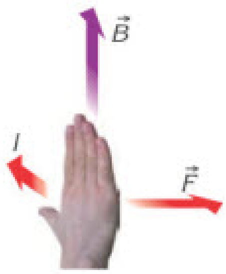
where α is the angle between the velocity and magnetic field vectors. This force is called Lorentz's force.

Example

What is the direction of the magnetic force on a positive charge that moves as shown in each of the six cases shown in Figure?



Formulas:



Solution:

a) Left (West)
(b) Into the page
(c) Up (North)
(d) No force
(e) Right (East)

(f) Down (South)

Example

Plane has a 1.5 μC charge and flies due east at a speed of 700 m/s over the south magnetic pole. Magnetic field is 810^{-5} Tesla straight up. What are the direction and the magnitude of the magnetic force on the plane? Is it a significant or negligible effect?

Given:

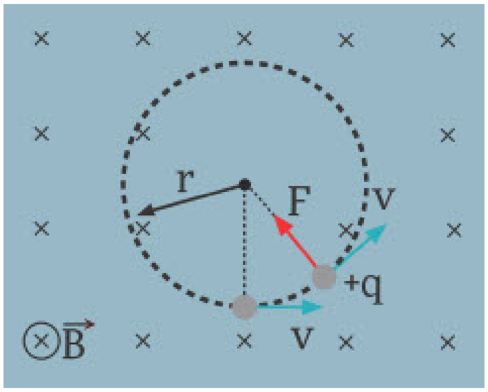
$q = 1.5\ \mu C = 1.5 \cdot 10^{-6}\ C$
$v = 700\ m/s$
$B = 8 \cdot 10^{-5}\ T$
$\alpha = 90^\circ$ (angle between velocity and magnetic field, east and straight up)
$F = ?\ N$

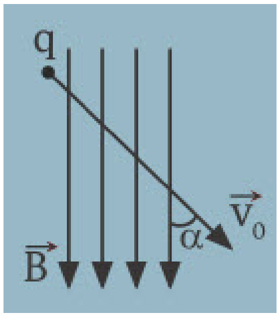
Formulas:
$F = qvBsin\alpha$

Calculations:
$F = qvBsin\alpha = 1.5 \cdot 10^{-6} \cdot 700 \cdot 8 \cdot 10^{-5} \cdot sin\,90^\circ$
$F = 8.4 \cdot 10^{-8}\ N$

Literacy

1. What is Lorentz force? Why Lorentz force does not act on neutral objects?
2. How does Lorentz force change when magnetic field and charge are doubled?
3. Point charge of 10 μC enters uniform magnetic field of 2 T at velocity of 5 m/s. Velocity and magnetic field are perpendicular to each other. Calculate magnitude and direction of force acting on a charge.
4. Point charge of 20 μC enters uniform magnetic field of 4 Tesla at velocity of 10 m/s. Angle between velocity and magnetic field is 45°. Calculate magnitude and direction of force acting on a charge.
5. Calculate frequency of rotation of an electron in a magnetic field of 0.2 T.
6. Electron that is accelerated from rest by accelerating voltage of 300 V moves parallel to straight wire at a distance of 4 mm from wire. What is the force acting on electron if current in the wire is 5 A?





Physics in life

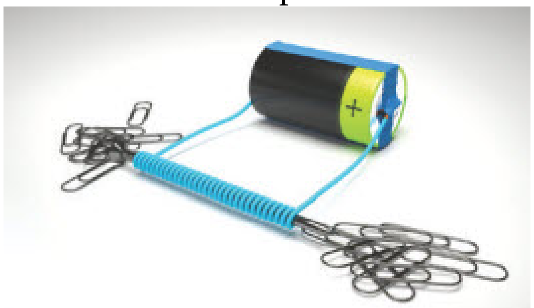
Charged particle accelerators like cyclotrons use the fact that particles move in a circular orbit when v and B are perpendicular to each other.

Activity

Draw scheme of mass-spectrometer and answer the questions. What is mass-spectrometer? How does it work? Why it is used? What is its price?

Research time

Make electromagnet shown on the figure. Change number of turns of wire and count number of paperclips that electromagnet can hold. Make table that shows relationship between number of turns and number of paper clips.

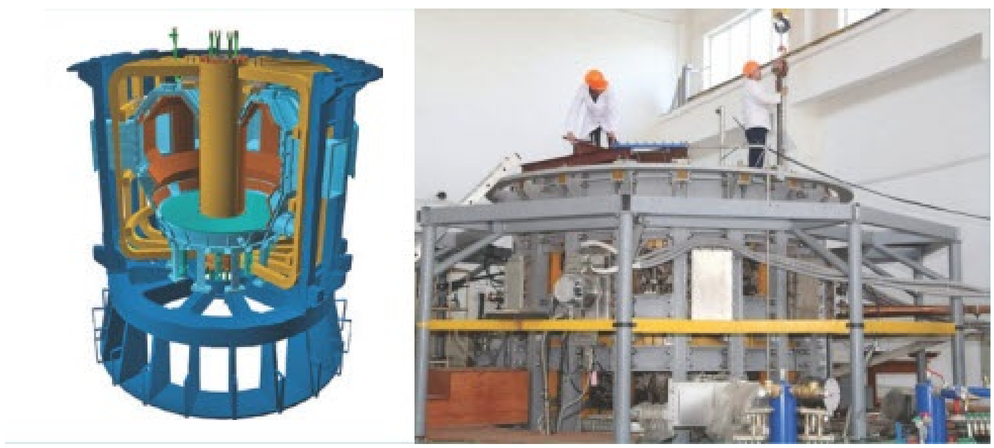


13.5 MOTION OF CHARGE IN MAGNETIC FIELD.

You will

- analyse working principles of cyclotron, magnetic trap, tokamak, hadron collider, explain nature of aurora borealis and aurora australis.

Question



This is Tokamak KTM located in Kurchatov, East Kazakhstan region (ktm.nnc.kz). Why do tokamaks use very strong magnetic fields?

Particle Motion In A Magnetic Field

The magnetic force on a moving charge is always perpendicular to the direction of the velocity, so the magnitude of velocity (that is speed) does not change. Since the velocity is constant, that the kinetic energy of the charge is constant which means magnetic force is not doing work.

In uniform circular motion, a mass connected to the end of a string turning in a circle, experiences a force perpendicular to the direction of v, causing the object to follow a circular path.

In this case the magnetic force is the centripetal force that keeps the charge turning in a circle, as shown in Figure 162.

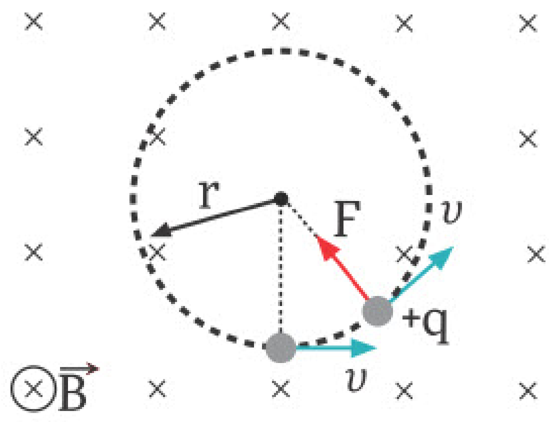


Figure 162

The radius of the curved path can be found as follows

$$F_{magnetic} = F_{centripetal}$$

$$qBv = \frac{mv^2}{r} \qquad r = \frac{mv}{qB}$$

Since F is perpendicular to , the magnitude of doesn't change. If B is constant, then r is also constant. The period of the rotation is

$$T = 2\pi\frac{m}{qB}$$

Applications Of Particle Motion

Cyclotron is device that accelerates charged particles along a spiral path. The particles are held to a spiral trajectory by a static magnetic field. Cyclotrons are used in nuclear medicine for the production of radionuclides, Figure 163.

Figure 163

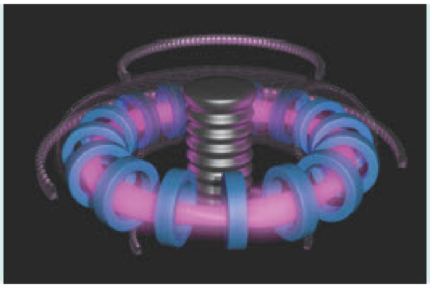


Figure 164

Magnetic trap is a device which uses a magnetic field to trap neutral particles. They are used in physics research to cool atoms to very low temperature.

Tokamak is a device that uses magnetic field to confine plasma in the shape of a torus, Figure 164. The tokamak is used to make fusion reactor. Nowadays international project ITER (International Thermonuclear Experimental Reactor) is the largest tokamak in the world.

Hadron refers to particles composed of quarks such as protons and neutrons. Collider is a particle accelerator in which two beams of particles collide with each other. Colliders are used in research of the subatomic world. The largest collider in the world is LHC (Large Hadron Collider). It is in the circular tunnel under the ground that has length of 27 km, Figure 165.

Figure 165

Aurora borealis (northern lights) and aurora australis (southern lights) are light displays in the sky on the poles, Figure 166. Auroras are produced when the magnetosphere is disturbed by the solar wind (electrons and protons). Lorentz's force on the poles is less than force on the other latitudes so charged particles can enter the atmosphere. As result these electrons and protons collide with molecules of the air, ionize them and light is emitted.

Figure 166

Example

A cosmic ray electron moves at 7×10^{6} m/s perpendicular to the Earth's magnetic field of 1.5×10^{-5}. What is the radius of the circular trajectory the electron follows?

Given:

$q = 1.6 \cdot 10^{-19}\,C$ (charge of electron)

$m = 9.1 \cdot 10^{-31}\,kg$ (mass of electron)

$v = 7 \cdot 10^{6}\,m/s$

$B = 1.5 \times 10^{-5} T$

$\alpha = 90°$ (perpendicular)

$r = ?\ m$

Formulas:

$$r = \frac{mv}{qB}$$

Calculations:

$$r = \frac{mv}{qB} = \frac{9.1 \cdot 10^{-31} \cdot 7 \cdot 10^{6}}{1.6 \cdot 10^{-19} \cdot 1.5 \cdot 10^{-5}} = 2.65\,m$$

Activity

Where is the largest hadron collider? Why it was biult? What was the latest scientific discovery made on it?

Example

A charged particle is projected into a uniform field of 40 Tesla along the +x direction. The angle between the particle's velocity and the field is 53°. If the particle has a velocity of 10 m/s, weighs 1 gram and has a charge of 0.1 Coulomb. Find the radius and distance d, of the trajectory of the helical path it follows, as shown in the figure.

Given:

$B = 40\ T$

$\alpha = 53^\circ\ (\sin 53^\circ = 0.8, \cos 53^\circ = 0.6)$

$v = 10\ m/s$

$m = 1\ g = 0.001\ kg$

$q = 0.1\ C$

$r = ?$

$d = ?$

Formulas:

$$r = \frac{mv\sin\alpha}{qB}$$

$$T = 2\pi\frac{m}{qB}$$

$$d = (v \cdot \cos\alpha)T$$

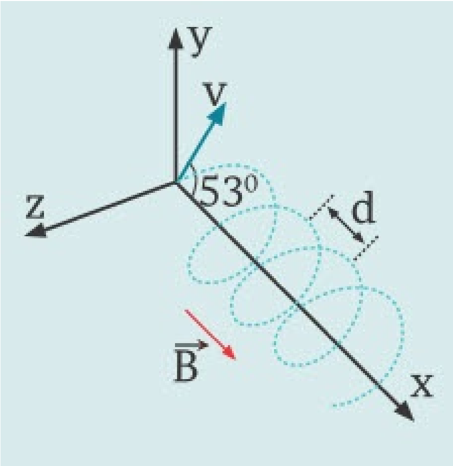
Calculations:

$$r = \frac{mv\sin\alpha}{qB} = \frac{0.001 \cdot 10 \cdot 0.8}{0.1 \cdot 40} = 2 \cdot 10^{-3} m$$

$$T = 2\pi\frac{m}{qB} = 2 \cdot 3.14 \cdot \frac{0.001}{0.1 \cdot 40} = 1.57 \cdot 10^{-3} s$$

$$d = (v \cdot \cos\alpha)T = 10 \cdot 0.6 \cdot 1.57 \cdot 10^{-3}$$

$$d = 9.42 \cdot 10^{-3}\ m$$



Research time

How many Tokamaks are there in Kazakhstan? Where is the largest tokamak in the world? Why it was biult?

Is it true?

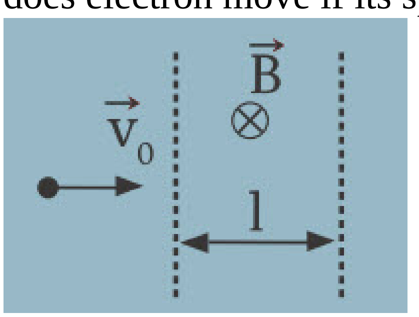
Particles in Large Hadron collider gain speed of light by the help of strong magnetic field.

Physics in life

Aurora australis can only be seen in southern hemisphere.

Literacy

1. What is “aurora borealis”? Why don’t we see auroras in Kazakhstan? How does aurora happen?
2. What is particle collider? How can you make particle collider? Where particle collider is used ?
3. Electron enters into uniform magnetic field of 1 mT perpendicular to magnetic field lines. Speed of the electron is 4000 km/s. Calculate normal acceleration (centripetal acceleration), tangential acceleration and radius of curvature of the electron.
4. Charged particle that has 1 keV energy moves in a circle of 1 mm radius in uniform magnetic field. Calculate force acting on the particle. 1 eV=1 electron-Volt $=1.6\cdot10^{-19}$ Joule.
5. There is uniform magnetic field of B=10 μT that has width of l=1 cm. What should be velocity of an electron υ_0 so that it can pass through magnetic field? How does electron move if its speed is very small? How does electron move if its speed is very big?



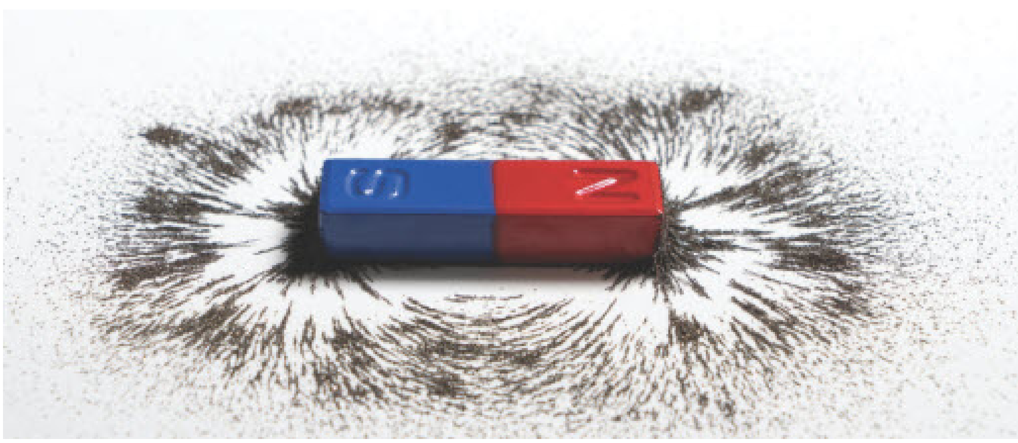
6. Alpha particle passes through accelerating voltage of 10^4 Volt and enters region of mutually perpendicular electric field and magnetic field. Electric field is 10 kV/m, magnetic field is 0.1 T. Calculate charge to mass ratio of alpha particle if it moves in straight line perpendicular to both electric field and magnetic field.

13.6 MAGNETIC PROPERTIES OF MATTER. CURIE TEMPERATURE.

You will

- classify materials according to their magnetic properties, determine areas of their application.

Question



Why do magnets lose their properties when they are heated?

Magnetic materials

There are three categories of magnetic materials: diamagnetic, paramagnetic and ferromagnetic. They are grouped according to their magnetic permeability which is the acceptance of magnetic field into the medium. Magnetic permeability is represented by μ.

The magnetic permeability of free space or a vacuum is μ_0 and has the value 4.10^{-7} N/A^2, as stated previously. The relative magnetic permeability of a substance is calculated as

$$\mu_r = \frac{B}{B_0} = \frac{\mu}{\mu_0}$$

B_0 is the magnetic field strength in a vacuum and B is the magnetic field strength in the presence of a medium. Relative permeabilities of some materials are listed in Table 11.

Material	Relative permeabilities
Copper	0.999999
Silver	0.999998
Bismuth	0.999983
Carbon	0.999956
Aluminium	1.00008
Magnesium	1.00015
Air	1.00167
Cobalt	250
Nickel	600
Iron	5000

Table 11

1. Diamagnetic Materials

Materials which have a relative magnetic permeability of slightly less than unity are called diamagnetic materials. When these materials are placed in a magnetic field, they are magnetised weakly in the opposite direction to the field and act to decrease the magnetic field strength as shown in Figure 167a. Examples of such materials are copper and silver, which are repelled towards weaker regions of the magnetic field.

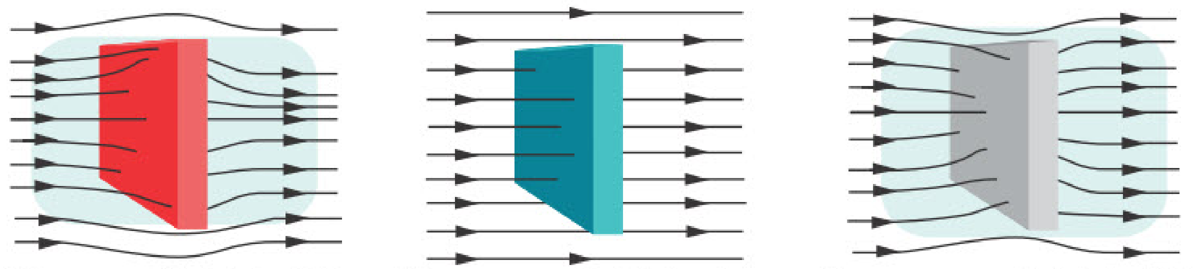


Figure 167

2. Paramagnetic Materials

Materials which have a relative permeability slightly higher than unity are called paramagnetic materials. Examples of paramagnetic materials are aluminum and magnesium and when they are placed in a magnetic field, they are weakly magnetised along the field direction, and are attracted towards stronger regions of the magnetic field as shown in Figure 167b.

3. Ferromagnetic Materials

Materials which have relative magnetic permeabilities much greater than unity (around 1000 to 10000 times) are called ferromagnetic materials. When these materials are placed in a magnetic field, they are magnetised strongly along the field direction and they are attracted towards the stronger regions of the magnetic field as shown in Figure 167c. Ferromagnetic materials are used in the production of artificial magnets. Examples of such materials are iron, cobalt and nickel.

The properties of the three groups of materials are summarised in Table 12.

Material	Magnetic Field	Magnetic Force	Permeability
Paramagnetic	Slightly increase	Slightly attracted	$\mu_r > 1$
Diamagnetic	Slightly decrease	Slightly repelled	$\mu_r < 1$
Ferromagnetic	Large increase	Strongly attracted	$\mu_r >> 1$

Table 12

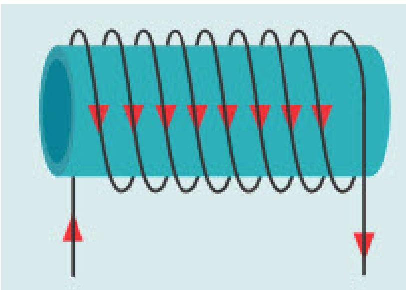
Curie temperature is the temperature above which materials lose their permanent magnetic properties.

Activity

Download a mobile application that can detect a metal. Start the application. Put magnet on the table and hold the mobile phone on fixed height. Place different objects between magnet and a phone. Identify if an object is paramagnetic, diamagnetic or ferromagnetic. Make table summarizing your research.

Example

A solenoid 0.5 m in length has 200 turns and carries a current of 0.5 A, as shown in the figure. Find the magnetic field strength at the centre of the solenoid when iron core is inserted in solenoid.



Given:

$l = 0.5\ m$

$N = 200\ turns$

$I = 0.5\ A$

$\mu_0 = 4\pi \cdot 10^{-7} T \cdot m/A$

$\mu_r = 5000$

$B = ?$

Formulas:

$B_0 = \dfrac{\mu_0 NI}{l}; \qquad \mu_r = \dfrac{B}{B_0}$

Calculations:

$$B_0 = \frac{\mu_0 NI}{l} = \frac{4 \cdot 3.14 \cdot 10^{-7} \cdot 200 \cdot 0.5}{0.5}$$

$$B_0 = 2.512 \cdot 10^{-4}\ T$$

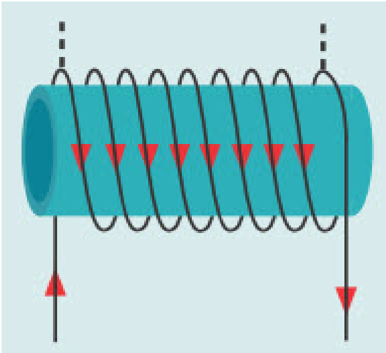
$$\mu_r = \frac{B}{B_0}$$

$$5000 = \frac{B}{2.512 \cdot 10^{-4}}$$

$$B = 1.256\ T$$

Example

A solenoid 0.5 m in length has 200 turns and carries a current of 0.5 Ampere, as shown in the figure. Find the magnetic field strength at the centre of the solenoid when iron core is inserted in solenoid. Temperature of iron core is 800 °C.



Given:
$l = 0.5\ m$
$N = 200\ turns$
$I = 0.5\ A$
$\mu_0 = 4\pi \cdot 10^{-7} T \cdot m/A$
$\mu_r = 5000$
$T_{curie} = 770°C$
$B = ?$

Formulas:

$$B_0 = \frac{\mu_0 NI}{l}$$

$$\mu_r = \frac{B}{B_0}$$

Calculations:

$$B_0 = \frac{\mu_0 NI}{l} = \frac{4 \cdot 3.14 \cdot 10^{-7} \cdot 200 \cdot 0.5}{0.5}$$

$$B_0 = 2.512 \cdot 10^{-4} T$$

Research time

Make flowchart that answers these questions. How magnets are made? What materials and methods are used? Can you do magnet at home?

Is it true?

Neodymium magnets can easily lift loads thousands of times bigger than their own weight.

Physics in life

Cobalt is the best heat resistant magnetic material. It has Curie temperature of 1388 K.

Literacy

1. What is difference between ferromagnetic, paramagnetic and diamagnetic materials? What is difference between protons, neutrons, electrons of ferromagnetic, paramagnetic and diamagnetic materials?
2. Search and watch video about scientists who made frog fly above magnet. Frog is not magnet but it levitates above magnet. Why?
3. Why does magnetic field of current carrying coil (solenoid) increases when iron core is inserted in the coil?

4. Spherical neodymium magnet has diameter of 1 cm. It applies 15 N force of attraction to steel plate. Curie temperature of neodymium magnet is 320 °C. Use "online magnet calculator" and plot force-temperature graph of magnet in temperature range of 0 °C-500 °C.
5. What is difference between ferromagnetism and antiferromagnetism? Draw internal structure of ferromagnets and antiferromagnets to answer the question. Where antiferromagnets are used?
6. What is ferrofluid? How can you make ferrofluid? Where ferrofluid is used?

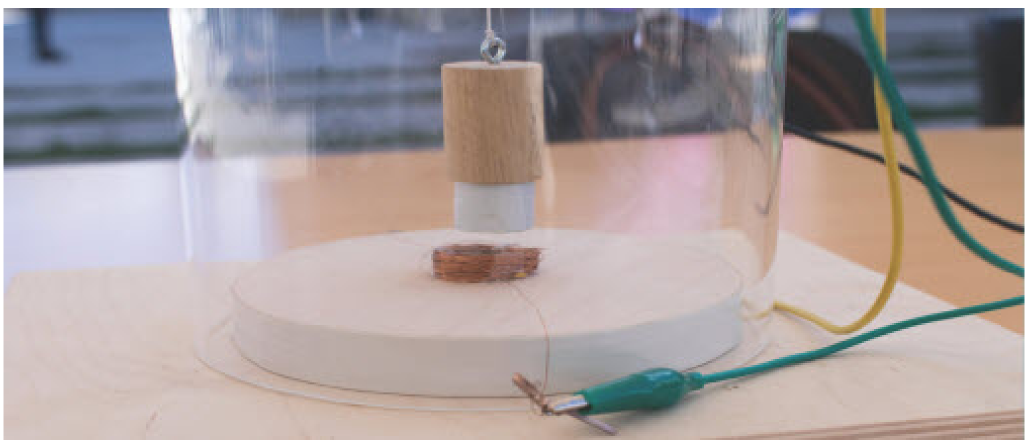
7. What is "magnetic putty"? Why does it move? How can you make it? Where can you use it?

13.7 APPLICATION OF MAGNETIC MATERIALS

You will

- analyse areas of application of magnetic materials (neodymium magnets, sensors, seismometers, metal detectors), discuss application trends of magnetic materials.

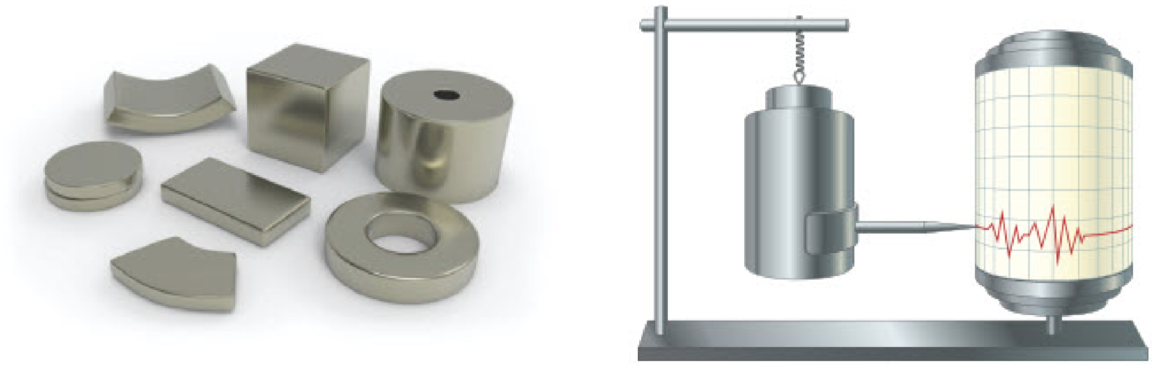
Question



This device is used to detect earthquakes. Why are there magnet and coil?

Neodymium magnets

Neodymium magnet is a permanent magnet made from an alloy of neodymium, iron and boron. Its chemical formula is $Nd_2Fe_{14}B$. They are used in modern products that require strong permanent magnets, such as motors, hard disk drives and magnetic fasteners, Figure 168a.



a Figure 168 b

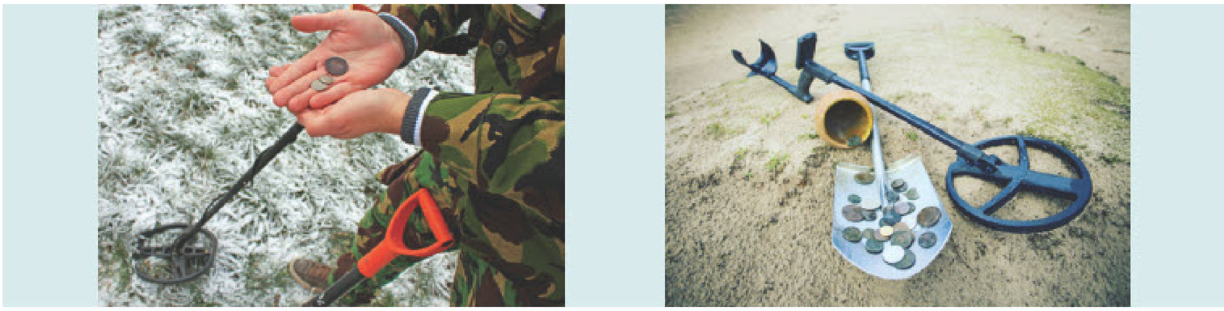
Seismometers, geophones, accelerographs

Accelerographs and geophones are heavy cylindrical magnets with a spring-mounted coil inside, Figure 168b. As case moves, the coil tends to stay stationary, so the magnetic field cuts the wires, inducing current in the output wires. The voltage generated in a coil by the magnet directly measures the instantaneous velocity of the ground. Geophones use same principle, Figure 169a and 169b.

a Figure 169 b

Metal detectors

Metal detector consists of device that produces current that passes through a coil producing an alternating magnetic field, Figure 170. If a piece of metal is close to the coil, current will be induced in the metal, and this current produces a magnetic field of its own. Another coil is used to measure the magnetic field, so metallic object is detected.

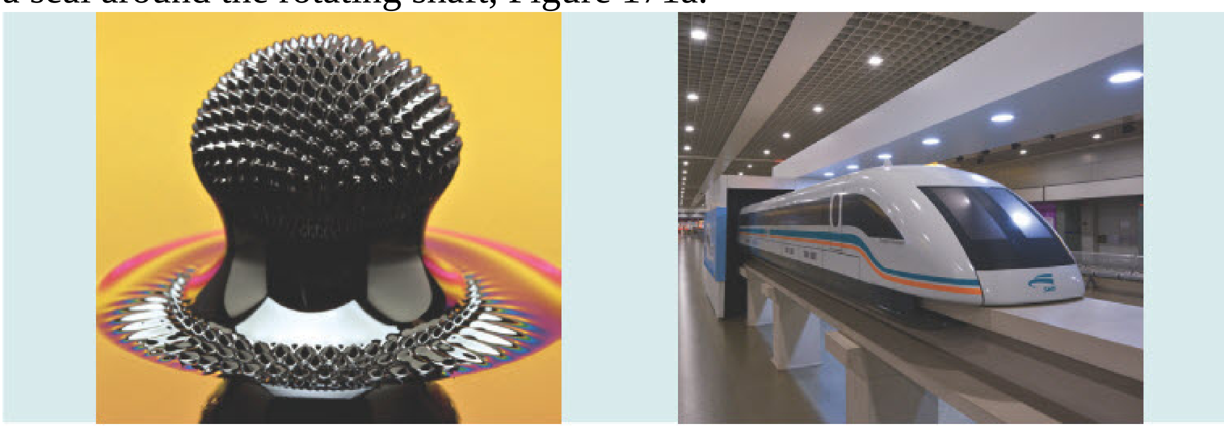


a b
Figure 170

Application of magnetic materials

Magnetic materials are utilized in the fabrication of brakes and shock absorbers (bridges and buildings, washing machines, fitness equipment, prosthetic limbs, cars and trucks).

Magnetic fluid called ferrofluid is used in computer hard-drives to form a seal around the rotating shaft, Figure 171a.



a b
Figure 171

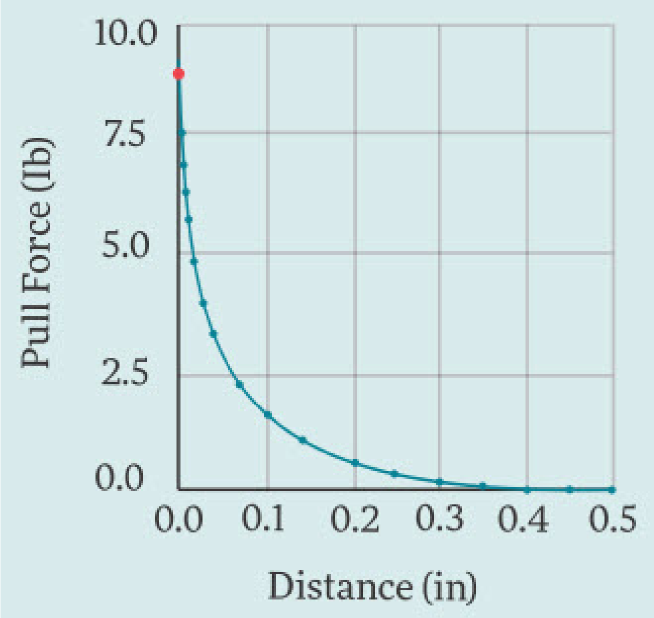
Magnetic liquids can be used to carry medications inside of the body and they can be used as a contrasting agent for MRI scans.

Magnetic fluids are used for the separation of magnetic materials from non-magnetic materials. Magnetic materials are attracted to the regions of strong magnetic field, whereas nonmagnetic materials are displaced to the regions of weak magnetic field.

Electrodynamic suspension (EDS) of MagLev trains uses superconducting electromagnets or strong permanent magnets, Figure 171b. They produce magnetic field, which induces currents in nearby metallic conductors. Then current produces magnetic field, which pushes and pulls the train towards the designed position on the tracks.

Example

There is force-distance graph of 1 cm·1 cm·1 cm neodymium magnet. Maximum force is 9.27 lbf. How many such magnets do you need to attach 70 kg person to steel ceiling? 1 lb force is 4.45 Newton, 1 inch is 2.54 cm.



Given:
1 lb force is 4.45 Newton.
1 inch is 2.54 cm.
$m = 70\ kg$
$g = 9.8\ N/kg$
$F_0 = 9.27\ lbf = 41.25\ N$
$N = ?$

Formulas:
$F = mg$
$F = N \cdot F_0$

Calculations:
$F = mg = 70 \cdot 9.8 = 686\ N$
$F = N \cdot F_0$
$686 = N \cdot 41.25$
$N = 16.63 \simeq 17$

You need minimum 17 neodymium 1 cm·1 cm·1 cm magnets to attach 70 kg person to steel ceiling.

Is it true?

Ferromagnetic fluids are used to treat cancer.

Physics in life

Hard disk drive (HDD) can break under powerful magnetic field. Why?

Research time

Research and build homemade seismometer.

Literacy

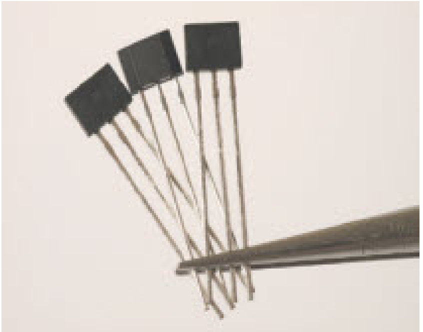
1. What is difference between regular magnet and “neodymium magnet”? How can you make neodymium magnet? Where neodymium magnets are used?

2. What is metal detector? How can you make metal detector? Where metal detectors are used? Do metal detector have magnets inside?

3. What is “geophone”? How can you make geophone? Where geophone is used?

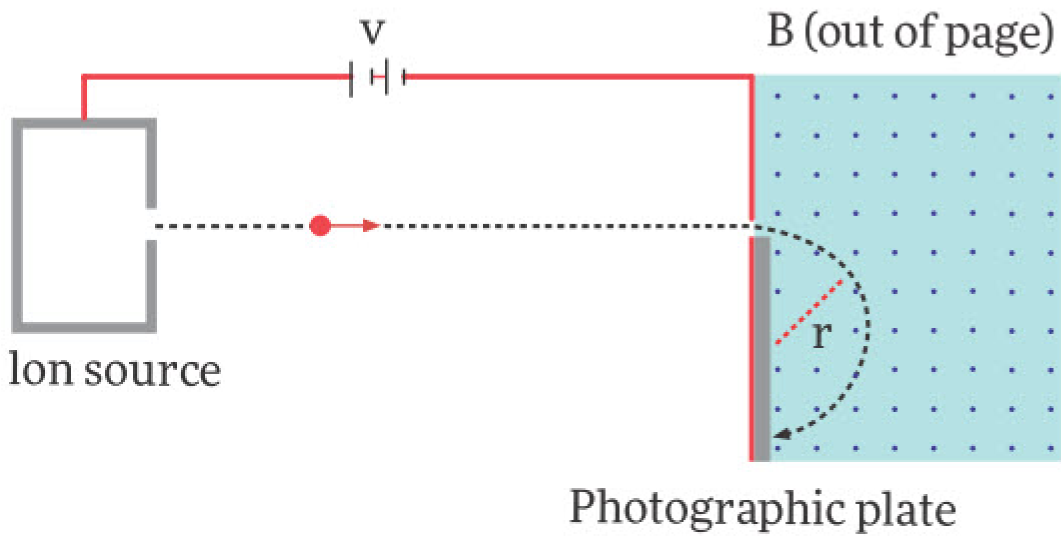
4. The sensitivity of passive geophone is about 30 Volts/(meter/second). Geophone registers 30 mV voltage. What is the speed of motion of the ground?

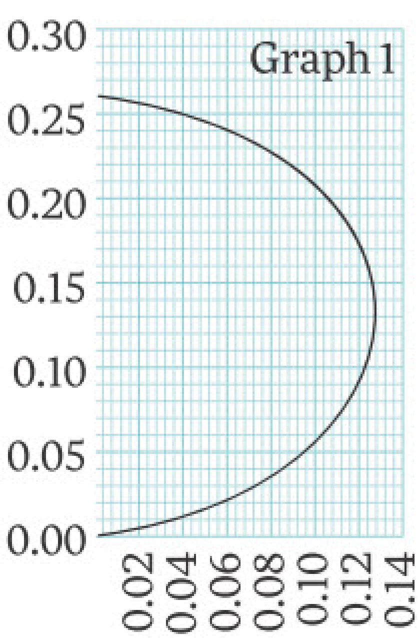
5. What is “Hall effect sensor”? How can you make Hall effect sensor? Where Hall effect sensor is used?

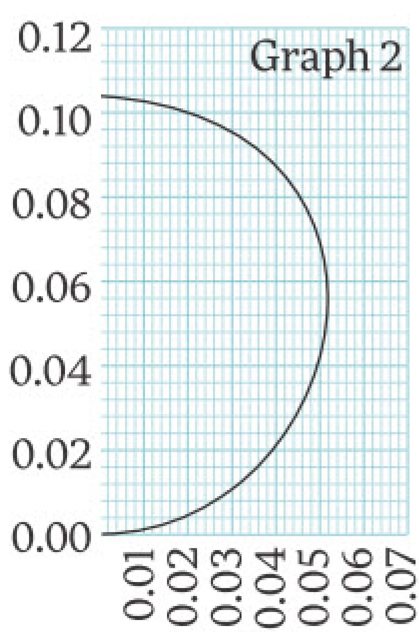


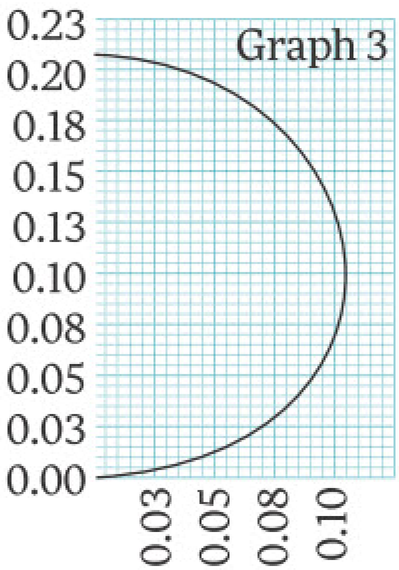
CHECK YOURSELF

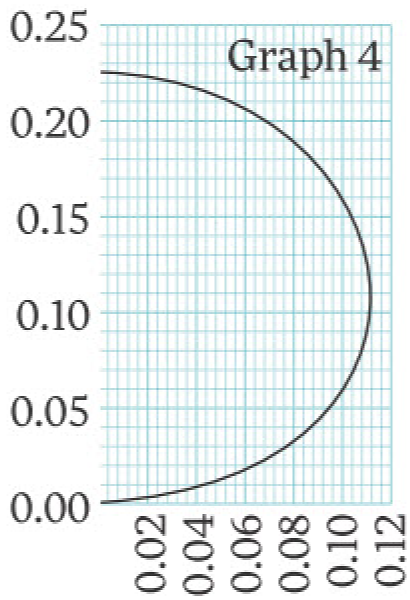
There is picture of mass-spectrometer. Mass spectrometer is used to study chemical composition of substance. As you can see charged particles (ions) travel with speed of 105 m/s in circular path in 0.02 Tesla magnetic field. Then there four graphs that show paths of charged particles in mass spectrometer. Vertical axis and horizontal axis are measured in metre. Use graphs and periodic table to answer questions.











1. What is radius of motion of particle in Graph 1?
A) 11.37 cm
B) 12.96 cm
C) 10.39 cm
D) 5.23 cm
E) There is no right answer

2. What is radius of motion of particle in Graph 2?
A) 11.37 cm
B) 12.96 cm
C) 10.39 cm
D) 5.23 cm
E) There is no right answer

3. What is radius of motion of particle in Graph 3?
A) 11.37 cm
B) 12.96 cm
C) 10.39 cm
D) 5.23 cm

E) There is no right answer

4. What is radius of motion of particle in Graph 4?
A) 11.37 cm
B) 12.96 cm
C) 10.39 cm
D) 5.23 cm
E) There is no right answer

5. What formula is used to determine radius of motion of charged particle in magnetic field?
A) R=m/(qB)
B) R=v/(qB)
C) R=mv/(qB)
D) R=mv/B
E) R=mv/q

6. What is mass to charge ratio (m/q) of the particle in the Graph 1?
A) $2.08\cdot10^{-8}$ kg/C
B) $1.0\cdot10^{-8}$ kg/C
C) $2.27\cdot10^{-8}$ kg/C
D) $2.59\cdot10\text{-}^{8}$ kg/C
E) There is no right answer

7. What is mass to charge ratio (m/q) of the particle in the Graph 2?
A) $2.08\cdot10^{-8}$ kg/C
B) $1.05\cdot10^{-8}$ kg/C
C) $2.27\cdot10^{-8}$ kg/C
D) $2.59\cdot10^{-8}$ kg/C

E) There is no right answer

8. What is mass to charge ratio (m/q) of the particle in the Graph 3?
A) $2.08 \cdot 10^{-8}$ kg/C
B) $1.05 \cdot 10^{-8}$ kg/C
C) $2.27 \cdot 10^{-8}$ kg/C
D) $2.59 \cdot 10^{-8}$ kg/C
E) There is no right answer

9. What is mass to charge ratio (m/q) of the particle in the Graph 4?
A) $2.08 \cdot 10^{-8}$ kg/C
B) $1.05 \cdot 10^{-8}$ kg/C
C) $2.27 \cdot 10^{-8}$ kg/C
D) $2.59 \cdot 10^{-8}$ kg/C
E) There is no right answer

10. What is charge of proton?
A) $1.232 \cdot 10^{-17}$ C
B) $1.6 \cdot 10^{-19}$ C
C) $4.64 \cdot 10^{-18}$ C
D) $3.2 \cdot 10^{-19}$ C
E) There is no right answer

11. What is charge of neutron?
A) $1.232 \cdot 10^{-17}$ C

B) $1.6 \cdot 10^{-19}$ C
C) $4.64 \cdot 10^{-18}$ C
D) $3.2 \cdot 10^{-19}$ C
E) There is no right answer

12. What is name of the particle on the Graph 1?
A) Iridium
B) Helium
C) Copper
D) Hydrogen
E) There is no right answer

13. What is name of the particle on the Graph 2?
A) Iridium
B) Helium
C) Copper
D) Hydrogen
E) There is no right answer

14. What is name of the particle on the Graph 3?
A) Iridium
B) Helium
C) Copper
D) Hydrogen
E) There is no right answer

15. What is name of the particle on the Graph 4?
A) Iridium
B) Helium
C) Copper

D) Hydrogen
E) There is no right answer

16. What is charge of the particle on the Graph 1?
A) $1.232 \cdot 10^{-17}$ C
B) $1.6 \cdot 10^{-19}$ C
C) $4.64 \cdot 10^{-18}$ C
D) $3.2 \cdot 10^{-19}$ C
E) There is no right answer

17. What is charge of the particle on the Graph 2?
A) $1.232 \cdot 10^{-17}$ C
B) $1.6 \cdot 10^{-19}$ C
C) $4.64 \cdot 10^{-18}$ C
D) $3.2 \cdot 10^{-19}$ C
E) There is no right answer

18. What is charge of the particle on the Graph 3?
A) $1.232 \cdot 10^{-17}$ C
B) $1.6 \cdot 10^{-19}$ C
C) $4.64 \cdot 10^{-18}$ C
D) $3.2 \cdot 10^{-19}$ C
E) There is no right answer

19. What is charge of the particle on the Graph 4?
A) $1.232 \cdot 10^{-17}$ C
B) $1.6 \cdot 10^{-19}$ C

C) $4.64 \cdot 10^{-18}$ C
D) $3.2 \cdot 10^{-19}$ C
E) There is no right answer

20. What is mass of the particle on the Graph 1?
A) $6.648 \cdot 10^{-27}$ kg
B) $1.055 \cdot 10^{-25}$ kg
C) $1.673 \cdot 10^{-27}$ kg
D) $3.192 \cdot 10^{-25}$ kg
E) There is no right answer

21. What is mass of the particle on the Graph 2?
A) $6.648 \cdot 10^{-27}$ kg
B) $1.055 \cdot 10^{-25}$ kg
C) $1.673 \cdot 10^{-27}$ kg
D) $3.192 \cdot 10^{-25}$ kg
E) There is no right answer

22. What is mass of the particle on the Graph 3?
A) $6.648 \cdot 10^{-27}$ kg
B) $1.055 \cdot 10^{-25}$ kg
C) $1.673 \cdot 10^{-27}$ kg
D) $3.192 \cdot 10^{-25}$ kg
E) There is no right answer

23. What is mass of the particle on the Graph 4?
A) $6.648 \cdot 10^{-27}$ kg
B) $1.055 \cdot 10^{-25}$ kg

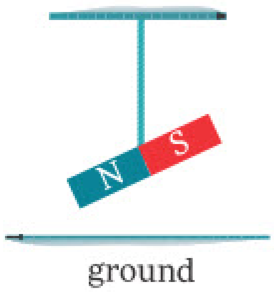
C) $1.673 \cdot 10^{-27}$ kg
D) $3.192 \cdot 10^{-25}$ kg
E) There is no right answer

24. What would be radius of motion of Uranium nucleus in this mass spectrometer?
A) 10.43 cm
B) 11.43 cm
C) 12.43 cm
D) 13.43 cm
E) 14.43 cm

25. How would radii of motion of particles change if magnetic field is doubled?
A) Increase 2 times
B) Decrease 2 times
C) Increase 4 times
D) Decrease 4 times
E) Do not change

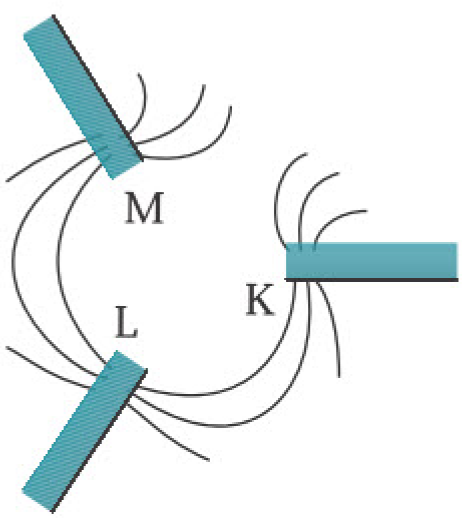
Magnetism

1. The bar magnet suspended by a string from its centre of gravity remains in equilibrium, as shown in the figure. On which of the following parameters does its equilibrium depend?
I. Angle of deflection
II. Angle of inclination
III. Centre of gravity



A) I only
B) II only
C) I and II
D) II and III
E) I, II and III

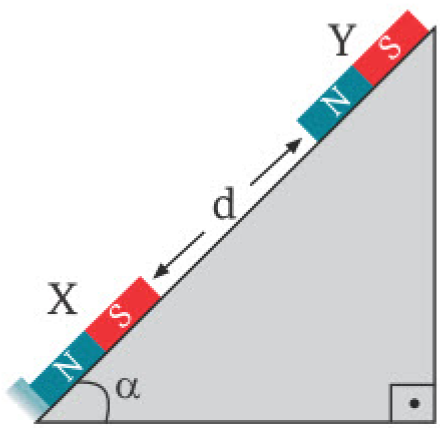
2. The magnetic field lines of three fixed identical magnets are shown in the figure. Which magnetic poles cannot be at the ends K, L and M of the magnets?



A) K : N
L : S
B) K : N
M : N

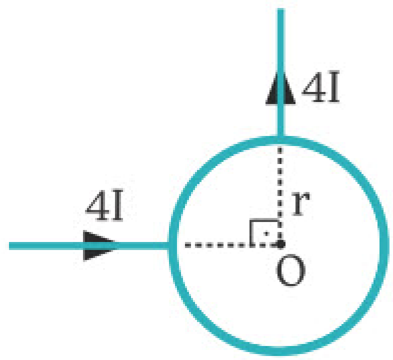
C) K : S
M : S
D) L : N
M : N
E) K : S
L : N

3. Magnets X and Y are identical. Magnet Y is in equilibrium on the inclined plane, as shown in the figure. On which of the following parameters does its equilibrium depend?
I. Magnetic pole strength of magnet X
II. Mass of magnet X
III. Distance d
IV. Angle



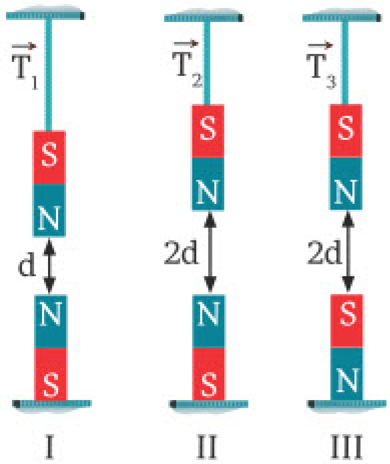
A) I and II
B) II and III
C) II and IV
D) III and IV
E) I, III and IV

4. A conducting ring of radius r is connected to a straight wire carrying a current of 4I. What is the magnitude of the resultant magnetic field at point O at the centre of the ring, in terms of I and r?



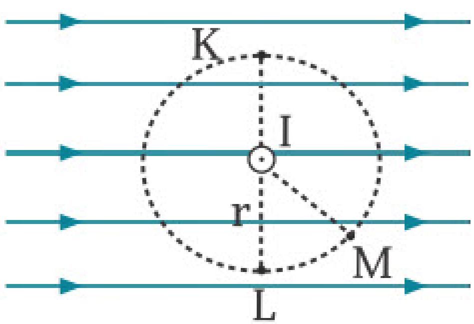
A) 0
B) $(\mu_o I)/8r$
C) $(9\mu_o I)/8r$
D) $(3\mu_o I)/2r$
E) $(3\mu_o I)/r$

5. In the figures I, II and III, the systems are constructed from identical magnets, the magnets on the ground are fixed. What is the relationship between the tensions T_1, T_2 and T_3? (Tensions are not equal to zero)



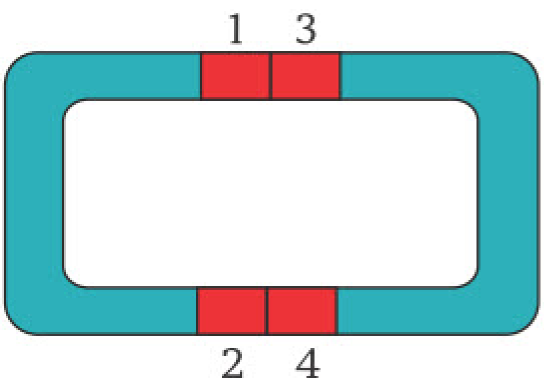
A) $T_1=T_2=T_3$
B) $T_2=T_3>T_1$
C) $T_1>T_2=T_3$
D) $T_3>T_2>T_1$
E) $T_2>T_3>T_1$

6. A long conducting wire perpendicular to the plane of the page is placed in a uniform magnetic field, as shown in the figure. A current I flows in the wire. What is the relationship between the magnitudes of the resultant magnetic fields B_K, B_L and B_M, produced at points K, L and M?



A) $B_K > B_L > B_M$
B) $B_L > B_M > B_K$
C) $B_M > B_L > B_K$
D) $B_M = B_L = B_K$
E) $B_K > B_M > B_L$

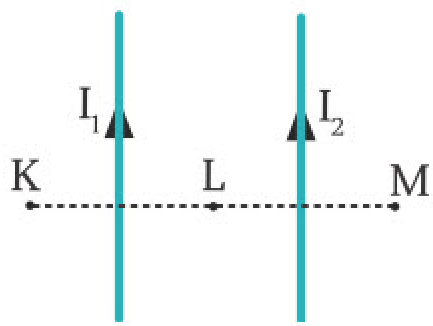
7. The poles of two horseshoe magnets are stuck together and labelled as shown in the figure. Which of the following represents the poles of the magnets?



	1	2	3	4
A)	N	S	S	N
B)	N	N	S	S
C)	S	N	S	N
D)	N	S	N	S

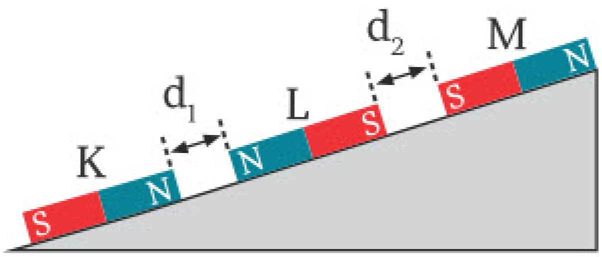
E) S S N N

8. Currents I_1 and I_2 pass through two conducting parallel wires placed in the same plane, as shown in the figure. At which point(s) may the resultant magnetic field become zero if $I_1>I_2$?



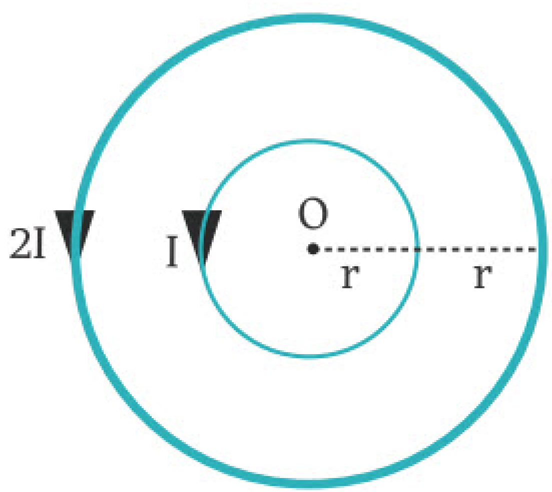
A) K only
B) L only
C) M only
D) K and M
E) L and M

9. Identical magnets K, L and M are in static equilibrium on a frictionless inclined plane, as shown in the figure.Which of the following statements is/are correct?
I. $d_1<d_2$
II. The resultant magnetic force exerted on magnet K is greater than that exerted on magnet L
III. $d_1=d_2$



A) I only
B) II only
C) I and II
D) I and III
E) II and III

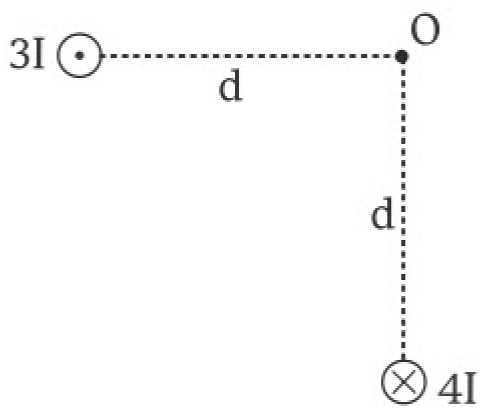
10. The conducting circular loops placed as shown in the figure, carry currents I and 2I. If the magnitude of the magnetic field at point O produced by current, I is B, what is the magnitude of the resultant magnetic field at point O, in terms of B?



A) –2
B) –1
C) 0

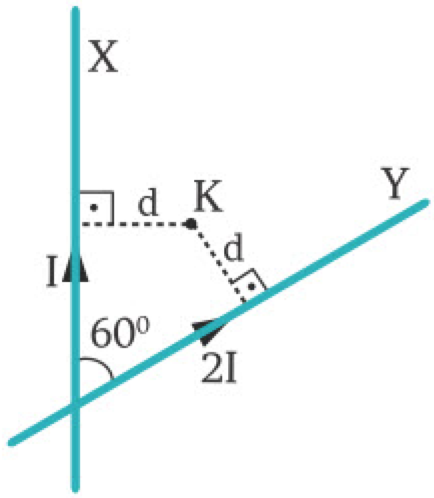
D) 1
E) 2

11. Currents 3I and 4I pass through the straight conducting wires placed perpendicular to the plane of the page, as shown in the figure. What is the magnitude of the resultant magnetic field produced at point O due to these currents, in terms of B, if $B=(\mu_0 I)/2\pi d$?



A) 3
B) 4
C) 5
D) 6
E) 7

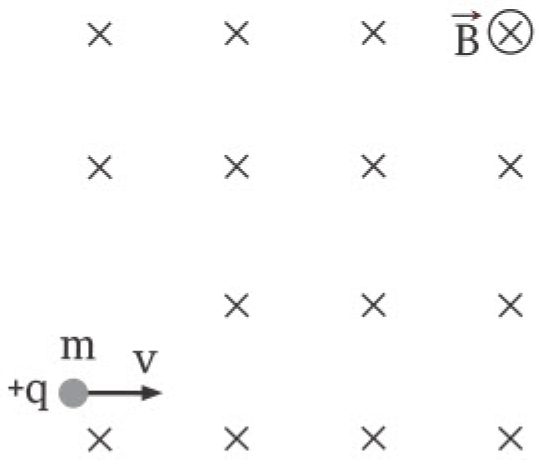
12. The wires X and Y placed in the plane of the page, as shown in the figure, carry currents of I and 2I, respectively. If the magnetic field produced at point K by the current in wire X is B, what is the resultant magnetic field at point K, in terms of B?



A) –2
B) –1
C) –1/2
D) 1
E) 2

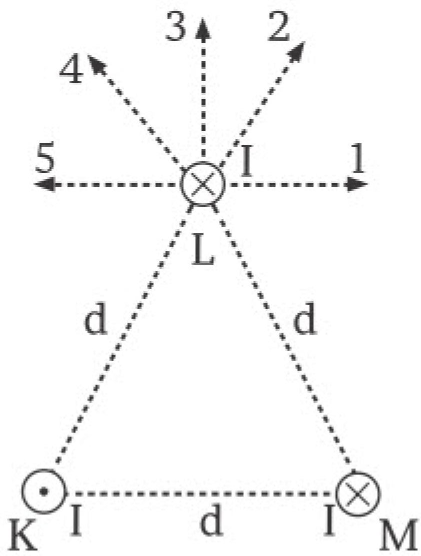
Lorentz's force

1. A particle of charge +q projected with a speed of v in a uniform magnetic field moves in a circular path. Which of the following parameters must be increased in order to increase the radius of the circular orbit?
I. The velocity of the particle
II. The mass of the particle
III. The magnitude of the magnetic field



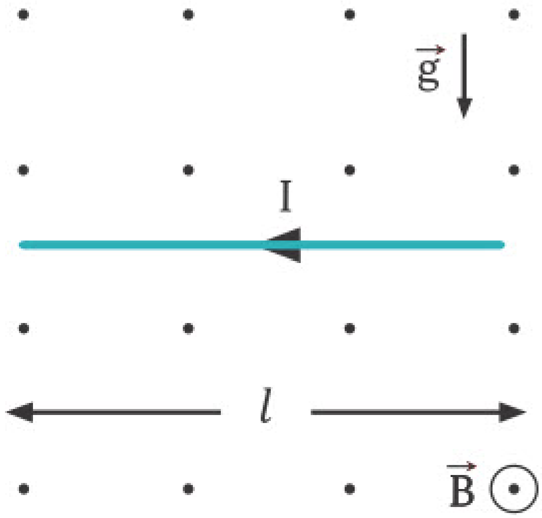
A) I only
B) II only
C) I and II
D) II and III
E) I, II and III

2. Wires K, L and M perpendicular to the plane of the page are placed at the corners of an equilateral triangle, as shown in the figure. They carry currents of I. What is the direction of the magnetic force exerted on wire L?



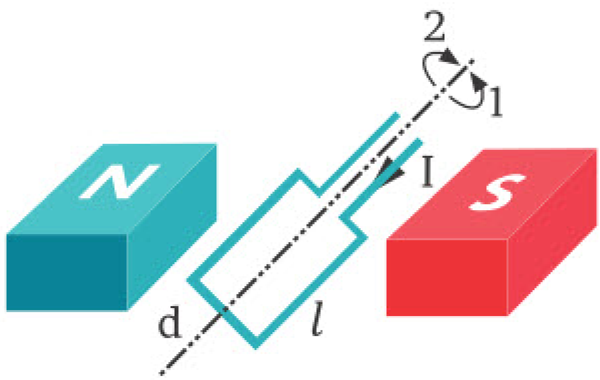
A) 1
B) 2
C) 3
D) 4
E) 5

3. A straight wire, carrying a current of I, remains in equilibrium in mid-air in a uniform magnetic field of magnitude **B** , as shown in the figure. Which equation can be used to calculate the mass of the wire, if the length of the section of wire in the uniform magnetic field is l? (g: gravitational acceleration)



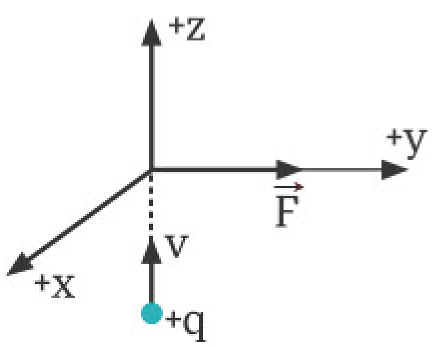
A) (BIl)/g
B)(B^2 I)/g
C)(BI^2 l)/2g
D)(BI)/lg
E)(Bl)/Ig

4. A current of magnitude I passes through a rectangular loop placed between two poles of a magnet, as shown in the figure. The length of the edges of the rectangular loop are d and l. If the magnitude of the magnetic field between the poles is B, which of the following statements is/are correct?
I. The torque acting on the loop is M = B ld I
II. The loop rotates in direction 1
III. The loop rotates in direction 2



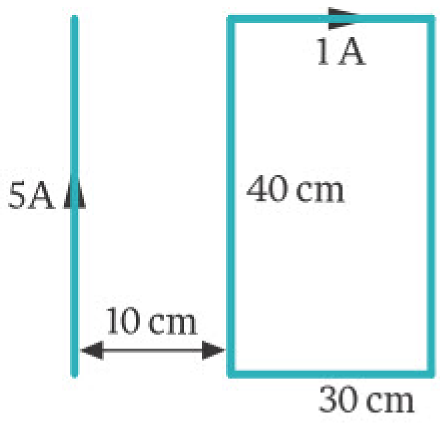
A) I only
B) II only
C) III only
D) I and II
E) I and III

5. When a particle of charge +q is projected into a uniform magnetic field with a velocity of v, in a direction perpendicular to the magnetic field, the direction of the magnetic force acting on the particle is +y. What is the direction of the magnetic field?



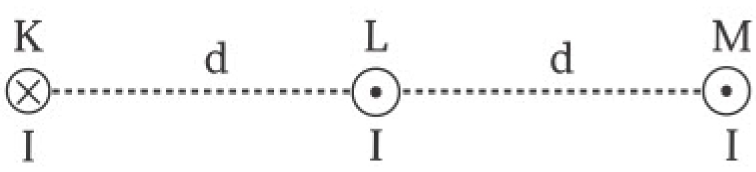
A) –z
B) +y
C) –y
D) +x
E) –x

6. A straight wire carrying a current of 5 A is fixed, a rectangular loop of wire carrying a current of 1 A is placed as shown in the figure. The lengths of the edges of the rectangular loop are 30 cm and 40 cm. What is the net force acting on the rectangular loop, in newtons?



A) 0
B) $2 \cdot 10^{-6}$
C) $3 \cdot 10^{-6}$
D) $4 \cdot 10^{-6}$
E) $5 \cdot 10^{-6}$

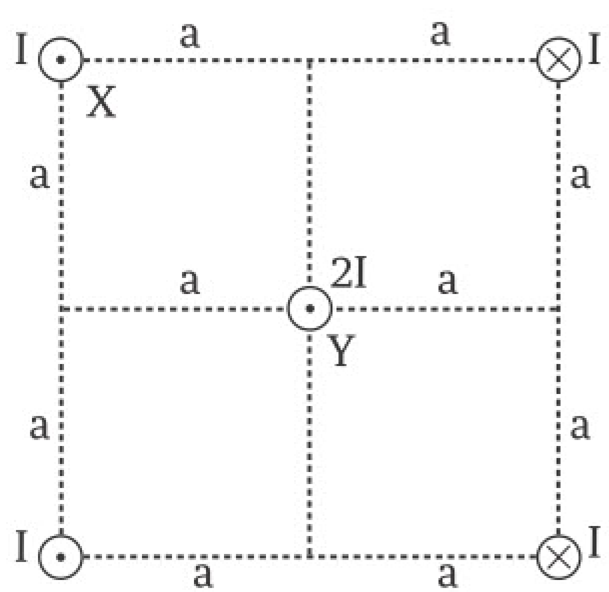
7. Wires K, L and M of the same length, are placed as shown in the figure. The currents flowing through the wires are equal. If the magnetic force on wire L due to wire K is F, what is the magnitude and direction of the resultant force exerted on wire L?



A) ← 2F

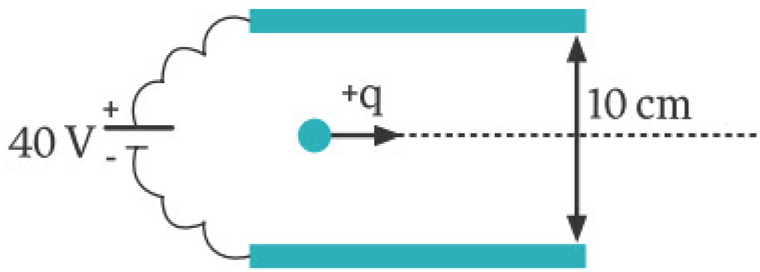
B) ← F
C) 0
D) →F
E) →2F

8. Currents of I pass through straight parallel wires perpendicular to the plane of the page, as shown in the figure. If the force exerted on wire Y by wire X is F, what is the magnitude and direction of the resultant force exerted on wire Y, in terms of F?



A) 0
B) → 2F
C) ← 2F
D) ←$2\sqrt{2}$F
E) →$2\sqrt{2}$F

9. When a weightless particle of charge +q is projected between two charged parallel plates with a velocity of 10^5 m/s, it leaves the plates without deflection. What is the direction and magnitude of the magnetic field between the parallel plates, in tesla?



A) 10^{-3}
B) ↓ $4 \cdot 10^{-3}$
C) ↑ $4 \cdot 10^{-3}$
D) left $4 \cdot 10^{-3}$
E) → $4 \cdot 10^{-4}$

Magnetic Field Produced by Electric Currents

1. Is the magnetic field produced by a current carrying wire uniform?

2. What is the magnetic field strength at a point 0.5 m from a straight wire, carrying a current of 2 A?

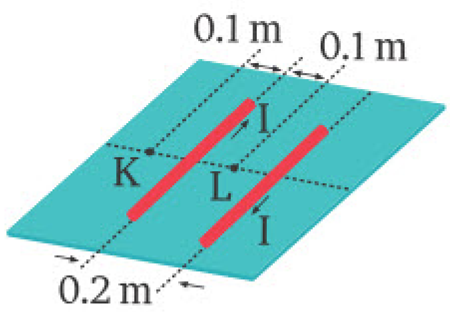
3. How large should a current flowing in a wire be in order that the magnetic field at a distance of 0.1 m from the wire is $5 \cdot 10^{-6}$ T?

4. At what distance from a wire carrying a 10 A current is the magnetic field equal to that of the Earth? (Earth's magnetic field is $5 \cdot 10^{-5}$ T)

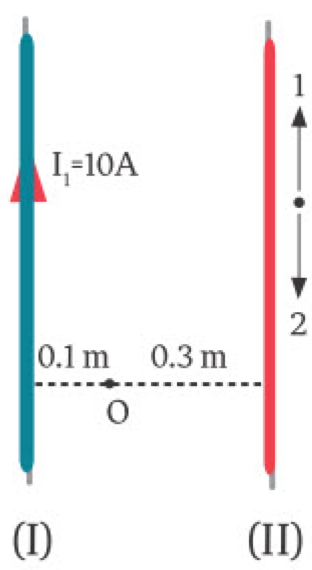
5. Two parallel straight wires are 1 m apart. Each wire carries a current of 2 A in the same direction. What is the resultant magnetic field produced by both wires at a point midway between them?

6. Two parallel straight wires, 1 m apart, carry currents of 2 A and 4 A. At what point between two wires is the magnetic field zero when both currents flow in the same direction?

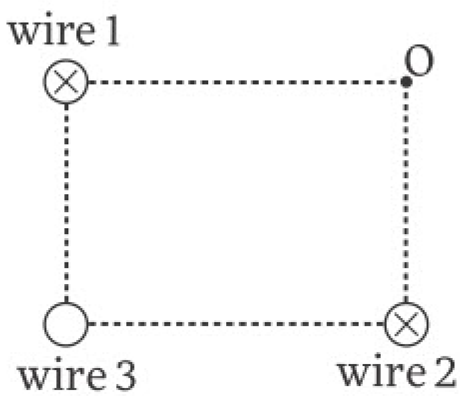
7. Two long straight wires are separated by a distance of 0.2 m. The wires carry currents of 24 A in opposite directions. Find the magnitude and direction of the net magnetic fields at points K and L.



8. The resultant magnetic field of wires I and II at point O is zero. Find the direction and magnitude of the current in wire II.

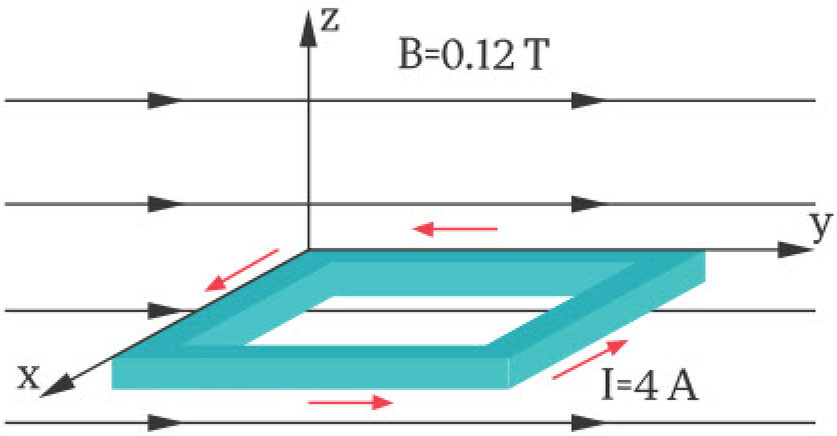


9. Three long straight wires are located parallel to each other. Their cross sections lie at the corners of a square having a side length of 1 m. The currents in wires 1 and 2 are $I_1=I_2=10$ A, and they are directed into the page. What is the direction and magnitude of the current in wire 3, such that the net magnetic field at point O is zero?

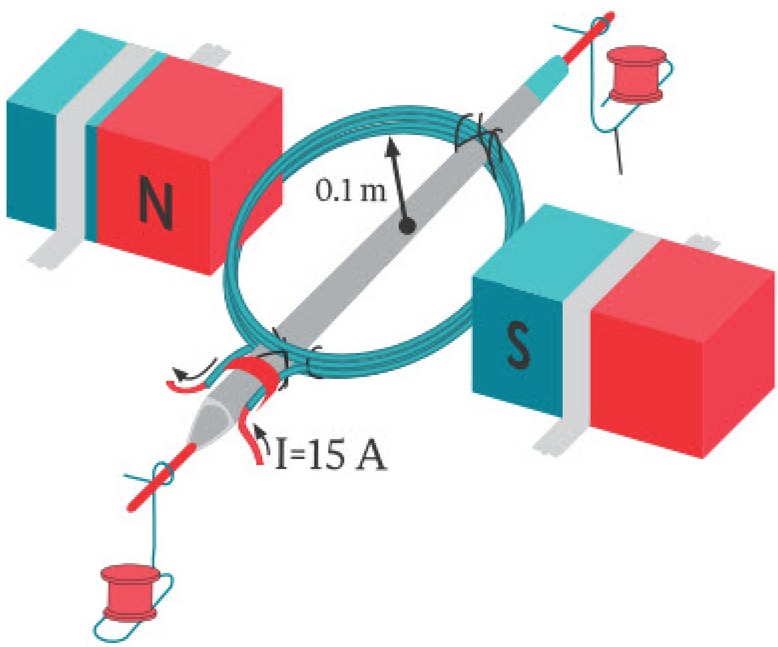


Magnetic Force on a Current Carrying Loop

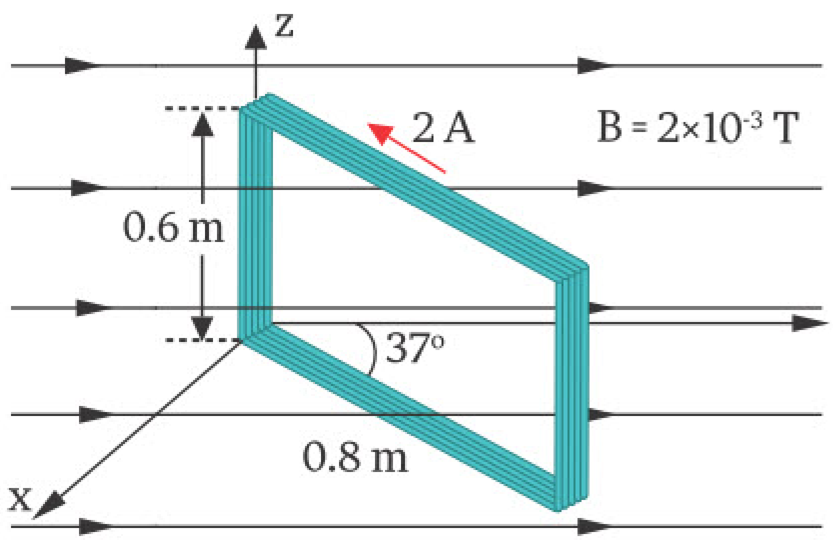
1. A square loop of sides 0.5 m is placed in a uniform field of 0.12 T. If the current in the loop is 4 A, what is the maximum torque that the loop can experience?



2. A circular coil of wire has a radius of 0.1 m and carries a current of 15 A. The coil consists of N=100 closely wrapped turns, and is placed in a magnetic field of 0.8 T. What is the maximum torque that the coil can experience in this field?

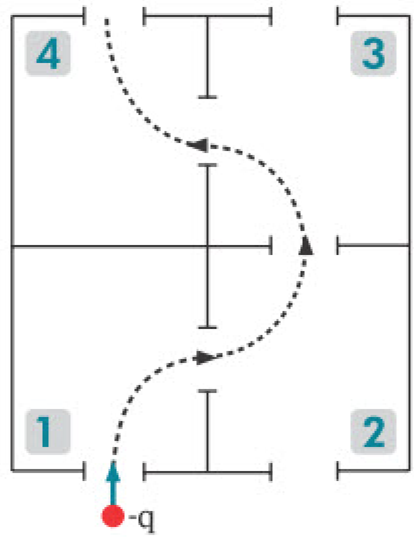


3. The rectangular loop in the figure consists of 150 turns and carries a current of 2 A. The loop is located in a magnetic field directed along the +y axis, with a magnitude of $2 \cdot 10^{-3}$ T. The loop is free to rotate about the Z axis.
a. Determine the magnitude of the net torque exerted on the loop.
b. State whether the 37° angle will increase or decrease.



Magnetic Force on Moving Charges

1. The figure shows a top view of four interconnected chambers. A negative charge is fired into chamber 1. By turning on separate magnetic fields in each chamber the charge can be made to exit from chamber 4, as shown.
a) Describe how the magnetic field in each chamber should be directed.
b) If the speed of the charge is v when it enters chamber 1, what is the speed of the charge when it exits chamber 4? Why?



2. A proton having a velocity of $2 \cdot 10^5$ m/s enters a uniform magnetic field of 0.2 T in a direction perpendicular to the field.
a) Find the force acting on the proton.
b) Calculate the radius of curvature of the path of the proton.
($m_p = 1.6 \cdot 10^{-27}$ kg; $q_p = 1.6 \cdot 10^{-19}$ C)

CHAPTER 14: ELECTROMAGNETIC INDUCTION

14.1 Work of Ampere's force. Motional EMF

You will

- analyse working principles of electromagnetics devices (electromagnetic relay, generator, transformer)

Question

Where electricity is produced? How is it produced? How does it come to your home?

The method of inducing current by moving a conducting rod in a uniform magnetic field is called motional electromotive force (EMF). Motional EMF is result of the magnetic force that acts on a moving charge. Under the influence of this force the free electrons will move to the lower end of the rod, leaving behind an equal amount of positive charge at the upper end shown in the Figure 172.

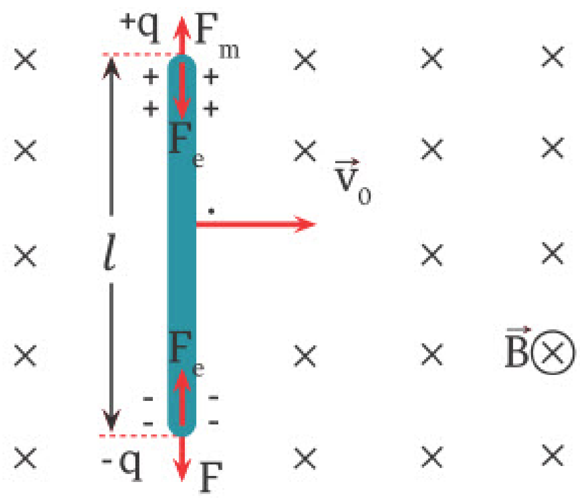


Figure 172

The positive and negative charges accumulate until the attractive electric force F = qE that they exert on each other is balanced by the magnetic force F = qυB. The electric field between the ends of the rod, when equilibrium is reached, is

$$qE = qB\upsilon$$

or

$$E = \upsilon B$$

Since the electric field is constant the electric field produced in the conductor is related to the potential difference across the ends according to the relationship

$$V = El$$

or

$$V = B\upsilon l$$

or

$$\varepsilon = B\upsilon l$$

where
ε : EMF(electromagnetive force) [Volt]

B : magnetic field [Tesla]
I: length of the rod [meter]
υ : velocity of rod [m/s]

If the velocity makes an angle α with the wire and if the velocity and wire are both perpendicular to the magnetic field, as shown in Figure 173, the potential difference across the wire is

$$\varepsilon = B\upsilon l \cdot sin\alpha$$

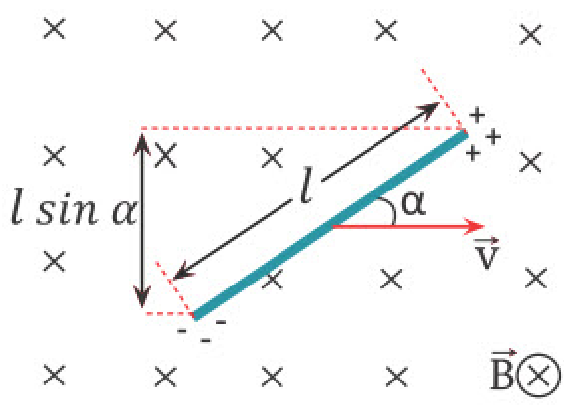


Figure 173

The value of current in the electric circuit shown in the Figure 174 can be calculated as

$$I = \frac{\varepsilon}{R} = \frac{B\upsilon l}{R}$$

where is R : resistance [Ohm]

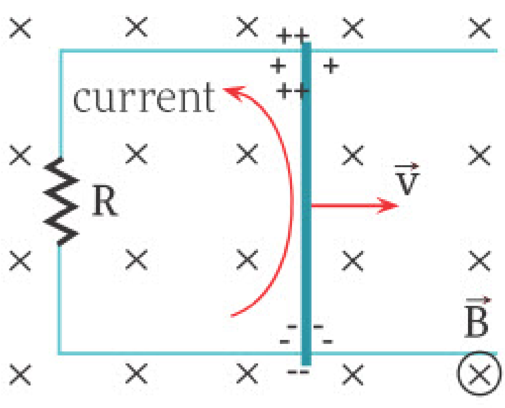


Figure 174

Example

Assume that R=6 Ω, l=1.2 m and a uniform 2.5 Tesla magnetic field is directed into the page in the Figure 3. At what speed should the rod be moved to produce a current of 0.5 A in the resistor?

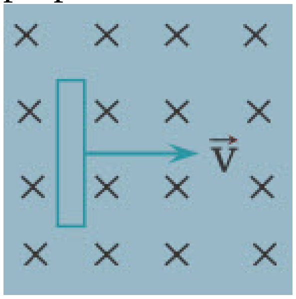
Given:	Formulas:	Calculations:
$R = 6\,\Omega$	$\varepsilon = IR$	$\varepsilon = IR = 0.5 \cdot 6 = 3\,V$
$l = 1.2\,m$	$\varepsilon = B\upsilon l$	$\varepsilon = B\upsilon l$
$B = 2.5\,T$		$\upsilon = \frac{\varepsilon}{Bl} = \frac{3}{2.5 \cdot 1.2}$
$I = 0.5\,A$		
$\upsilon = ?\ m/s$		$\upsilon = 1\ m/s$

Activity

Open "Phet Faraday's Law". Move magnet near coil or move coil near magnet. Write down your observations and explain them.

Literacy

1. What is motional EMF? How can you produce motional EMF?
2. How would motional EMF change if magnetic field and velocity double?
3. Calculate motional EMF of 0.5 m long wire that moves with 5 m/s speed perpendicular to magnetic field lines of uniform magnetic field of 8 mT.



4. Calculate electric field inside of a wire that moves with 4 m/s speed in 0.2 Tesla magnetic field.
5. Calculate motional EMF in 0.25 metre long wire that moves with 5 m/s speed at an angle of 30° to the magnetic field lines of 8 mT uniform magnetic field.

6. Calculate motional EMF generated by vertical component of Earth’s magnetic field of   in the airplane that has wingspan of 38 metre and flies horizontally with 900 km/h speed.

Important note

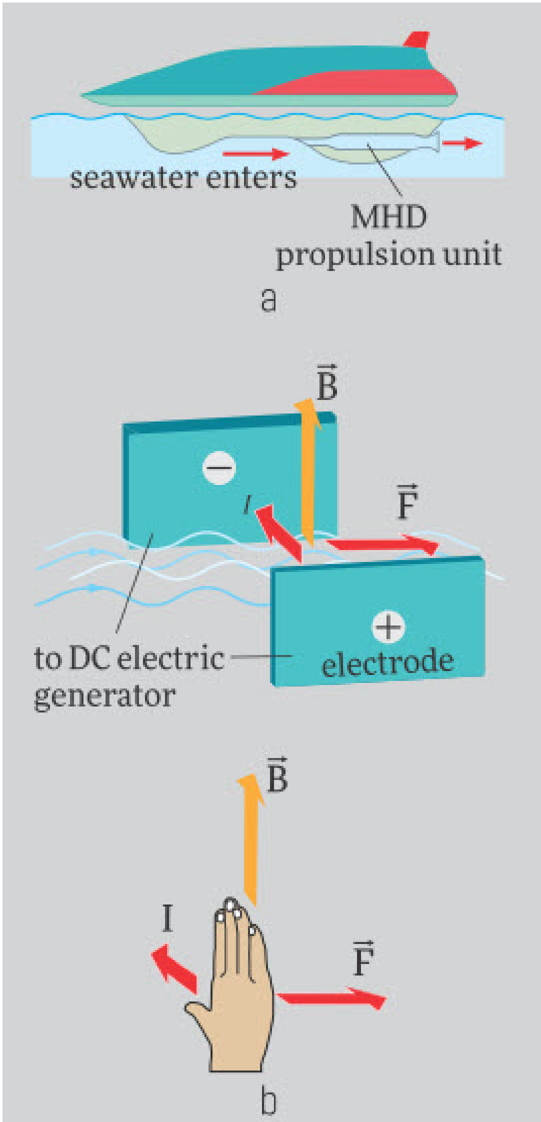
In the early 1800's, the only source of current was chemical energy from metals dissolved in acids. Nowadays electric power systems depend directly on magnetically induced current.

Research time

GFCI (ground fault circuit interrupter) prevents electric shock. How?

Physics in life

Magnetohydrodynamics (MHD) is the technical name given to a clever application where magnetic force pumps fluids without moving mechanical parts. Is it more ergonomic than mechanical pumps?


seawater enters
MHD
propulsion unit
a
B
I
F
to DC electric
generator
electrode
B
I
F
b

14.2 Magnetic flux. Electromagnetic induction.

You will

- analyse working principles of electromagnetics devices (electromagnetic relay, generator, transformer)

Question

Dynamo torch emits light when you squeeze it and it does not use batteries. How does it work?

Magnetic flux

Magnetic flux is the quantity of magnetic field lines that pass through a surface area. The concept of magnetic flux is shown in Figure 175a.

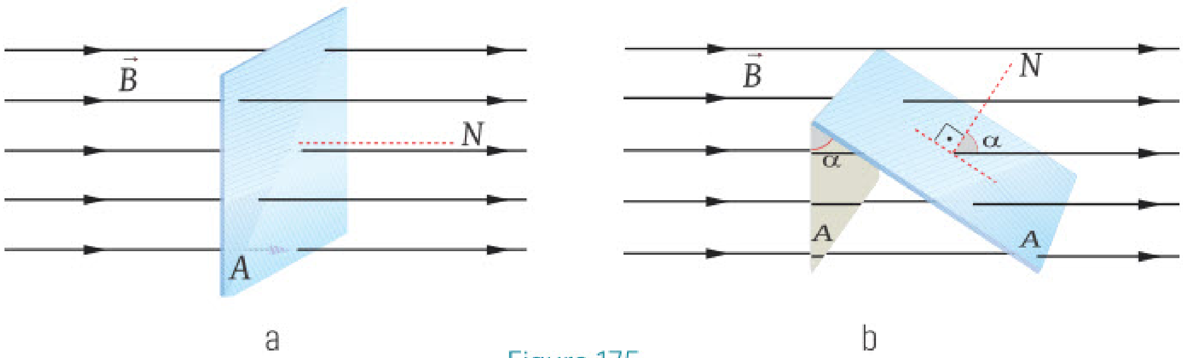


Figure 175

Magnetic flux is the product of the magnetic field and the surface area through which it passes. If the magnetic field and the normal to the surface are not parallel as shown in Figure 175b, then the flux can be calculated by the formula

$$\Phi = BAcos\alpha$$

Φ : magnetic flux [Weber]
B : magnetic field [Tesla]
A: area [m^2]
α: angle between the normal to the surface and the magnetic field lines.

Electromagnetic induction

Electromagnetic induction is the process of inducing current and electromotive force (EMF) by changing magnetic flux. Magnetic flux depends on three factors B, A and . A change in any of these parameters will cause an induced emf. EMF of electromagnetic induction can be calculated by this formula

$$\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$$

where
ε: EMF [Volt]
N : number of loops in the coil
ΔΦ: change in magnetic flux through one loop [Weber]
Δt: time interval during which the change occurs [seconds].

Electromagnetic induction is used to generate electric current that we use daily. Device that is used to generate current is called generator. Scheme of generator is shown on the Figure 176. Generator consists of coil that rotates near permanent magnet.

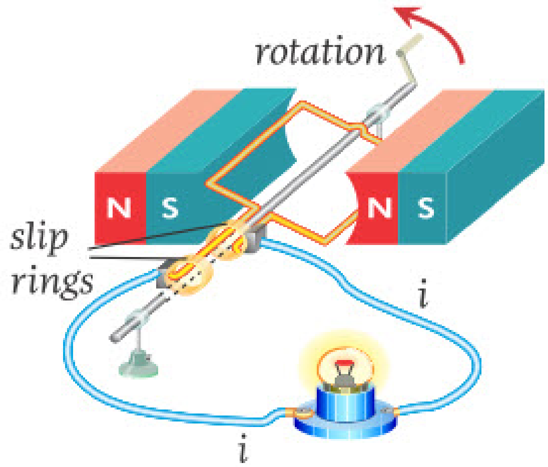


Figure 176

On the Figure 177a you can see generator that is shown in schools and universities. Again notice permanent magnets and coil.

In the beginning of the topic you have seen dynamo torch that uses electromagnetic induction. Similarly, power bank shown on the Figure 177b can be charged by turning the crank. Thus you can recharge it by hand and you do not need mains electricity.


a b
Figure 177

Example

A rectangular loop of sides 1 m and 2 m is confined to a magnetic field of 0.5 T. Calculate the magnetic flux through the loop, if the angle between the normal of the loop and the magnetic field is

a) 0° b) 30° c) 90° d) 120°.

Given:

$A = 1\ m \cdot 2\ m = 2\ m^2$

$B = 0.5\ T$

$\alpha = 0°, 30°, 90°, 120°$

$\Phi = ?$

Formulas:

$\Phi = BAcos\alpha$

Calculations:

a) $\Phi = BAcos\alpha = 0.5 \cdot 2 \cdot cos\ 0° = 1\ Wb$

b) $\Phi = BAcos\alpha = 0.5 \cdot 2 \cdot cos\ 30° = 0.87\ Wb$

c) $\Phi = BAcos\alpha = 0.5 \cdot 2 \cdot cos\ 90° = 0$

d) $\Phi = BAcos\alpha = 0.5 \cdot 2 \cdot cos\ 120° = -0.5\ Wb$

Example

A rectangular coil of sides 20 cm by 10 cm contains 100 turns and is positioned perpendicular to a magnetic field of B = 2 T. The loop is pulled out of the magnetic field in a time of 0.2 s. Find the induced emf on the coil.

Given:

$A = 20\ cm \cdot 10\ cm = 0.2\ m \cdot 0.1\ m = 0.02\ m^2$

$N = 100\ turns$

$B_0 = 2\ T$

$\Delta t = 0.2\ s$

$\varepsilon = ?$

B=0 (because loop is pulled out of the magnetic field)

Formulas:

$\Phi = BA$

$\Delta\Phi = \Phi - \Phi_0$

$\varepsilon = -N\dfrac{\Delta\Phi}{\Delta t}$

Calculations:

$\Phi_0 = B_0 A = 2 \cdot 0.02 = 0.04\ Wb$

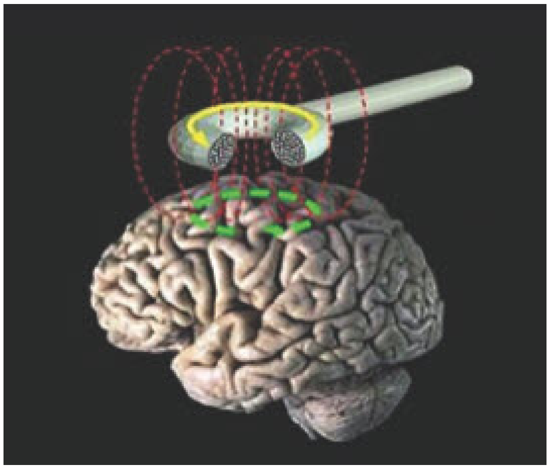
$\Phi = BA = 0 \cdot 0.02 = 0$

$\Delta\Phi = \Phi - \Phi_0 = 0 - 0.04 = -0.04\ Wb$

$\varepsilon = -N\dfrac{\Delta\Phi}{\Delta t} = (-100)\dfrac{(-0.04)}{0.2} = 20\ V$

Physics in life

Transcranial magnetic stimulation is used to measure the connection between the brain and a muscle. What kind of diseases can be identified by this method?

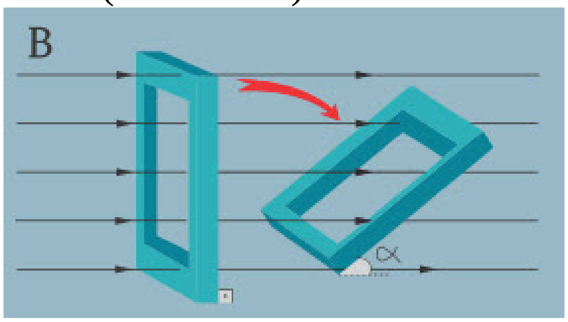


Research time

Make a scheme for the flashlight that works on electromagnetic induction principle.

Literacy

1. What is definition of “magnetic flux”?
2. What is definition of “electromagnetic induction”? Where electromagnetic induction is used?
3. Calculate magnetic flux through 25 cm^2 wire loop that is placed in 0.04 Tesla magnetic field. Angle between plane of the loop and magnetic field is

30°.
4. Rod of 1 metre length is rotated about one end in 0.05 Tesla magnetic field. Axis of rotation is parallel to the magnetic field lines. Calculate magnetic flux per one rotation.
5. Wire loop in the shape of square with 10 cm side is placed in uniform magnetic field of 2 Tesla so that it is perpendicular to magnetic field lines. What angle should you rotate loop so that magnetic flux changes by 10 mWb (milliWeber)?


6. Circular loop of wire is placed in the 5 mT uniform magnetic field so that angle between the axis of loop and magnetic field lines is 60°. Radius of loop is 20 cm. How should you change number of loops so that magnetic flux changes by 0.1 Weber?

14.3 Application of Electromagnetic induction

You will

- analyse working principles of electromagnetics devices (electromagnetic relay, generator, transformer)

Question

When electricity is cut-off, the device on the figure is used to produce electricity. How does it work? How can you make it? What do you put inside of this device?

Loudspeaker

On the Figure 178 you can see a magnified view of one type of speaker design which shows a cone, a voice coil and a permanent magnet. Due to the current in the voice coil the magnetic field causes a force F to be exerted on the voice coil and cone. As a result diaphragm (a thin membrane) attached to cone vibrates and produces sound.

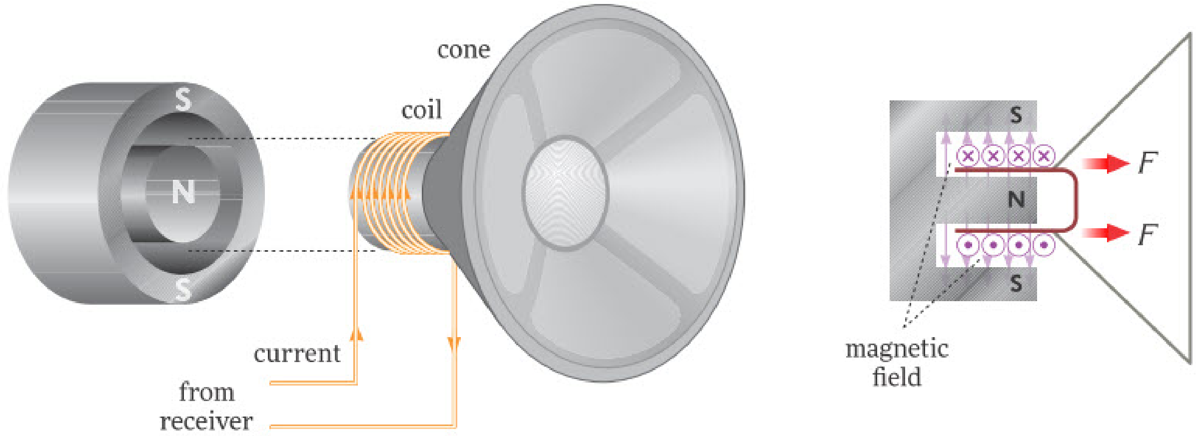


Figure 178

Generator

Generator is device that changes energy of motion into electrical energy. On the Figure 179 you see simple generator that consists of coil rotating near permanent magnet. For example, in hydroelectric power plants coils are rotated by flowing water.

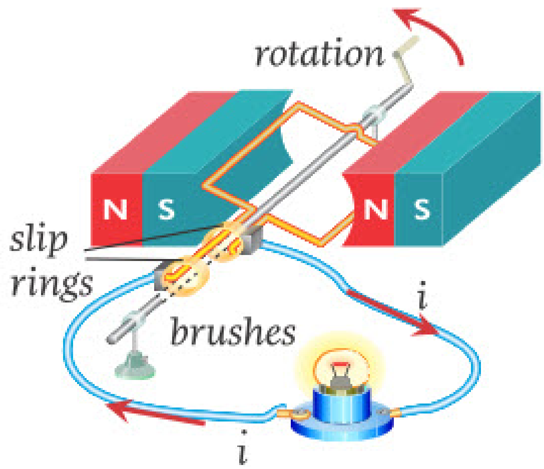


Figure 179

Transformer

A transformer is a device which changes a voltage from one value into another, Figure 180.

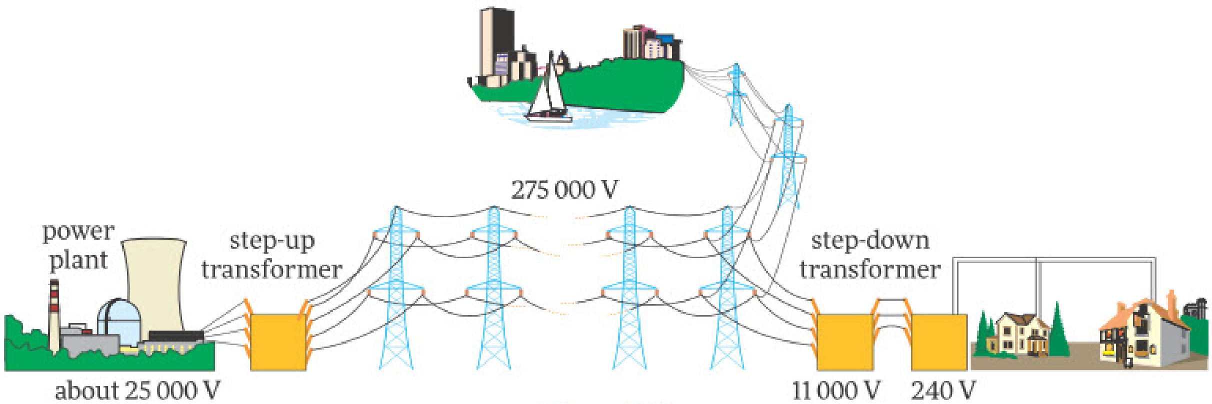


Figure 180

It only works with alternating current (A.C.). High voltage is used to minimize power losses in wires.

A transformer includes two coils wound upon a soft iron core as shown in Figure 181. The coils are called the primary and secondary coil. An alternating current supplied to the primary coil induces an alternating current in the secondary coil.

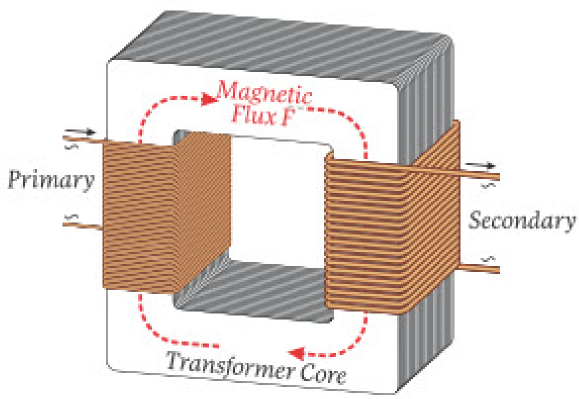


Figure 181

Electromagnetic relay

An electromagnetic relay is a switch which includes an electromagnet. It uses a small current to control a large current in another circuit.

As shown in the Figure 182, when the switch is on, the current flowing through the coil produces a magnetic field in the centre of the core which attracts the soft–iron armature so that the head of the armature switches on the motor circuit.

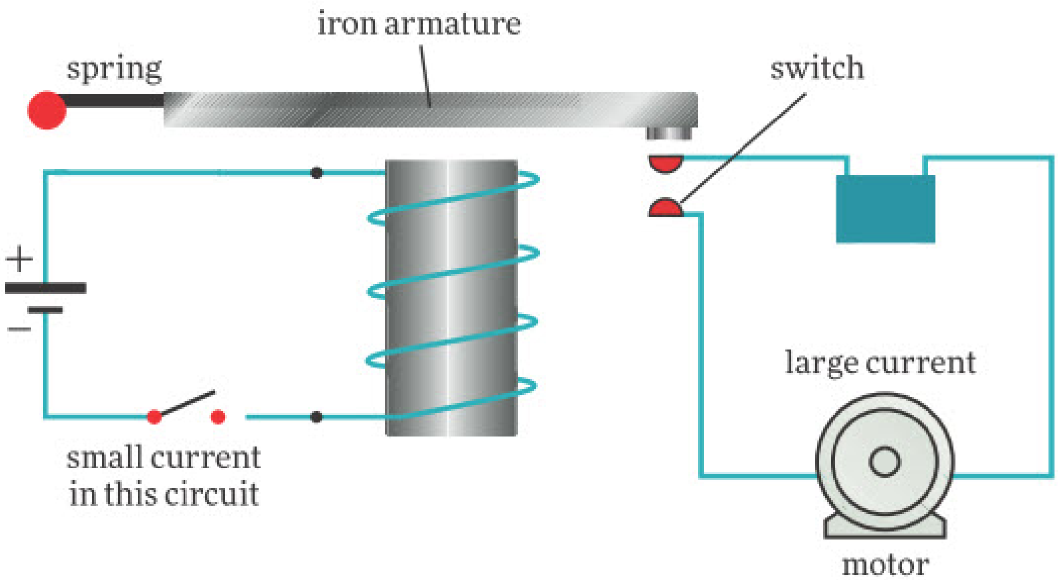


Figure 182

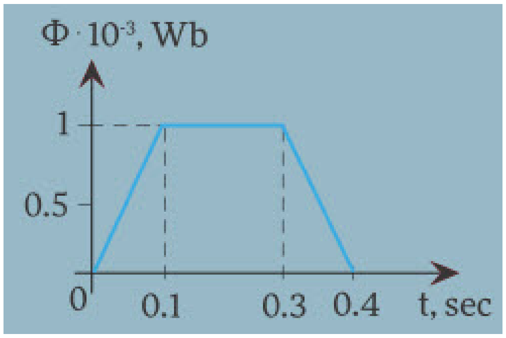
The spring pulls the iron strip back when the switch is off. There are many applications of relay systems in various electric machines. For example elevators include relay systems so that the powerful motors are operated by small currents in the elevator buttons.

Activity

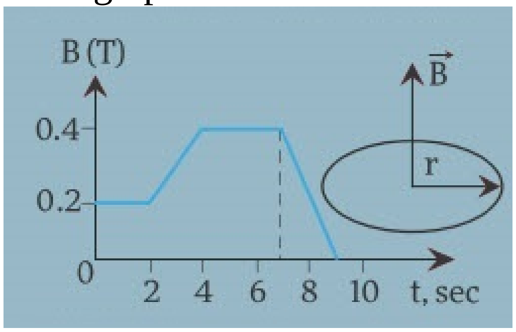
Split open old headphones or loudspeakers. Make list of materials that are used to make headphones or loudspeakers.

Literacy

1. What is electromagnetic relay? How can you make electromagnetic relay? Where electromagnetic relay is used?
2. What is generator? How can you make generator? Where generator is used?
3. Calculate EMF of electromagnetic induction in solenoid that has 500 turns of wire if magnetic flux decreases from 7 mWb to 3 mWb in 5 ms.
4. Calculate rate of change of magnetic flux in solenoid that has 200 turns of wire if EMF is 120 Volt.
5. There is magnetic flux versus time graph. Plot EMF versus time graph, and calculate maximum EMF if number of turns in coil is 400.



6. Conducting ring that has 2 cm radius and 0.1 Ohm resistance is placed into magnetic field that changes as shown on the graph. Plot current versus time graph.



Research time

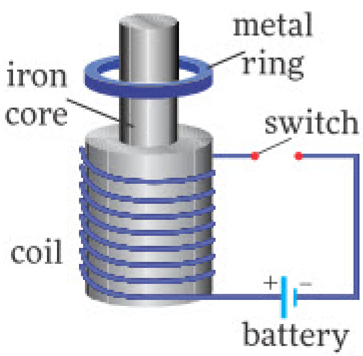
During MRI ‘contrast agents’ are used. Why?

14.4 Lenz's law. Self-induction. Inductance

You will

- apply Faraday's law of electromagnetic induction for problem solving.

Question



When the switch in the circuit is closed, a current is established in the coil and the metal ring ‘jumps’ upward. Explain why.

Lenz's Law

The polarity of induced EMF is such that it causes an induced current whose direction induces a magnetic field in the opposite direction to the external flux change, Figure 183.

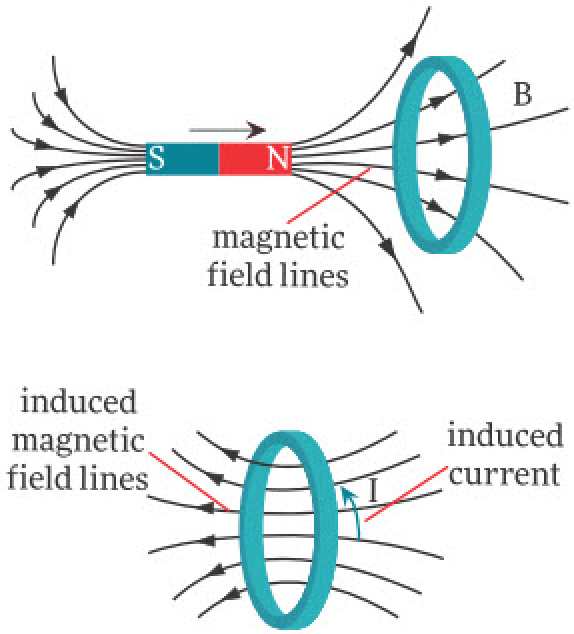


Figure 183

The minus sign in Faraday's Law of induction is a reminder of this opposition to the external flux changes.

The reasoning strategy of Lenz's Law to determine polarity of induced emf is as follows:

1. Determine whether the magnetic flux that penetrates the coil is increasing or decreasing.
2. Find what direction the induced magnetic field must be, in order that it can oppose the change in flux, by adding to or subtracting from the external field.
3. Determine the direction of induced current that produces the induced magnetic field.

Self-Induction

Self induction is the effect in which a change in current ΔI in a coil induces an EMF in the same coil.

EMF (electromotive force) of self induction can be calculated by this formula

$$\varepsilon = -L\frac{\Delta I}{\Delta t}$$

where

ε : electromotive force[Volt]

L: inductance [Henry]

ΔI : change of current [Ampere]

Δt: change of time [second]

Inductor (coil) opposes a change in current. This property is called inductance. Inductors are widely used in electronics to prevent the hazards of the sudden current changes. For example ferrite bead inductor is an electric component that suppresses high frequency noise in electronic circuits, Figure 184.

Figure 184

Inductance (self-inductance) of solenoid (coil) shown on the Figure 185 can be calculated by this formula

$$L = \frac{\mu\mu_0 N^2 A}{l}$$

where

L : inductance [Henry]

μ relative magnetic permeability of iron core

$\mu_o = 4\pi \cdot 10^{-7}$: permeability of vacuum [T·m/A]

N: Number of turns

A : cross-sectional area of solenoid [m^2]

I: length of solenoid [m]

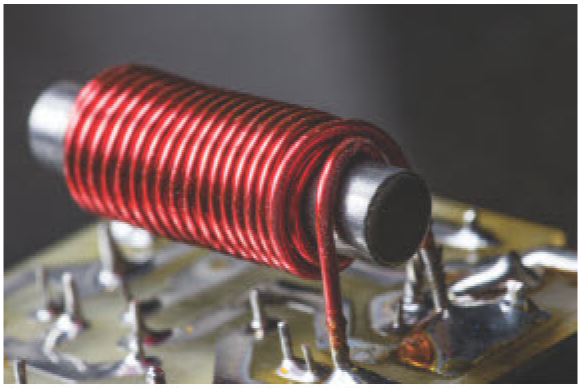
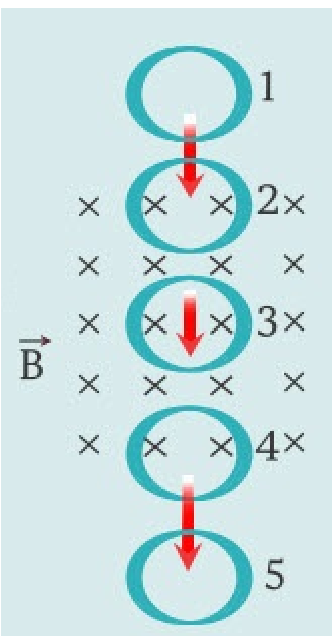


Figure 185

Example

A constant magnetic field exists in a rectangular region of space. This field is directed perpendicularly into the plane of the paper. A copper ring slides through the region, from position 1 to position 5. For each of the five positions, determine if an induced current exists in the ring and find its direction.



Solution:
Position 1: Magnetic field is zero so flux is zero, so no induced current is produced.
Position 2: Magnetic field is uniform and directed inward and the flux is increasing through the ring, since flux is increasing the induced flux must

be outward. In order to produce an outward magnetic field the induced current must be in the anticlockwise direction.
Position 3: Magnetic field is non-zero and flux is constant. Since flux is not changing, no current is induced in the ring.
Position 4: As the ring leaves the field, flux decreases. Since flux is decreasing the induced flux must be directed inward like the external flux. In order to produce an inward magnetic field, the induced current must be in the clockwise direction.
Position 5: As in position 1, magnetic field is zero thus, flux is zero, so, no induced current is produced.

Example

A long solenoid of length 10 cm and cross sectional area 5 cm^2 contains 300 turns.
a) Find the self-inductance of the solenoid.
b) Determine the emf induced in the solenoid when the current increases from 1 A to 3 A in a time of 0.1 s.

Given:

$l = 10\ cm = 0.1\ m$

$A = 5\ cm^2 = 5 \cdot 10^{-4}\ m^2$

$N = 300\ turns$

$\mu_0 = 4\pi \cdot 10^{-7}\ T \cdot m/A$

$L = ?$

$\varepsilon = ?$

Formulas:

$$L = \frac{\mu_0 N^2 A}{l}$$

$$\varepsilon = -L\frac{\Delta I}{\Delta t}$$

Calculations:

$$L = \frac{\mu_0 N^2 A}{l} = \frac{4 \cdot 3.14 \cdot 10^{-7} \cdot 300^2 \cdot 5 \cdot 10^{-4}}{0.1}$$

$$L = 5.652 \cdot 10^{-4}\ H$$

$$\varepsilon = -L\frac{\Delta I}{\Delta t} = (-5.652 \cdot 10^{-4})\frac{(3-1)}{0.1}$$

$$\varepsilon = 0.011304\ V \simeq 0.01\ V$$

Research time

For self-inductance:
1. Write down your own definition;
2. Draw a picture;
3. Translate it.

Activity

Take long aluminium foil and cylinder-like neodymium magnet that fits in the foil. Measure the time of fall for magnet inside the aluminium foil and outside of it. Is there a difference in time? What happens if you make the foil thicker? Try it.

Literacy

1. What is definition of inductance? How can you calculate inductance?
2. What is definition of Lenz's law?

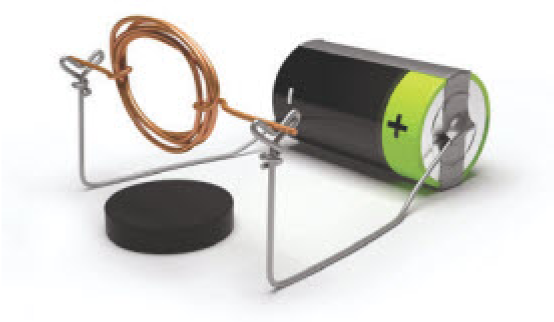
3. Calculate inductance of loop if 10 A current produces 0.5 W magnetic flux.
4. Current of 40 mH loop increases by 0.2 A in 0.01 second. What is induced EMF? What is change of magnetic flux?
5. Current passing through solenoid induces magnetic field of 1.5 T. Solenoid has 1000 turns of wire and cross-sectional area of 10 cm^2. Calculate induced EMF if current is decreased to zero in 500 μs.
6. How many turns of wire should you wound on paper cylinder of 2 cm diameter so that inductance is equal to 1 mH? Diameter of wire is 0.4 mm.

14.5 Energy of Magnetic Field

You will

- draw an analogy between mechanical energy and magnetic energy.

Question



Does wire loop shown in figure have energy? Does wire loop have energy if it is disconnected from battery? How are energy and current related with each other?

Kinetic energy depends on mass and velocity of object. For example, kinetic energy of 1000 gram ball is twice more than energy of 500 gram ball when they move at same velocity. Kinetic energy of 1 kg ball that moves at 4 m/s is four times more than kinetic energy of 1 kg ball that moves at 2 m/s. Formula of kinetic energy is

$$E_K = \frac{1}{2}mv^2$$

where
E_K: kinetic energy [Joule]
m: mass [kg]

υ: velocity [m/s]

There are many other types of energy. One of them is energy of magnetic field. Because of this energy electromagnet shown on the Figure 186 can attract objects and do work.

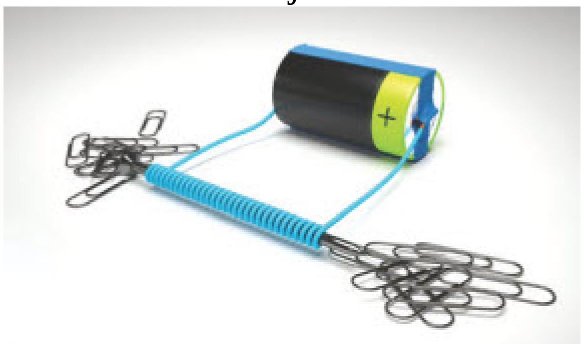


Figure 186

Wire shaped into coil with iron object inside is called inductor, Figure 187. Inductor is a device that stores energy of magnetic field when current passes through it. Inductor opposes a change in current. This property is called inductance.

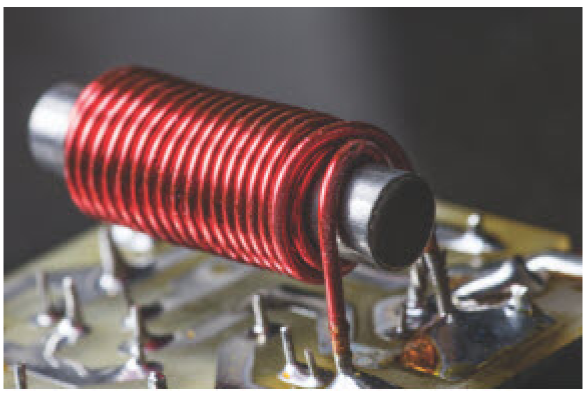


Figure 187

Energy of magnetic field and kinetic energy are analogous to each other. Velocity (motion of object) is analogous to current (motion of electrons). Mass opposes change in motion and similarly inductance opposes change in current.

Energy of magnetic field stored in inductor can be calculated by this formula:

$$E = \frac{1}{2}LI^2$$

where
E: energy of magnetic field [Joule]
L: inductance [Henry]
I: current [Ampere]

Energy of magnetic field is the energy stored in an inductor (of inductance L) when current I, is passing through it.

Example

How much energy is stored in the 0.5 mH inductor when a 20 A current flows through it?

Given:

$L = 0.5\, mH = 0.5 \cdot 10^{-3}\, H$

$I = 20\, A$

$E = ?$

Formulas:

$$E = \frac{1}{2}LI^2$$

Calculations:

$$E = \frac{1}{2}LI^2 = \frac{1}{2} \cdot 0.5 \cdot 10^{-3} \cdot 20^2 = 0.1\, J$$

Example

The heating coils in a hair dryer are 0.8 cm in diameter, have a combined length of 1 m, and a total of 400 turns.
a) What is their total self-inductance assuming they act like a single solenoid?
b) How much energy is stored in them when 6 A flows?

Given:

$d = 0.8\ cm = 0.008\ m$

$l = 1\ m$

$N = 400\ turns$

$\mu_0 = 4\pi \cdot 10^{-7} T \cdot m/A$

$I = 6\ A$

$L = ?$

$E = ?$

Formulas:

$$A = \frac{\pi d^2}{4}$$

$$L = \frac{\mu_0 N^2 A}{l}$$

$$E = \frac{1}{2} L I^2$$

Calculations:

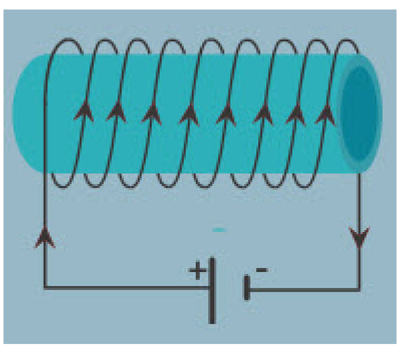
a) $A = \frac{\pi d^2}{4} = \frac{3.14 \cdot 0.008^2}{4} = 5.024 \cdot 10^{-5}\ m^2$

$$L = \frac{\mu_0 N^2 A}{l} = \frac{4 \cdot 3.14 \cdot 10^{-7} \cdot 400^2 \cdot 5.024 \cdot 10^{-5}}{1}$$

$L = 10^{-5} H$

b) $E = \frac{1}{2} L I^2 = \frac{1}{2} \cdot 10^{-5} \cdot 6^2$ $\qquad E = 1.8 \cdot 10^{-4}\ J$

Literacy

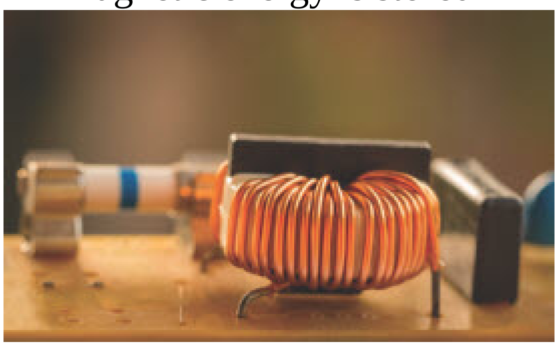


1. What is the energy of magnetic field? How can you calculate magnetic field?
2. How would magnetic energy change when inductance and current double?

3. Current of 10 A flows through 0.2 H coil. What is energy of magnetic field in the coil? How would energy change if current is doubled?
4. Calculate current in a coil that has magnetic energy of 0.5 J and magnetic flux of 0.1 Wb passes through coil.
5. Calculate magnetic flux and magnetic energy in a 0.5 m long coil that has cross-sectional area of 10 cm^2 and 1000 turns of wire if 10 A current flows through coil.
6. Calculate energy of magnetic field of 25 mH and 8.2 Ohm coil that is connected to 55 Volt power source. What amount of heat is released when coil is disconnected from power source?

Is it true?

All magnetic energy is stored in inductors.



Physics in life

Metal detectors at the airport use principle of inductance to identify metal objects.

14.6 Electric motor and electric generator

You will

 - investigate parameters of model of electric motor, explain results of investigation by using Faraday's law and Lenz's law.

Question

 Why lamp is connected to stationary bike? Why lamp is emitting light?

Electric motor

We have seen that a current-carrying wire can experience a force when placed in a magnetic field, Figure 188. If a loop of wire is suspended properly in a magnetic field, the magnetic force produces a torque (turning effect of a force) that tends to rotate the loop.

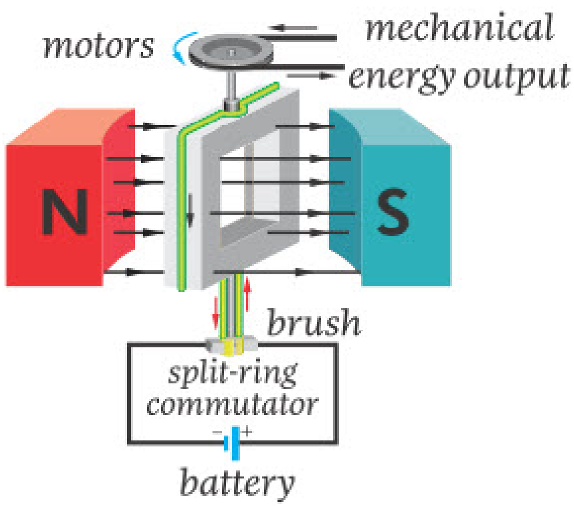


Figure 188

Torque can be calculated by this formula:

$$\tau = NBIA\sin\alpha$$

where:
τ: torque [N·m]
N: number of turns of loop
B: magnetic field through loop [Tesla]
I: current in loop [Ampere]
A: area of loop [m^2]
α: angle between magnetic field and normal to the loop

The torque that is produced by the magnetic force rotates the loop and generates rotational kinetic energy. This principle is used for the basis of one of the most useful machines today: electric motor, shown in Figure 189.

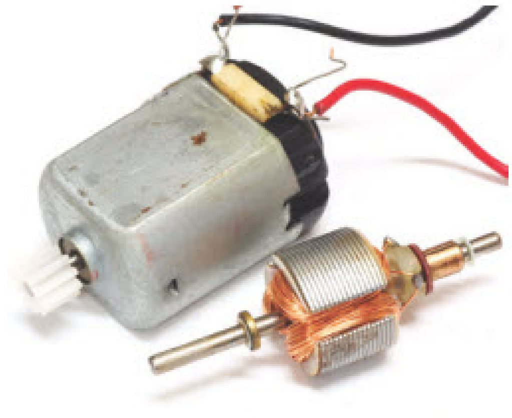


Figure 189

Electric generator

Electric generator is a device for converting mechanical work into electric energy; it induces an EMF by rotating a coil in a magnetic field, Figure 190.

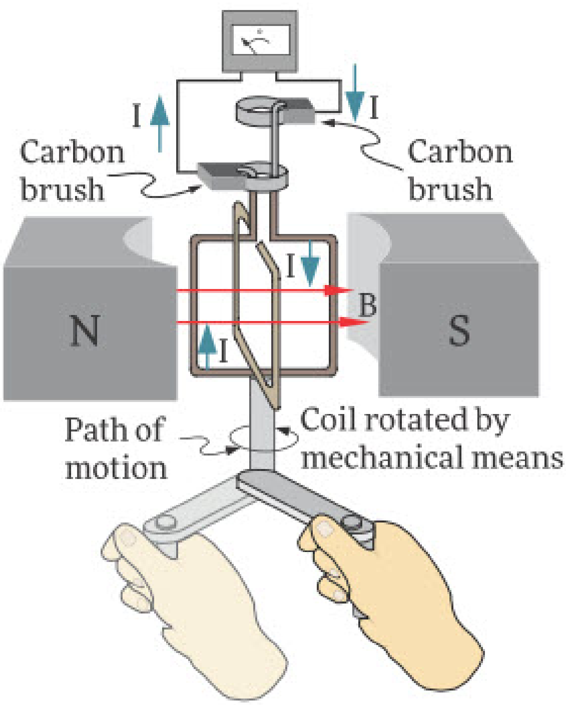


Figure 190

EMF (electromotive force) induced in generator can be calculated by this formula:

$$\varepsilon = NBA\omega cos\omega t$$

where:
ε : EMF [Volt]
N: Number of turns of coil
B: magnetic field [Tesla]
A: Area of coil [m^2]
ω: angular speed [rad/sec]
t: time [sec]

Example

A circular coil of wire has a radius of 0.1 m and carries a current of 15 A, Figure 191. The coil consists of N=100 closely wrapped turns, and is placed in a magnetic field of 0.8 T. What is the maximum torque that the coil can experience in this field?

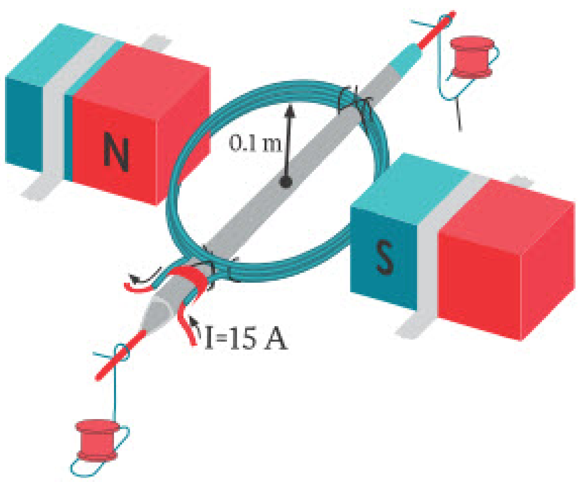


Figure 191

Given:	$\alpha = 90°$
$r = 0.1\ m$	(because we need to find maximum torque, and
$I = 15\ A$	$sin\ 90° = 1$ is maximum value of $sin\ \alpha$)
$N = 100\ turns$	$\tau = ?\ N \cdot m$
$B = 0.8\ T$	

Formulas:

$A = \pi r^2$

$\tau = NBIAsin\alpha$

Calculations:

$A = \pi r^2 = 3.14 \cdot\ 0.1^2 = 0.0314\, m^2$

$\tau = NBIAsin\alpha = 100\ \cdot\ 0.8\ \cdot 15\ \cdot 0.0314\ \cdot\ sin\,90°$

$\tau = 37.68\, N \cdot m$

Example

The generator consists of 200 turns square coil and magnet. Coil has 4 cm side. Magnet produces a uniform 1.5 T magnetic field. How fast do you need to rotate coil to generate maximum emf of 12 V?

Given:

$N = 200\ turns$

$a = 0.04\, m$

$B = 1.5\, T$

$\mathcal{E} = 12\, V$

$\alpha = \omega t = 0°$

(because we need to find maximum emf, and cos 0°=1 is maximum value of $cos\ \alpha$)

f =?

Formulas:

$A = a^2$

$\mathcal{E} = NBA\omega \cos \omega t$

$\omega = 2\pi f$

Calculations:

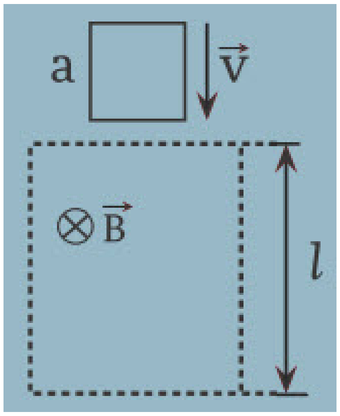
$$f = \frac{\mathcal{E}}{2\pi NBa^2 \cos \omega t}$$

$$f = \frac{12}{2 \cdot 3.14 \cdot 200 \cdot 1.5 \cdot 0.04^2 \cdot 1}$$

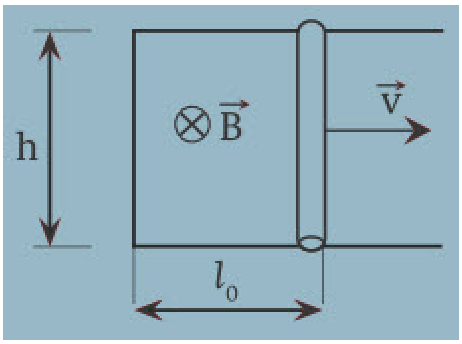
$$f = 3.98\, Hz \cong 4\, Hz$$

Literacy

1. What is electric motor? How can you make electric motor? Where electric motor is used? What is the difference between motor and generator?
2. What is generator? How can you make generator? Where generator is used?
3. Square loop that has side of a=2 mm is moved at υ=2 cm/s speed through region of B=1 T magnetic field. Width of region is I=1 cm. Resistance of square loop is 0.02 Ohm. Plot EMF versus time graph for square loop. What amount of heat is released in square loop?



4. Conducting rod is moved with υ=2 m/s speed along two metal tracks as shown in the figure. There is uniform magnetic field of perpendicular to the plane of loop. Length of rod is h=0.5 m , initial position of rod is I_0=1 m . Resistance per unit length of loop is R=1 Ω/m. Calculate current in the loop after t=0.5 sec from the start of motion.



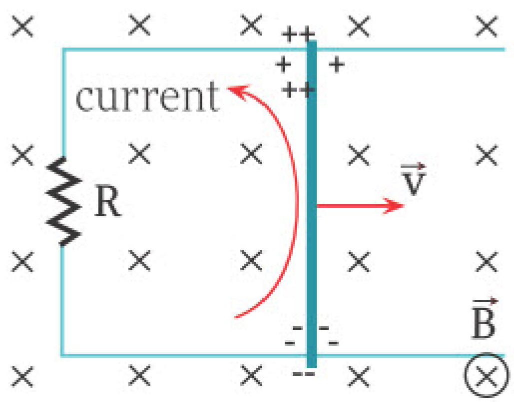
5. Maximum moment of force (torque) acting on a 1 cm^2 loop in a magnetic field is equal to M=2 μN·m. Current in the loop is 0.5 Ampere. Calculate magnetic field.
6. Rectangular loop that has 200 turns of wire and sides of 10 cm and 5 cm is placed in a 50 mT magnetic field. What is the maximum moment of force (torque) acting on the loop if current through loop is 2 A?

Is it true?

The world's smallest electric motor was announced in 2011, measuring one nanometre (a billionth of a metre or 1/60000 the width of a human hair) across and consisting of a single molecule.

CHECK YOURSELF

14.1 Motional EMF



	Length (meter)	B (Tesla)	v (m/s)	EMF (Volt)	R (Ohm)	I (Ampere)
Rod A	1	0.2		0.8		8
Rod B		2	0.2	0.6	2	
Rod C	0.5	0.1	1		0.01	
Coil D	0.8		2		2	0.8

There are four rods A, B, C, D that move on two metal tracks as shown on the figure. Information about length of rods, magnetic fields, velocities, EMFs, resistances and currents is given in the table. Fill the table and use it to answer the questions 1-30.

1. Which rod is the longest?
A) Rod A
B) Rod B
C) Rod C

D) Rod D
E) There is no right answer

2. Which rod is the shortest?
A) Rod A
B) Rod B
C) Rod C
D) Rod D
E) There is no right answer

3. Which rod is shorter than 0.4 m?
A) Rod A
B) Rod B
C) Rod C
D) Rod D
E) There is no right answer

4. Which rod is longer than 1.6 m?
A) Rod A
B) Rod B
C) Rod C
D) Rod D
E) There is no right answer

5. Which rod moves in the strongest magnetic field?
A) Rod A
B) Rod B
C) Rod C
D) Rod D
E) There is no right answer

6. Which rod moves in the weakest magnetic field?
A) Rod A
B) Rod B
C) Rod C
D) Rod D
E) There is no right answer

7. Which rods move in the magnetic field less than 0.5 T?
A) Rod A
B) Rod B
C) Rod C
D) Rod D
E) There is no right answer

8. Which rods move in the magnetic field more than 0.8 T?
A) Rod A
B) Rod B
C) Rod C
D) Rod D
E) There is no right answer
9. Which rod moves the fastest?
A) Rod A
B) Rod B
C) Rod C
D) Rod D
E) There is no right answer

10. Which rod moves the slowest?
A) Rod A
B) Rod B
C) Rod C
D) Rod D
E) There is no right answer

11. What is the ratio of velocities of the fastest and the slowest rods?
A) 40
B) 20
C) 10
D) 2
E) There is no right answer

12. Which rod travels 12 meters in one minute?
A) Rod A

B) Rod B
C) Rod C
D) Rod D
E) There is no right answer

13. Which rod has the highest motional EMF?
A) Rod A
B) Rod B
C) Rod C
D) Rod D
E) There is no right answer

14. Which rod has the lowest motional EMF?
A) Rod A
B) Rod B
C) Rod C
D) Rod D
E) There is no right answer

15. Which rods have motional EMF less than 1.5 V?
A) Rod A
B) Rod B
C) Rod C
D) Rod D
E) There is no right answer

16. Which rods have motional EMF more than 12 V?
A) Rod A
B) Rod B
C) Rod C
D) Rod D
E) There is no right answer

17. Which circuit has the highest resistance?
A) Rod A
B) Rod B
C) Rod C

D) Rod D
E) There is no right answer
18. Which circuit has the lowest resistance?
A) Rod A
B) Rod B
C) Rod C
D) Rod D
E) There is no right answer

19. Which circuits have resistance greater than 0.5 Ohm?
A) Rod A
B) Rod B
C) Rod C
D) Rod D
E) There is no right answer

20. Which circuits have resistance less than 0.07 Ohm?
A) Rod A
B) Rod B
C) Rod C
D) Rod D
E) There is no right answer

21. Which circuit has the highest current?
A) Rod A
B) Rod B
C) Rod C
D) Rod D
E) There is no right answer

22. Which circuit has the lowest current?
A) Rod A
B) Rod B
C) Rod C
D) Rod D
E) There is no right answer

23. Which circuit has current more than 1 Ampere?
A) Rod A
B) Rod B
C) Rod C
D) Rod D
E) There is no right answer

24. Which circuit has current less than 6 Ampere?
A) Rod A
B) Rod B
C) Rod C
D) Rod D
E) There is no right answer

25. In which circuit heat dissipated in the resistor is the greatest?
A) Rod A
B) Rod B
C) Rod C
D) Rod D
E) There is no right answer

26. In which circuit heat dissipated in the resistor is the smallest?
A) Rod A
B) Rod B
C) Rod C
D) Rod D
E) There is no right answer

27. What is the ratio of the greatest heat and the smallest heat dissipated in the resistors?
A) 40
B) 30
C) 20
D) 10
E) There is no right answer

28. Which circuit dissipates 384 Joules of heat in one minute?

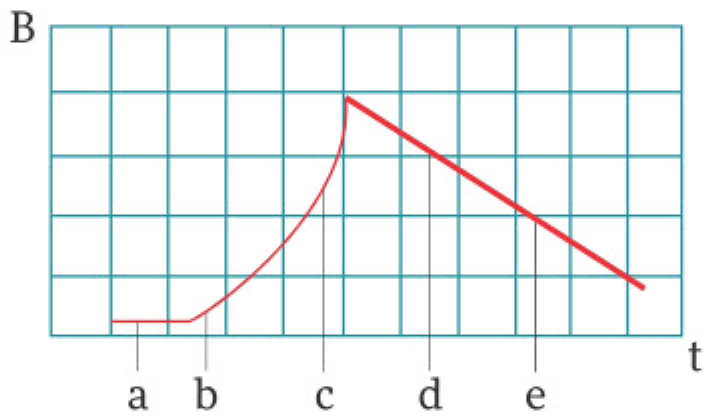
A) Rod A
B) Rod B
C) Rod C
D) Rod D
E) There is no right answer

29. How many Joules of heat are dissipated in circuit D in 10 minutes?
A) 786
B) 678
C) 867
D) 768
E) There is no right answer

30. What is the ratio of EMF in rod D and Rod A?
A) 2
B) 3
C) 4
D) 1
E) There is no right answer

14.2 Magnetic flux. Electromagnetic induction.

There is B-t graph of changing magnetic field that passes through 500 cm^2 coil that has 200 turns. Vertical unit length on the graph is 0.01 Tesla, horizontal unit length on the graph is 0.01 second. Use graph to answer questions 1-25.



1. Which point on the graph shows the highest magnetic field?
A) a
B) b
C) c
D) d
E) e

2. Which point on the graph shows the lowest magnetic field?
A) a
B) b
C) c
D) d
E) e

3. Which point on the graph shows the highest magnetic flux?
A) a
B) b
C) c
D) d
E) e

4. Which point on the graph shows the lowest magnetic flux?
A) a
B) b
C) c
D) d
E) e

5. Which points on the graph show magnetic field less than 10 mT?
A) a
B) b
C) c
D) d
E) e

6. Which points on the graph show magnetic field more than 20 mT?
A) a
B) b
C) c
D) d
E) e

7. Estimate maximum magnetic field that passes through coil.
A) 40 mT
B) 50 mT
C) 60 mT
D) 30 mT
E) 20 mT

8. Estimate minimum magnetic field that passes through coil.
A) 32 mT
B) 42 mT
C) 2 mT
D) 12 mT
E) 22 mT

9. Estimate maximum magnetic flux that passes through coil.

A) 2 mWb
B) 2.5 mWb
C) 3 mWb
D) 1.5 mWb
E) 1 mWb

10. Estimate minimum magnetic flux that passes through coil.
A) 1.8 mWb
B) 2.3 mWb
C) 0.1 mWb
D) 0.8 mWb
E) 1.3 mWb

11. How many degrees should we rotate coil so that magnetic flux at point e is 0.5 mWb?
A) 0^o
B) 30^o
C) 60^o
D) 90^o
E) 180^o

12. How many degrees should we rotate coil so that magnetic flux at point e is 0 mWb?
A) 0^o
B) 30^o
C) 60^o
D) 90^o
E) 180^o

13. What should be number of turns in coil so that maximum flux is 1 Weber?
A) 1000
B) 200
C) 300
D) 400
E) 500

14. What should be number of turns in coil so that flux at point e is 1 Weber?
A) 1000
B) 200
C) 300
D) 400
E) 500

15. What formula is used to calculate magnetic flux?
A) $\Phi=B\cos\alpha$
B) $\Phi=A\cos\alpha$
C) $B=\Phi\cdot A\cdot\cos\alpha$
D) $A=B\cdot\Phi\cdot\cos\alpha$
E) $\Phi=B\cdot A\cos\alpha$

16. What formula is used to calculate electromotive force of electromagnetic induction?

A) $\Delta\Phi=-N\cdot\varepsilon/\Delta t$

B) $\Delta t=-N\cdot\Delta\Phi/\varepsilon$

C) $\varepsilon=-N\cdot\Delta t/\Delta\Phi$

D) $\varepsilon=-N\cdot\Delta\Phi/\Delta t$

E) $N=-\varepsilon\cdot\Delta\Phi/\Delta t$

17. Which point on the graph shows the highest EMF?
A) a
B) b
C) c
D) d
E) e

18. Which point on the graph shows the lowest EMF?
A) a

B) b
C) c
D) d
E) e

19. Which point on the graph shows zero EMF?
A) a B) b
C) c D) d
E) e

20. Which points on the graph have equal EMF?
A) a
B) b
C) c
D) d
E) e

21. Which points have EMF greater than 7 Volt?
A) a
B) b
C) c
D) d
E) e

22. Estimate EMF of point a.
A) 8 Volt
B) 20 Volt
C) 5 Volt
D) 3 Volt
E) 0

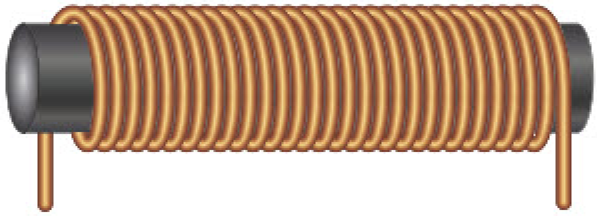
23. Estimate EMF of point d.
A) 8 Volt
B) 25 Volt
C) 5 Volt
D) 3 Volt
E) 0

24. Estimate EMF of point e.
A) 8 Volt
B) 25 Volt
C) 5 Volt
D) 3 Volt
E) 0

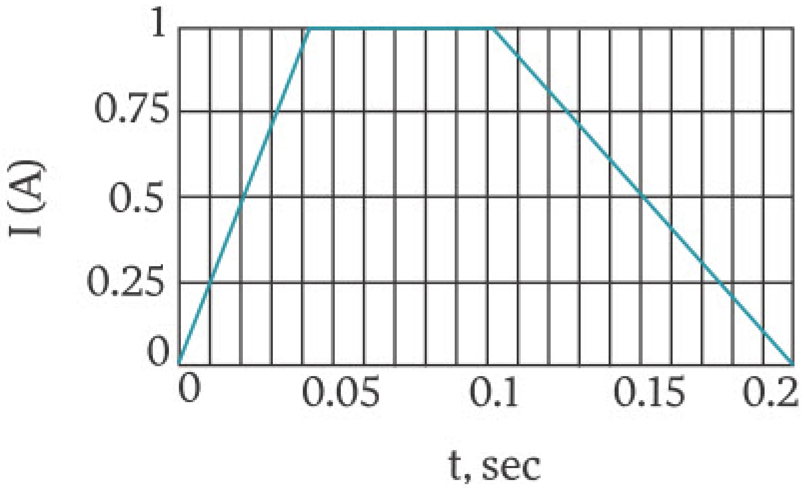
25. Estimate EMF of point c.
A) 8 Volt
B) 25 Volt
C) 5 Volt
D) 3 Volt
E) 0

14.4 Self-Induction. Inductance. Energy of Magnetic Field

You need to construct 1 mH solenoid by using plastic cylinder of 2 cm diameter and copper wire of 0.4 mm diameter. Relative magnetic permeability of plastic is $\mu=1$. Then this solenoid is connected to the source of changing current. I-t graph and table are shown on the Figure. Use this information to answer questions 1-25.



	t (sec)	I (A)
Point A	0.02	0.5
Point B	0.06	1
Point C	0.1	1
Point D	0.14	0.6
Point E	0.2	0



1. What formula is used to calculate inductance?

A) $A = \frac{\mu\mu_0 N^2 L}{l}$

B) $L = \frac{\mu\mu_0 N^2 l}{A}$

C) $L = \frac{\mu N^2 A}{\mu_0 l}$

D) $N^2 = \frac{\mu\mu_0 L A}{l}$

E) $L = \frac{\mu\mu_0 N^2 A}{l}$

2. What formula is used to calculate EMF of self-inductance?

A) $\Delta I = -L\frac{\varepsilon}{\Delta t}$

B) $\varepsilon = -L\frac{\Delta I}{\Delta t}$

C) $\varepsilon = -\Delta t\frac{\Delta I}{L}$

D) $\varepsilon = -L\frac{\Delta t}{\Delta I}$

E) $L = -\varepsilon\frac{\Delta I}{\Delta t}$

3. What formula is used to calculate energy of magnetic field?

A) $I=1/2 \cdot L \cdot E^2$

B) $E=1/2 \cdot I \cdot L^2$

C) $E=1/2 \cdot L \cdot I^2$

D) $E=1/2 \cdot LI$

E) $L=1/2 \cdot E \cdot I^2$

4. How many turns of wire should you wound on plastic cylinder in one layer to make 1 mH solenoid?
A) 4110
B) 1410
C) 1014
D) 1104
E) 4101

5. What type of cylinder should you use instead of plastic cylinder to obtain 5 Henry solenoid?
A) Electrical steel $\mu=4000$
B) Mu-metal $\mu=50000$
C) Carbon steel $\mu=100$
D) Iron $\mu=5000$
E) Platinum $\mu=1.000265$

6. Which point(s) show the highest current?
A) Point A
B) Point B
C) Point C
D) Point D
E) Point E
7. Which point(s) show the lowest current?
A) Point A
B) Point B
C) Point C
D) Point D
E) Point E

8. Which point(s) show the highest energy of magnetic field?
A) Point A
B) Point B
C) Point C
D) Point D

E) Point E

9. Which point(s) show the lowest energy of magnetic field?
A) Point A
B) Point B
C) Point C
D) Point D
E) Point E

10. Which point(s) show the energy less than 0.2 mJ?
A) Point A
B) Point B
C) Point C
D) Point D
E) Point E

11. Which point(s) show the energy more than 0.4 mJ?
A) Point A
B) Point B
C) Point C
D) Point D
E) Point E

12. Which point(s) show EMF of self-induction equal to 0?
A) Point A
B) Point B
C) Point C
D) Point D
E) Point E

13. Which point(s) show EMF of self-induction less than 15 mV?
A) Point A
B) Point B
C) Point C
D) Point D
E) Point E

14. Which point(s) show EMF of self-induction more than 20 mV?
A) Point A
B) Point B
C) Point C
D) Point D
E) Point E

15. What is the maximum EMF of self-induction shown on graph?
A) 25 mV
B) 20 mV
C) 15 mV
D) 10 mV
E) 5 mV

16. What is the energy of magnetic field at point A?
A) 0.18 mJ
B) 0.5 mJ
C) 0
D) 0.125 mJ
E) There is no right answer

17. What is the energy of magnetic field at point B?
A) 0.18 mJ
B) 0.5 mJ
C) 0
D) 0.125 mJ
E) There is no right answer

18. What is the energy of magnetic field at point C?
A) 0.18 mJ
B) 0.5 mJ
C) 0
D) 0.125 mJ
E) There is no right answer

19. What is the energy of magnetic field at point D?
A) 0.18 mJ

B) 0.5 mJ
C) 0
D) 0.125 mJ
E) There is no right answer

20. What is the energy of magnetic field at point E?
A) 0.18 mJ
B) 0.5 mJ
C) 0
D) 0.125 mJ
E) There is no right answer

21. What is the EMF of self-induction at point A?
A) 25 mV
B) 0
C) 10 mV
D) 50 mV
E) There is no right answer

22. What is the EMF of self-induction at point B?
A) 25 mV
B) 0
C) 10 mV
D) 50 mV
E) There is no right answer

23. What is the EMF of self-induction at point C?
A) 25 mV
B) 0
C) 10 mV
D) 50 mV
E) There is no right answer

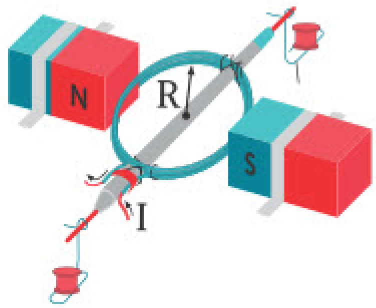
24. What is the EMF of self-induction at point D?
A) 25 mV
B) 0
C) 10 mV

D) 50 mV
E) There is no right answer

25. What is the EMF of self-induction at point E?
A) 25 mV
B) 0
C) 10 mV
D) 50 mV
E) There is no right answer

14.6 Circular Coils

There are five circular coils that first are used as motors and then as generators as shown in the figure. Lengths of wires that are used to make coils, radii of coils, strength of magnetic fields of magnets, currents in coils and angular speeds are given in table. Use figure and table to answer the questions.



	R (meter)	L (meter)	B (Tesla)	I (Ampere)	Angular speed (rad/sec)
Coil A	0.044	0.876	0.567	0.783	1.42
Coil B	0.034	2.423	0.260	0.905	10.61
Coil C	0.023	2.561	0.975	0.696	6.52
Coil D	0.005	2.618	0.752	0.447	6.42
Coil E	0.077	2.541	0.999	0.036	14.72

1. What formula is used to calculate torque acting on current carrying coil in magnetic field?

A) $\tau = NBIAsin\alpha$
B) $\tau = NIAsin\alpha$
C) $\tau = NBAsin\alpha$
D) $\tau = NBIsin\alpha$
E) $B = NI\tau Asin\alpha$

2. What formula is used to calculate EMF of coil rotating in magnetic field?

A) $\varepsilon = NA\omega cos\omega t$
B) $\varepsilon = NB\omega cos\omega t$
C) $\varepsilon = NBAcos\omega t$
D) $N = \varepsilon BA\omega cos\omega t$
E) $\varepsilon = NBA\omega cos\omega t$

3. What formula is used to calculate length of one turn of coil?
A) πR
B) $2\pi R$
C) $3\pi R$
D) $4\pi R$
E) $5\pi R$

4. What formula is used to calculate number of turns of coil?
A) (Length of wire)·(length of one turn)
B) (Length of wire)÷(length of one turn)
C) (Length of wire)+(length of one turn)
D) (Length of wire)-(length of one turn)
E) $(\text{Length of wire})^{(\text{length of one turn})}$

5. What formula is used to calculate area of circular coil?
A) $\pi R^2/2$
B) $4\pi R^2$
C) $3\pi R^2$
D) $2\pi R^2$
E) πR^2

6. Which coil has area of 0.79 cm^2?
A) Coil A
B) Coil B
C) Coil C
D) Coil D
E) Coil E

7. Which coil has area of 36.32 cm^2?
A) Coil A
B) Coil B
C) Coil C
D) Coil D
E) Coil E

8. Which coil has area of 60.82 cm^2?
A) Coil A
B) Coil B
C) Coil C
D) Coil D
E) Coil E

9. Which coil has area of 186.27 cm^2?
A) Coil A
B) Coil B
C) Coil C
D) Coil D
E) Coil E

10. Which coil has area of 16.62 cm^2?
A) Coil A
B) Coil B
C) Coil C
D) Coil D
E) Coil E

11. Which coil has number of turns equal to 18?
A) Coil A
B) Coil B
C) Coil C
D) Coil D
E) Coil E

12. Which coil has number of turns equal to 5?

A) Coil A
B) Coil B
C) Coil C
D) Coil D
E) Coil E

13. Which coil has number of turns equal to 3?
A) Coil A
B) Coil B
C) Coil C
D) Coil D
E) Coil E

14. Which coil has number of turns equal to 11?
A) Coil A
B) Coil B
C) Coil C
D) Coil D
E) Coil E

15. Which coil has number of turns equal to 83?
A) Coil A
B) Coil B
C) Coil C
D) Coil D
E) Coil E

16. Which coil experiences maximum torque of 2.2 mN·m?
A) Coil A
B) Coil B
C) Coil C
D) Coil D
E) Coil E

17. Which coil experiences maximum torque of 3.5 mN·m?
A) Coil A
B) Coil B

C) Coil C
D) Coil D
E) Coil E

18. Which coil experiences maximum torque of 8.6 mN·m?
A) Coil A
B) Coil B
C) Coil C
D) Coil D
E) Coil E

19. Which coil experiences maximum torque of 9.7 mN·m?
A) Coil A
B) Coil B
C) Coil C
D) Coil D
E) Coil E

20. Which coil experiences maximum torque of 20 mN·m?
A) Coil A
B) Coil B
C) Coil C
D) Coil D
E) Coil E

21. Which coil generates maximum EMF of 32 mV?
A) Coil A
B) Coil B
C) Coil C
D) Coil D
E) Coil E

22. Which coil generates maximum EMF of 16 mV?
A) Coil A
B) Coil B
C) Coil C
D) Coil D
E) Coil E

23. Which coil generates maximum EMF of 187 mV?
A) Coil A
B) Coil B
C) Coil C
D) Coil D
E) Coil E

24. Which coil generates maximum EMF of 1439 mV?
A) Coil A
B) Coil B
C) Coil C
D) Coil D
E) Coil E
25. Which coil generates maximum EMF of 114 mV?
A) Coil A
B) Coil B
C) Coil C
D) Coil D
E) Coil E

26. By how many degrees should we rotate coil C so that it experiences torque of 10 mN·m?
A) 0^{o}
B) 30^{o}
C) 60^{o}
D) 90^{o}
E) 180^{o}

27. By how many degrees should we rotate coil A so that it experiences torque of 0 mN·m?
A) 0^{o}
B) 30^{o}
C) 60^{o}
D) 90^{o}
E) 180^{o}

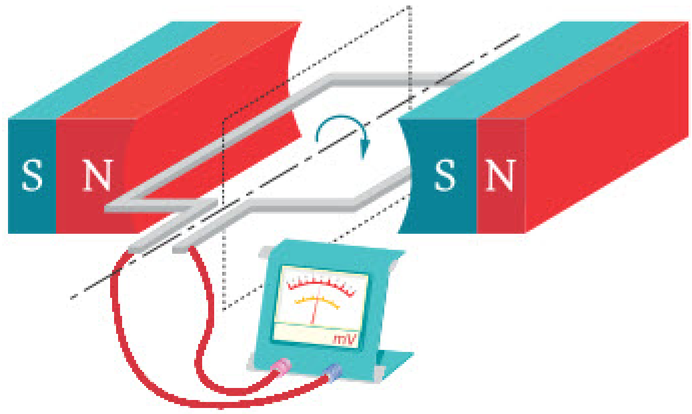
28. What should be angular speed of coil C so that maximum EMF equals 1 V?
A) 5 rad/sec
B) 15 rad/sec
C) 25 rad/sec
D) 35 rad/sec
E) 45 rad/sec

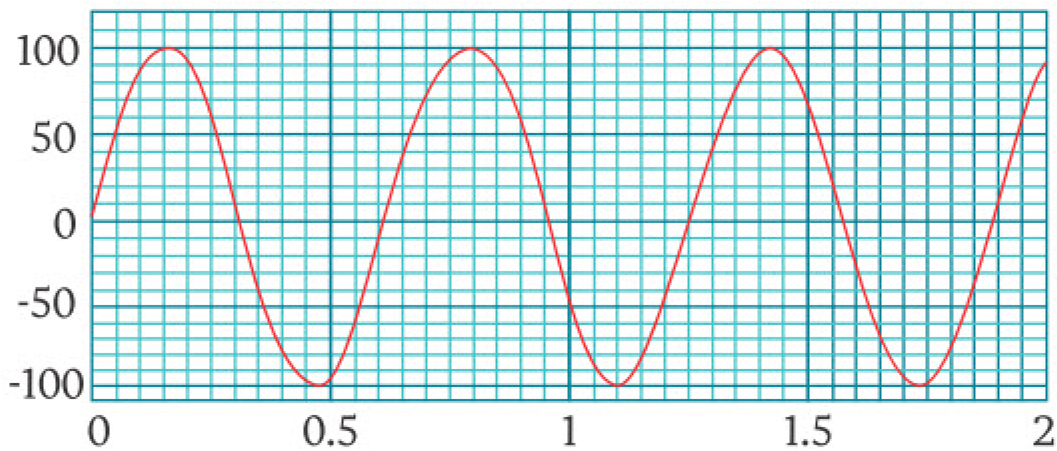
29. Which coil is the best motor?
A) Coil A
B) Coil B
C) Coil C
D) Coil D
E) Coil E

30. Which coil is the best generator?
A) Coil A
B) Coil B
C) Coil C
D) Coil D
E) Coil E

14.6 Electric motor and electric generator.

Electric generator consists of rectangular loop that has area of 500 cm^2. Rectangular loop consists of 500 turns of copper wire. Loop is rotated with constant angular speed. There is graph of induced EMF (electromotive force) versus time. Use graph to answer questions 1-25.





1. What parameter is represented by vertical axis?
A) magnetic field (Tesla)
B) time (sec)
C) magnetic flux (Weber)
D) induced EMF (Volt)
E) There is no right answer

2. What parameter is represented by horizontal axis?
A) magnetic field (Tesla)
B) time (sec)
C) magnetic flux (Weber)
D) induced EMF (Volt)
E) There is no right answer

3. What is period of rotation of loop?

A) 3.628 sec
B) 2.628 sec
C) 1.628 sec
D) 0.628 sec
E) There is no right answer

4. What is frequency of rotation of loop?
A) 1.59 Hz
B) 614.25 mHz
C) 380.52 mHz
D) 275.63 mHz
E) There is no right answer
5. What is angular speed of rotation of loop?
A) 1.73 rad/s
B) 10 rad/s
C) 3.86 rad/s
D) 2.39 rad/s
E) There is no right answer

6. What formula is used to calculate induced EMF?
A) $\varepsilon = -\frac{N}{\Delta t}$
B) $\varepsilon = -N \cdot \Delta\Phi$
C) $\varepsilon = -N\frac{\Delta\Phi}{\Delta t}$
D) $\varepsilon = -N^2\frac{\Delta\Phi}{\Delta t}$
E) There is no right answer
7. What formula is used to calculate induced EMF of this electric generator?
A) $\varepsilon = NB\omega \cdot \sin(\omega t)$
B) $\varepsilon = NBA\omega \cdot \sin(\omega t)$
C) $\varepsilon = NBA\omega \cdot \cos(\omega t)$
D) $\varepsilon = BA\omega \cdot \sin(\omega t)$
E) There is no right answer

8. How does magnetic field passing through loop change?
A) increases
B) decreases
C) stays constant
D) continuously increases and decreases (oscillates)
E) There is no right answer

9. How does magnetic flux passing through loop change?
A) increases
B) decreases
C) stays constant
D) continuously increases and decreases (oscillates)
E) There is no right answer

10. How does angular speed of loop change?
A) increases
B) decreases
C) stays constant
D) continuously increases and decreases (oscillates)
E) There is no right answer

11. What is maximum induced EMF?
A) 1 V B) 10 V
C) 100 V D) 1000 V
E) There is no right answer

12. When induced EMF is negative?
A) when magnetic flux increases
B) when magnetic flux decreases
C) when magnetic flux stays constant
D) it is impossible to determine
E) There is no right answer

13. What is induced EMF at t=0?
A) 1 V B) 10 V
C) 100 V D) 1000 V

E) There is no right answer

14. What is induced EMF at t=1?
A) 54 V B) -54 V
C) 100 V D) -100 V
E) There is no right answer

15. What is induced EMF at t=2?
A) 100 V B) 0 V
C) 54 V D) 91 V
E) There is no right answer

16. At what moment EMF is not zero?
A) 1.414 s B) 1.571 s
C) 0.942 s D) 1.257 s
E) 1.885 s

17. At what moment EMF is not maximum?
A) 0.785 s B) 2 s
C) 1.414 s D) 0.157 s
E) There is no right answer

18. What is maximum magnetic flux passing through loop?
A) 0.02 Wb B) 0.2 Wb
C) 2 Wb D) 20 Wb
E) There is no right answer

19. What is magnetic field passing through loop?
A) 0.4 T B) 0.3 T
C) 0.2 T D) 0.1 T
E) There is no right answer

20. How would maximum EMF change if angular speed is doubled?
A) increase twice
B) decrease twice
C) increase four times
D) decrease four times

E) There is no right answer

21. How would maximum EMF change if dimensions of loop are doubled?
A) increase twice
B) decrease twice
C) increase four times
D) decrease four times
E) There is no right answer

22. How would maximum EMF change if number of turns is doubled?
A) increase twice
B) decrease twice
C) increase four times
D) decrease four times
E) There is no right answer

23. How would incandescent light bulb emit light when it is connected to this electric generator?
A) It will emit light continuously
B) It will turn on and turn off with period of 0.314 sec
C) It will not emit light
D) It is impossible to connect incandescent light bulb to generator
E) There is no right answer

24. Is it safe to read with light of incandescent light bulb that is connected to this electric generator?
A) No. Because light will turn on and turn off continuously and this hurts eyes.
B) No. Because light will be too bright.
C) Yes. Because bulb will emit light continuously.
D) No. Because incandescent light bulb will not emit light when connected to generator.
E) There is no right answer

25. What is maximum current in the 50 Ohm resistor that is connected to this electric generator?
A) 0.02 A

B) 0.2 A
C) 2 A
D) 20 A
E) There is no right answer

ANSWERS

Chapter 1

Test questions: Stuntman

1. D	14. C
2. B	15. B
3. B	16. E
4. D	17. A
5. D	18. D
6. B	19. B
7. C	20. E
8. B	21. C
9. A	22. A
10. E	23. A
11. C	24. B
12. E	25. C
13. B	

Motion with Constant Acceleration

1. CD	6. D

2. A	7. C
3. B	8. E
4. D	9. C
5. E	10. A

Freely Falling Objects

1. D	2. A
3. D	4. B
5. B	

Relative Velocity

1. B	2. B
3. E	4. D
5. A	

Horizontal Projectile Motion

1. E	2. D
3. B	4. B
5. D	6. A

Projectile motion

1. C 2. B

3. D 4. E

5. A 6. C

Equations of Motion with Constant Acceleration

1. 15 m/s, 75 m

2. a) 50 s b) 375 m

3. a) 2.4 m/s, 14.4 m b) 75 s

4. a) 40 m/s, 325 m b) 10 m/s, 175 m

5. 36 m

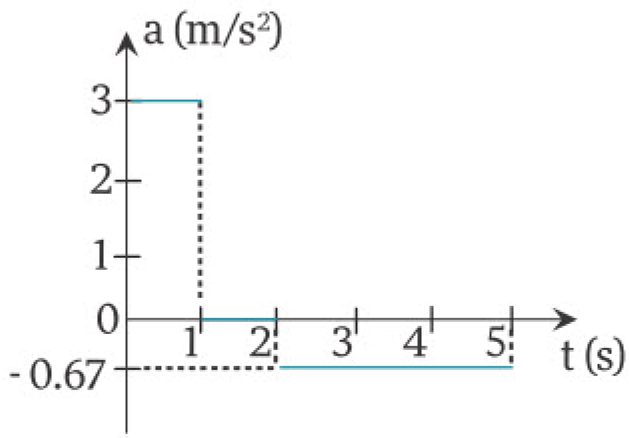
6. 17.5 m

7. 6.25 m/s^2, 4 s

8. 62.5 m

9. a) 3 m/s^2, 0 m/s^2, -0.67 m/s^2

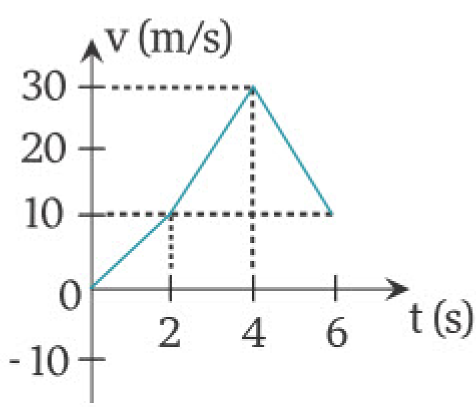
b)

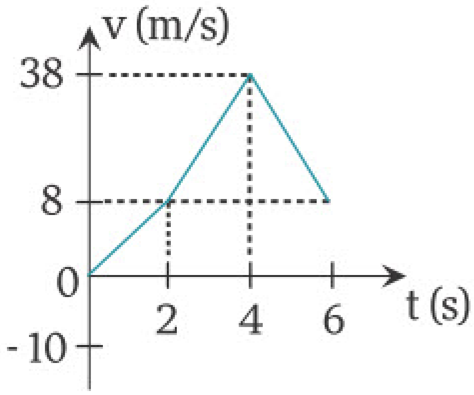


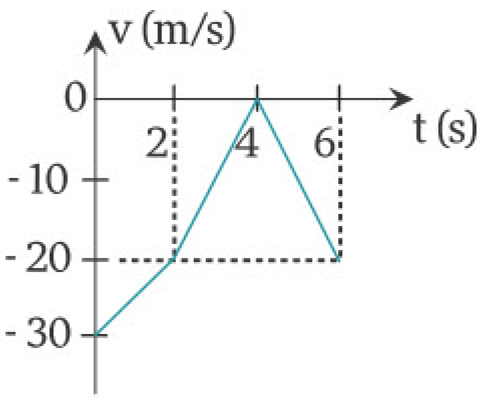
10. t_1-t_4

11. 7 m/s

12.







Freely Falling Objects

1. 120 m

2. a) 6 s b) 40 m/s c) 75 m

3. 80 m

4. 1.5 s

Projectile motion

1. a) 6 s b) 33.54 m/s, 63.43°

2. 20 m

3. 25.69°

4. a) 6 s b) 180 m c) 60 m

5. 30 m/s

Circular motion

1. a) 0.05 s b) 314 m/s

2. 1022.39 m/s

3. a) 5 rad/s b) 7.5 m/s^2 c) 5 N

4. 4800 N, lighter

Chapter 2

Test questions: Boy and Crate

1. C	14. B
2. B	15. E
3. D	16. B
4. E	18. A
5. B	19. C
6. B	20. A

7. A	21. E
8. D	22. B
9. B	23. C
10. D	24. A
11. A	25. C
12. E	
13. C	

Test questions: Comet

26. C	41. A
27. E	42. A
28. D	43. E
29. C	44. B
30. B	45. D
31. C	46. D
32. C	47. A
33. C	48. A
34. A	49. A
35. C	51. E

50. E
36. A
37. A
38. C
39. E
40. A

52. E
53. A
54. E
55. A

Resultant Force

1. D
2. E
3. C
4. C
5. D

Laws of Motion

1. E
2. D
3. B

4. C

5. E

Motion on Surfaces with Friction

1. D

2. B

3. C

4. D

5. E

System of blocks and inclined plane

1. C

2. B

3. E

4. D

5. B

6. A

7. D

8. C

9. A

10. E

11. B

12. C

General Problems

1. A

2. C

3. A

4. A

5. A

6. D

Laws of motion

1. a) 5 m/s^2 b) 4 N

2. a) 2 m/s^2 b) 16 N

3. a) 1 s b) 2.5 m/s c) 2.45 s

4. 312 N

5. a) a_1=12 m/s^2, a_2=6 m/s^2

b) T_1=12 N, T_2=24 N

6. 20 m/s^2

7. μ=0.6

Chapter 3

Test questions: Equilibrium

1. A	11. D
2. C	12. D
3. E	13. D
4. C	14. E
5. C	15. B
6. C	16. A
7. D	17. A
8. B	18. E
9. C	19. A
10. A	20. E

Centre of Mass

1. B	8. B
2. C	9. E
3. B	10. E
4. C	11. D
5. D	12. C

6. D 13. A

7. A

Centre of Mass and Equilibrium

1. D

2. C

3. A

4. $T_1/T_2=5/7$

5. $d_1/d_2=8$

Chapter 4

Test questions: Velocity-time graph of a car.

1. B	14. C
2. C	15. D
3. E	16. E
4. D	17. D
5. B	18. B
6. A	19. D

7. B 20. B

8. C 21. A

9. C 22. C

10. A 23. B

11. C 24. D

12. E 25. E

13. A

Momentum and Impulse

1. B 5. D

2. C 6. D

3. C 7. C

4. A

Impulse and Change of Momentum

1. E 5. E

2. D 6. B

3. C 7. D

4. A 8. B

Collisions

1. C 4. A

2. B 5. D

3. E 6. A

Conservation of Momentum

1. B 5. D

2. C 6. C

3. E 7. B

4. E

Conservation of Mechanical Energy

1. A 6. D

2. D 7. E

3. B	8. C
4. E	9. D
5. E	10. A

Chapter 5

Test questions: Marble viscosity experiment

1. A	14. A
2. A	15. A
3. D	16. A
4. B	17. A
5. C	18. E
6. C	18. E
7. B	19. E
8. A	20. C
9. A	21. A
10. C	22. C
11. A	23. B
12. B	24. A

13. A	25. E

Fluid mechanics

1. 1 m/s

2. 2

3. 720 kg

4. Speed increases, cross-sectional area decreases.

5. 30 cm

Chapter 6

Test questions: Temperature and root mean square speed

1. D	11. C
2. B	12. B
3. B	13. C
4. B	14. B
5. B	15. B
6. C	16. A
7. C	17. A
8. E	18. B

9. E 19. D

10. B 20. A

Root Mean Square Value

1. 42.43 m/s

2. $8.3 \cdot 10^{-22}$ J

The Pressure of an Ideal Gas

1. 500 m/s

2. 600 m/s

3. 387.6 kPa

4. Pressure increases 4 times

Root-Mean-Square Velocity

1. $6.21 \cdot 10^{-21}$ J

2. 510.76 m/s

3. 346.41 m/s

4. 2.65

Chapter 7

Test questions: Cyclic process

1. D
2. C
3. B
4. C
5. A
6. ABC
7. E
8. CDE
9. A
10. C
11. AE
12. A
13. C
14. A
15. B
16. B
17. A
18. C
19. A

20. E

The Gas Laws

1. 120 kPa

2. 24 L

3. 200 kPa

4. 75 cm-Hg

5. 92 kPa

6. 150 K

7. 500 K

8. $p_2/p_1 = 0.5$

9. 133.33 kPa

10. 275 K

The Ideal Gas Law

1. 623250 Pa

2. 13.728 L

3. 95.28 kg

4. 498600 Pa

5. 2.29 kg

6. 2.07 cm^3

7. 90 kPa

8. 0.831 m

Expressing the Ideal Gas Law in Terms of Number of Molecules

1. 103500 Pa

3. $3.62 \cdot 10^{24}$ m^{-3}

Chapter 8

Test questions: Oxygen gas O_2

1. B	14. D
2. A	15. E
3. E	16. D
4. A	17. A
5. C	18. B

6. B	19. D
7. B	20. B
8. E	21. D
9. A	22. C
10. D	23. E
11. B	24. D
12. B	25. D
13. A	

The First Law of Thermodynamics

1. $Q=W+\Delta U$

2. 380 J

3. 465 J

4. 650 J

5. 300 J

6. 450 J

Work in a Thermodynamic Process

1. 300 J

2. $5 \cdot 10^{-4}$ m^3

3. -450 kJ

4. 1350 J

5. 1500 J

6. 9972 J

7. 50 J

Thermal Processes

1. $p_2 = 3.17p$

2. 300 J

3. -20 J

4. 0

5.

Heat Engines

1. 0.33

2. 2142.86 J

3. 0.312

4. a) $4.32 \cdot 10^{13}$ J b) $5.28 \cdot 10^{13}$ J

The Second Law of Thermodynamics

1. No

2. a) 0.63

3. 0.75

4. 400 J

5. 630 K

Chapter 9

Test questions: Strain and stress

1. B	16. C
2. A	17. B
3. D	18. A
4. A	19. C
5. D	20. A
6. A	21. A
7. D	22. C
8. C	23. D
9. B	24. C
10. A	25. A

11. B	26. C
12. D	27. A
13. C	28. C
14. A	29. B
15. D	30. D

Capillary Action

8. 4.8 mm

9. $4.52 \cdot 10^{-5}$ kg

Surface Potential Energy

12. $5.76 \cdot 10^{-5}$ J

14. $5.26 \cdot 10^{-3}$ J

The Exceptional Behavior of Water

16. $-4^{o}C$

Stress and Strain, Elasticity, Young's Modulus

22. a) D b) AB c) plastic deformation

23. 63.69 MPa

24. a) 40 MPa b) 0.0002 c) $2 \cdot 10^{11}$ Pa

Hooke's Law

25. 100 N

26. 4

27. $1.78 \cdot 10^{-3}$ and 10.62 mm

28. 314000 N

29. 70 MPa

30. 4102.56 m

Chapter 10

Test questions:

1. BD	21. E
2. AC	22. C
3. AD	23. D
4. BC	24. C
5. C	25. B
6. A	26. C
7. A	27. E
8. C	28. C
9. B	29. B
10. B	30. A
11. B	31. B
12. B	32. C
13. B	33. D
14. C	34. D
15. B	35. C
16. D	36. A
17. E	37. E

18. B	38. D
19. B	39. C
20. C	40. C

Electrostatics

1. E
2. B
3. A
4. D
5. B
6. E
7. B
8. E
9. E
10. E

Electric Potential Energy and Electric Potential

1. D
2. E
3. A

4. E

5. C

6. B

7. B

Capacitance and Capacitors

1. B

2. E

3. B

4. C

5. B

6. D

Chapter 11

Test questions: Kettles

1. A	11. D
2. C	12. B
3. B	13. C

4. B	14. E
5. C	15. D
6. B	16. A
7. A	17. D
8. B	18. D
9. D	19. B
10. E	20. E

Test questions: Electrician

21. E	31. B
22. E	32. B
23. E	33. E
24. B	34. C
25. A	35. D
26. C	36. D
27. C	37. B
28. B	38. B
29. B	39. E
30. E	40. B

Test Problems

1. D	14. 3/2
2. D	15. 3/2
3. A	16. C
4. B	17. 7/4
5. B	18. E
6. C	19. D
7. D	20. B
8. E	21. E
9. A	22. D
10. D	23. 1/2
11. D	24. A
12. B	25. A
13. 2/5	

Chapter 12

Test questions: I-V curves

1. D	24. B
2. B	25. D
3. C	26. D
4. A	27. D
5. B	28. B
6. B	29. C
7. D	30. D
8. A	31. D
9. B	32. C
10. C	33. B
11. A	34. E
12. C	35. C
13. B	36. A
14. D	37. D
15. C	38. C
16. B	39. D

17. C	40. B
18. A	41. C
19. A	42. D
20. A	43. E
21. B	44. E
22. B	45. E
23. D	

Electric Current in Various Media

1. B
2. C
3. D
4. E
5. B
6. A
7. C
8. E
9. C
10. C

11. D

12. D

13. C

14. B

15. D

16. D

17. C

18. D

19. C

28. 0.3348 g

29. 30.4 MJ

30. 14.4 cm^3 H2 and 7.2 cm^3 O2

34. 30 MV/m

35. 2 mm

Chapter 13

Test questions: Mass-spectrometer

1. B	10. B	19. C
2. D	11. E	20. D

3. C	12. A	21. C
4. A	13. D	22. A
5. C	14. B	23. B
6. D	15. C	24. D
7. B	16. A	25. B
8. A	17. B	
9. C	18. D	

Magnetism

1. D	7. A
2. D	8. C
3. E	9. C
4. A	10. E
5. D	11. C
6. B	12. B

Lorentz's force

1. C	6. C
2. A	7. E
3. A	8. D

4. D 9. D

5. D

Magnetic Field Produced by Electric Currents

1. No

2. $8\cdot10^{-7}$ T

3. 2.5 A

4. 0.04 m

5. 0

6. 0.33 m

7. $B_K = 4.64\cdot10^{-5}$ T $\odot$, $B_L = 9.6\cdot10^{-5}$ T $\otimes$

8. 30 A in direction 1

9. $I_3 = 20$ A $\odot$

Magnetic Force on a Current Carrying Loop

1. 0.12 N·m

2. 37.68 N·m

3. a) 0.2304 N·m b) decrease

Magnetic Force on Moving Charges

2. a) $6.4 \cdot 10^{-15}$ N b) 10.44 cm

Chapter 14

Test questions: Motional EMF

1. B	11. B	21. A
2. C	12. B	22. B
3. E	13. D	23. AC
4. E	14. C	24. BCD
5. D	15. ABC	25. A
6. C	16. E	26. B
7. AC	17. BD	27. E
8. BD	18. C	28. A
9. A	19. BD	29. D
10. B	20. C	30. D

Magnetic flux. Electromagnetic induction.

1. D	10. C	19. A
2. A	11. C	20. DE
3. D	12. D	21. BC
4. A	13. E	22. E
5. AB	14. A	23. C
6. CD	15. E	24. C
7. A	16. D	25. B
8. C	17. C	
9. A	18. A	

Self-Induction. Inductance. Energy of Magnetic Field

1. E	10. ADE	19. A
2. B	11. BC	20. C
3. C	12. BC	21. A
4. C	13. BCDE	22. B
5. D	14. A	23. B
6. BC	15. A	24. C

7. E	16. D	25. C
8. BC	17. B	
9. E	18. B	

Circular Coils

1. A	11. C	21. D
2. E	12. E	22. A
3. B	13. A	23. C
4. B	14. B	24. E
5. E	15. D	25. B
6. D	16. D	26. B
7. B	17. E	27. D
8. A	18. A	28. D
9. E	19. B	29. C
10. C	20. C	30. E

Electric motor and electric generator.

1. D	10. C	19. A
2. B	11. C	20. A
3. D	12. A	21. C
4. A	13. E	22. A
5. B	14. B	23. B
6. C	15. D	24. A
7. B	16. A	25. C
8. C	17. B	
9. D	18. A	

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PHYSICS

Grade 10

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