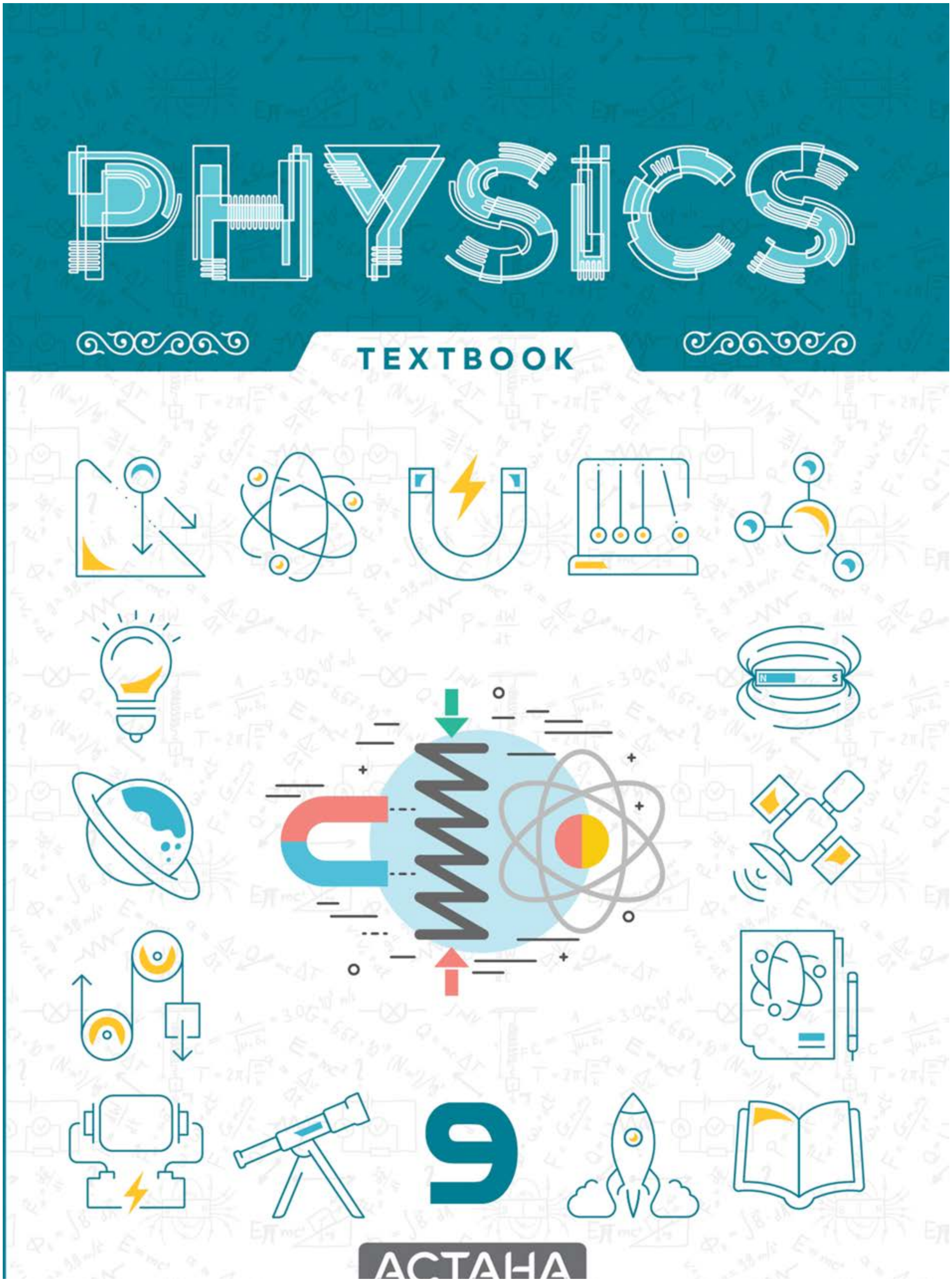
PHYSICS
TEXTBOOK
9
АСТАНА

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PHYSICS

Grade 9

1ST EDITION

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ASTRONOMY

FORCE

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 first 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 difficult for you to understand science in English language. Each page contains translations of all the important terms, both in Kazakh and Russian. This textbook will not only help you improve your English, but it will also make you a part of a big international science community.

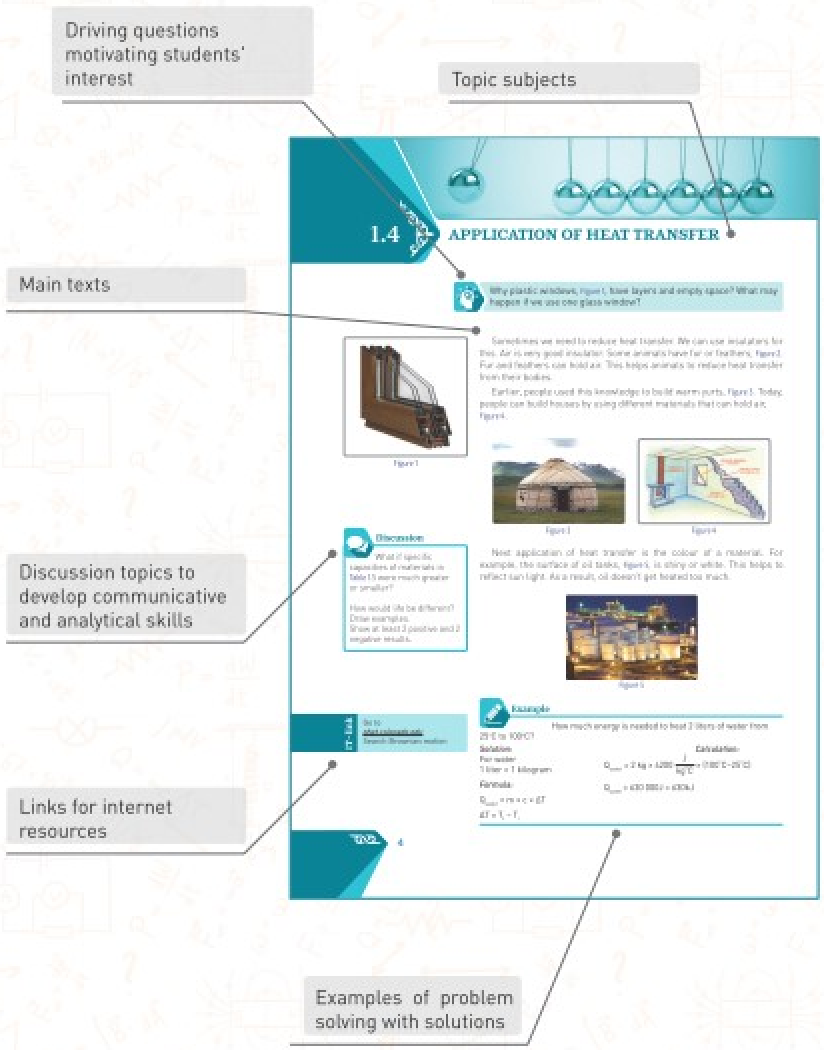
Please pay attention to the structure of this textbook. Remember: a textbook is no longer the only source of information in the modern world. With the help of carefully selected tasks, you are going to learn such important skills as critical thinking, problem solving, information analysis, creativity,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

Dear students, teachers and parents, as this is the first editio n of the 9 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”

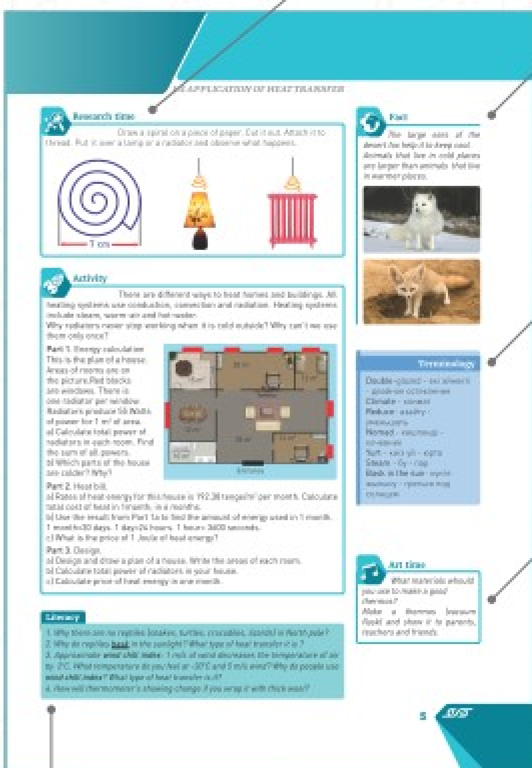
HOW TO USE THIS BOOK



Activities to do during the lesson by students themselves

Mini research related to the topic of the lesson

Interesting facts



New terms related to the topic in three languages

Creative approaches

Questions to consolidate topic

CHAPTER 1

MOTION

1.1 MOTION

1.2 VECTORS

1.3 MOTION WITH ACCELERATION

1.4 EQUATIONS OF MOTION

1.5 FREE FALL

1.6 MOTION OF BODY THROWN HORIZONTALLY

1.7 CIRCULAR MOTION

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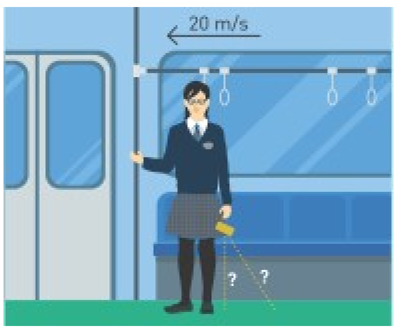
1.9 CENTRIPETAL ACCELERATION

1.1 MOTION

You will:

- define point particle, reference frame, relativity of motion, apply the theorem of an addition of velocities and displacements;

QUESTION:



A girl drops phone on a train that moves with constant speed. How does phone fall (look at figure)? Why does phone fall in that way?

1.1 MOTION

You know from 7-th grade that physics studies motion of matter. Therefore, motion of simple objects in everyday life plays crucial role to understand physics. Kinematics is a branch of physics which studies motion of bodies.

a) Point mass

Think of 2 cases:

Figure a
1. A car approaches the parking lot. Here we must know the dimensions of the car. If we neglect it, we may damage the car.

Figure b
2. A car travels from Aktobe to Astana. Here we don't need to know the dimensions of the car. We need to know its speed, duration of time in motion, and the distance it travels.

If we neglect the dimensions of an object, while considering its motion, we can imagine it as a small point - point mass.

b) Positive and negative directions

We need to define the sign of directions. For example, Figure 1.

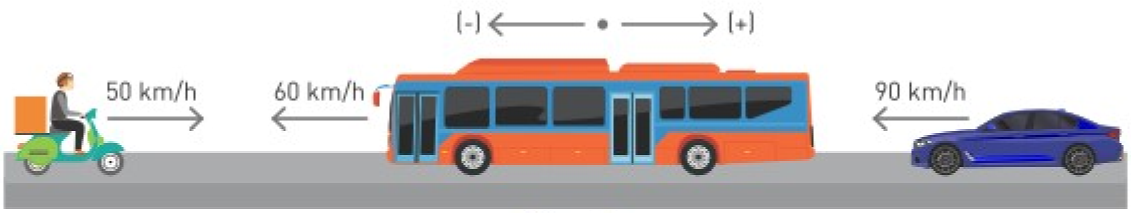


Figure 1

If we name the direction "to the right" as positive(+), then we must name the direction "to the left" as negative(-). Then, velocities of vehicles are: $\upsilon_{motorbike} = +50$km/h, $\upsilon_{bus} = -60$ km/h, $\upsilon_{car} = -90$ km/h. If you want, you can reverse the signs of the directions.

c) Relativity and reference frame

The speeds and directions of bodies are shown on the Figure 2a.

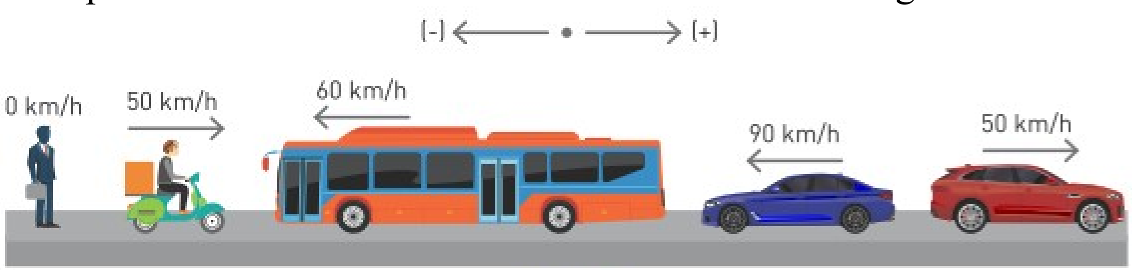


Figure 2a

Imagine you are on the motorbike. When you look at other bodies, they will have different speeds, Figure 2b. In physics, this is called relativity of motion.

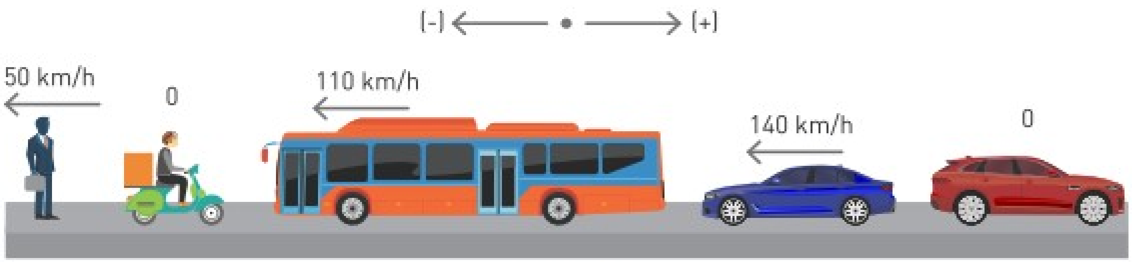


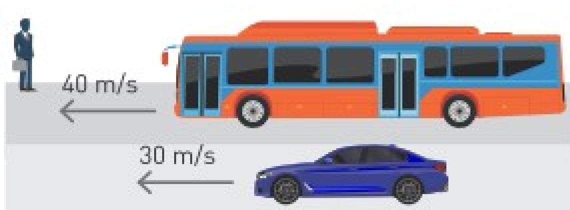
Figure 2b

All speeds on Figure 2a are called “speeds relative to the ground”.

All speeds on Figure 2b are called “speeds relative to the motorbike”.

We consider the ground never moves. When we find speeds relative to a certain body, we call that body as a reference frame. In the Figure 2a, the ground is the reference frame. In the Figure 2b, the motorbike is the reference frame.

Example



The velocities of the vehicles on the picture are relative to the ground. What is the velocity of the bus relative to the car? What is the velocity of the car relative to the bus?

Solution:

$\upsilon_{bus} = 40$ m/s

$\upsilon_{car} = 30$ m/s

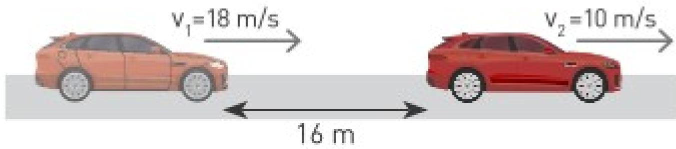
Velocity of the bus relative to the car:

$\upsilon_{bus} - \upsilon_{car} = 40$ m/s - 30 m/s= 10 m/s

Velocity of the car relative to the bus:

$\upsilon_{car} - \upsilon_{bus} = 30$ m/s - 40 m/s= -10 m/s.

Example



The first car is chasing second car, see Figure. Find time needed to reach second car. Distance between them is 16 meters.

Solution:

υ_1 = 18 m/s

υ_2 = 10 m/s

$x = v \times t$
$x = (v_1 - v_2)t = (18\ m/s - 10\ m/s)\ t \Rightarrow 16\ m = 8\ m/s \times t$
$t = 2\ s$

Fact

There are some relationships between symbols of some physical terms in every country. In book, distance represented as d or x, but displacement as s. In most cases x, d and s are equal to each other.

Research time

Draw a treasure map. Write instructions for the map. For example: “start here, go north 100 m, go east 60 m”. Give the instructions and the map to your friends. Let them find your treasure.

Activity

Draw a picture that must have at least:

a) one body with a speed of 0 m/s relative to the ground.
b) a body that does not move relative to any other 2 bodies.
c) 2 bodies that move to "+", and 2 bodies that move to "-".
d) one body that moves with the speed of 60 km/h relative to another.

Fact

Black marlin can speed up to 129 km/h.

Art time

Show two dances. First, when you move relative to the group. Second, when you do not move relative to the group.

Literacy

1. You are on a bus that moves with 40 km/h. What is your speed relative to the bus driver? What is your speed relative to the bus stop?
2. Can you think of yourself as a point object relative to a pen, a desk, a car, a building, a city, a country, a planet, the Earth, the Sun, galaxy, supercluster?

Terminology

dimension - өлшем / измерение
relative - салыстырмалы / относительный
to neglect - ескермеу / пренебрегать
to define - анықтау / определить
to reverse - ауыстыру / поменять
reference frame - санақ жүйесі / система отсчета
vehicle - көлік / средство передвижения
speed - жылдамдық / скорость
velocity -векторлық жылдамдық/векторная скорость

1.2 VECTORS

You will:

- perform addition and subtraction of vectors and multiplication of vector by scalar;
- determine components of vector;

Question

The team on the left pulls with the same force as the team on the right.
Which team does win? Why?

All quantities in physics can be divided into 2 groups.

Scalars	Vectors
Have magnitude, but do not have direction. Example: 5 kilograms.	Have both magnitude and direction. Example, 20 m/s to the East.

Other examples are on the table.

scalars	vectors
mass	weight
speed	velocity
distance	displacement
energy	force
temperature	acceleration
charge	electric field

We show vectors by arrows. We name vector by a letter and a small arrow above it. For example velocity, Figure 1. We say "the vector has the magnitude of 20 m/s and direction to the right".

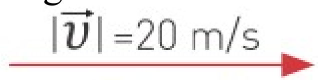


Figure 1

Operations with vectors

We can add, subtract, and multiply a vector by a scalar. To add two vectors we must use their directions. For example, Figure 2. In "a" we just add 3 N and 4 N to find the resultant vector $\mathbf{R_a}$ because they are in the same direction. However, in "b" two vectors are perpendicular. We use the Pythagorean theorem to find the resultant vector $\mathbf{R_b}$.

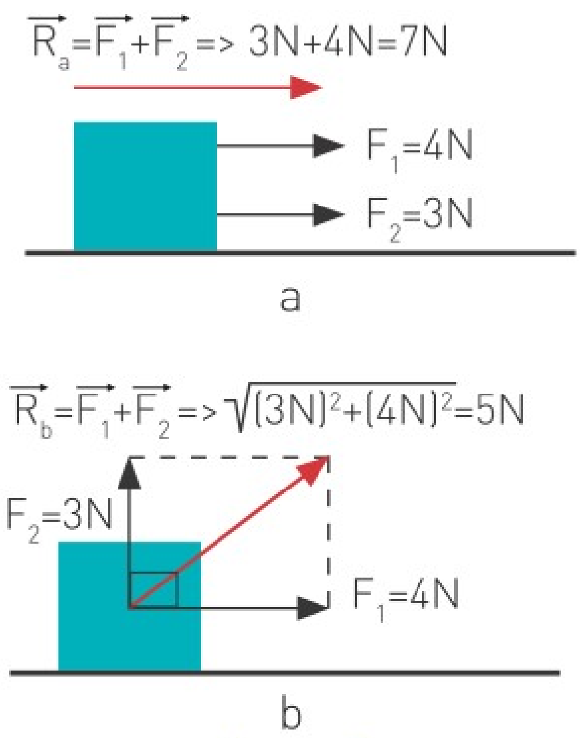


Figure 2

Subtraction of two vectors is a little bit different, Figure 3.

When we add vectors (a), we don't change original directions. When we subtract vectors (b), we change direction of second vector to the opposite.

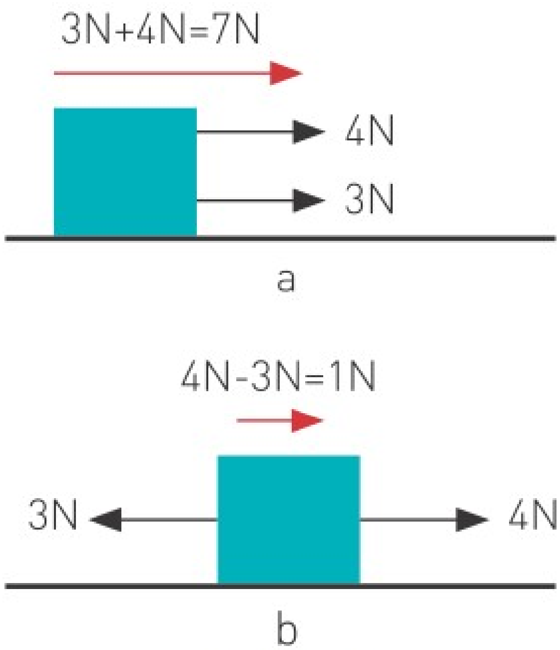
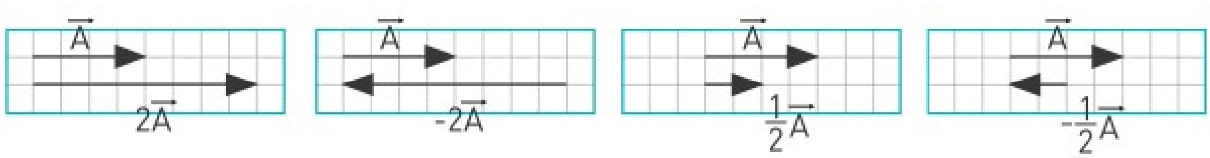


Figure 3

Multiplication of vectors by scalars is shown on the pictures below:



Sometimes vector can be at an angle, Figure 4a. A car travels 30 km at 53° . We can find horizontal (A_x) and vertical (A_y) displacements, when we divide vector **A** into 2 components by using sine and cosine, Figure 4b.

$$\cos\alpha = \frac{adjacent\ side}{hypotenuse} \Rightarrow \cos\alpha = \frac{A_x}{A} \Rightarrow A\cos\alpha = A_x$$

$$\sin\alpha = \frac{opposite\ side}{hypotenuse} \Rightarrow \sin\alpha = \frac{A_y}{A} \Rightarrow A\sin\alpha = A_y$$

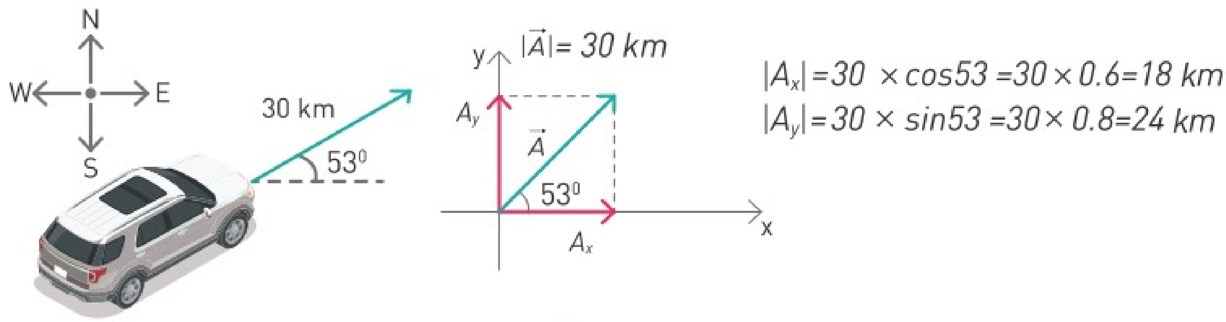
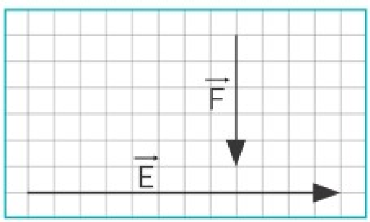


Figure 4

A_x is adjacent to the angle, so to find it main vector **A** is multiplied by cos 53° . A_y is opposite to the angle, so to find it main vector **A** is multiplied by sin 53° .

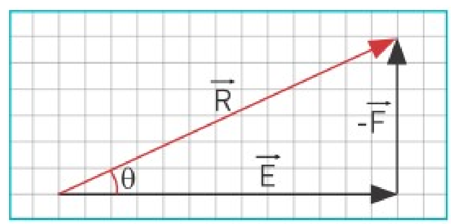
Example

Vectors $\vec{E}$ and $\vec{F}$ of magnitudes 12 units and 5 units. Find the magnitude and direction of the resultant vector $\vec{R} = \vec{E} - \vec{F}$.



Solution: $\vec{E} - \vec{F} = \vec{E} + (-\vec{F})$

of magnitudes 12 units and 5 units.

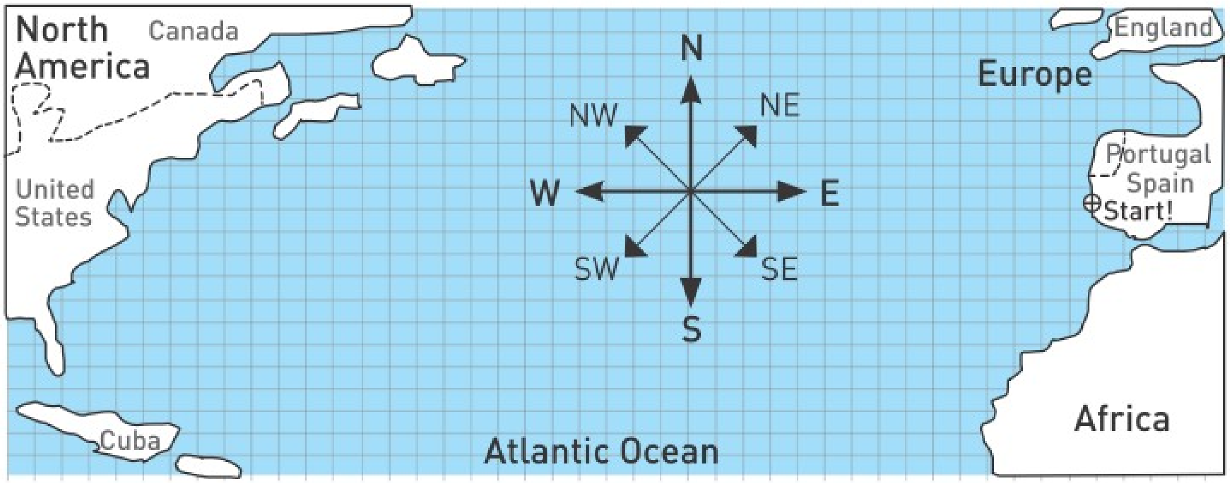


Using the Pythagorean theorem:

$R^2 = E^2 + F^2 = 144 + 25$

$R^2 = 169 \Rightarrow R = 13$ units.

Activity



Wind changes the direction of your ship. Without wind, your ship can sail straight 10 squares/month. Find your final destination, if you sail only to the west.
The direction of wind for each month:
Month 1: 2 squares south
Month 2: 4 diagonal squares southeast
Month 3: 2 squares west
Month 4: no wind

Fact

If you define a quantity to be a vector first, you can neglect to put arrows above symbol every time. But putting arrows makes it easier to notice it quickly, and also helps to distinguish vectors and scalars.

Research time

Materials: Ruler, the map of Kazakhstan with scale.
Choose one city from each part of Kazakhstan (North-South-East-West-Central). There are 3 flights from each city. All of them have 1 hour to take off. Make Departures & Arrivals Information Board. Draw paths of all flights on the map. Speed of each plane is 900 km/h. Make sure that planes will not bump into each other. Planes are at the same altitude.

Terminology

to add - қосу / сложить
to subtract - азайту / вычитать
component - проекция, құраушы / проекция
adjacent - іргелес / прилежащий

Literacy

1. You go out of your home with 2 m/s for 2 minutes to the North. Then you go with 1 m/s for 4 minutes to the West. How many meters from your home are you?
2. You throw a ball with 10 m/s at 30° to horizontal. What are vertical and horizontal components of speed?

Important note

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

1.3 MOTION WITH ACCELERATION

You will

determine displacement, velocity and acceleration from the displacement-time graph, velocity-time graph, acceleration-time graph;

Question

What is a difference between the motion of soccer player and marathon runner?

When the car begins to move, its speed is increasing, Figure 1. This speeding up is called acceleration.

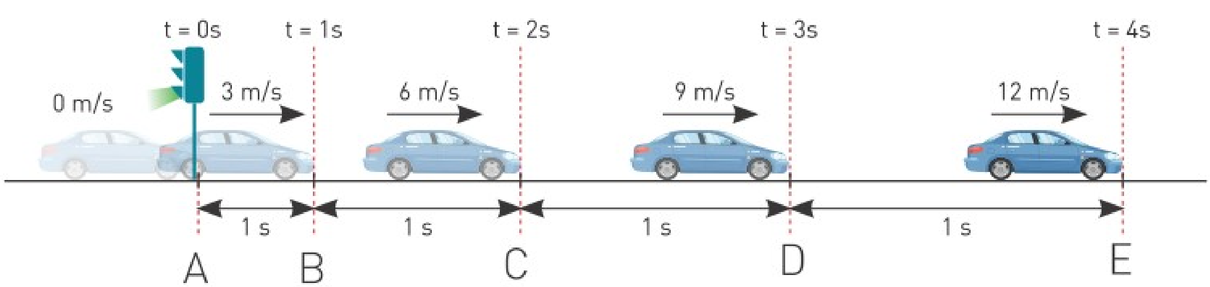


Figure 1

The formula of acceleration is

$$\vec{a} = \frac{\Delta\vec{\upsilon}}{\Delta t} = \frac{\vec{\upsilon}_2 - \vec{\upsilon}_1}{\Delta t}$$

$\Delta\vec{\upsilon}$ - change in speed between two points [m/s]
Δt - time interval between two points [s]
$\vec{a}$ - acceleration [m/s²]

Let's use this formula for the car. We choose points B and E.
$\Delta\upsilon$ is 12-3= 9 m/s.
Δt - time between E and B is 3 seconds.
Then,

$$a = \frac{9\ \mathrm{m/s}}{3\ \mathrm{s}} = 3\ \mathrm{m/s^2}.$$

The acceleration means how speed of the object changes in each second. Sometimes speed can decrease, Figure 2.

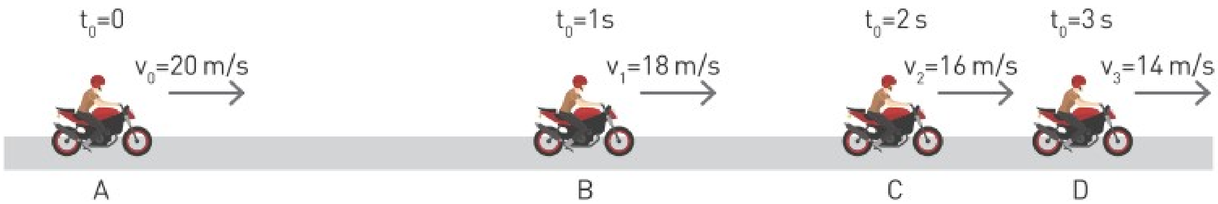


Figure 2

When we use formula for points A and D, we get:

$$a = \frac{14\ \mathrm{m/s} - 20\ \mathrm{m/s}}{3\ \mathrm{s}} = -2\ \mathrm{m/s^2}.$$

The result is negative because the speed decreases. This is called deceleration or negative acceleration.

Graph of acceleration

A car starts from the rest with the acceleration of 5 m/s 2 for 4 seconds. Then, it moves with constant speed for 10 seconds. Finally, it decelerates with 2 $\mathrm{m/s^2}$ until it stops. We can show all data on the graphs, Figure 3.

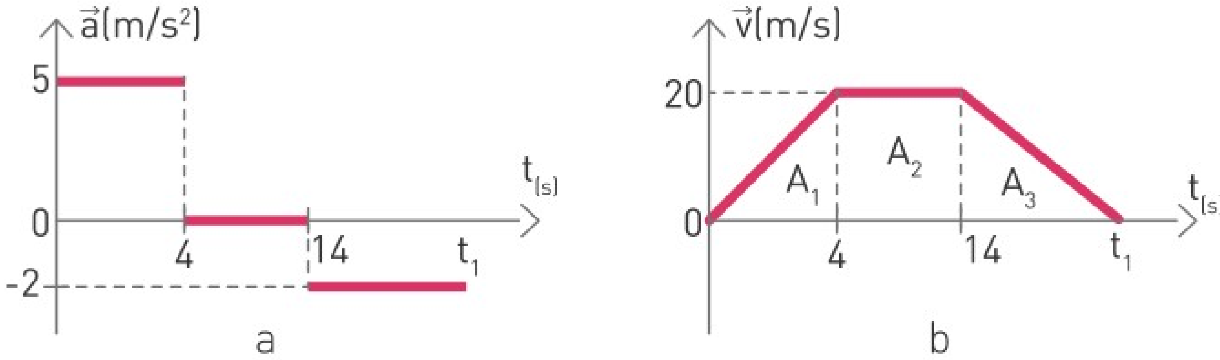


Figure 3

All accelerations are constant. That's why on a-t graph they are straight lines. On v-t graph speed increases (0-4 seconds), then it is constant (4-14 seconds), then decreases (14-t_1 seconds). Acceleration is a slope of v-t graph. We can use the formula to find when it stops.

$$a = \frac{\Delta v}{\Delta t} \quad \rightarrow \quad -2 = \frac{0-20}{\Delta t} \quad \rightarrow \quad \Delta t = 10\ \text{s}$$

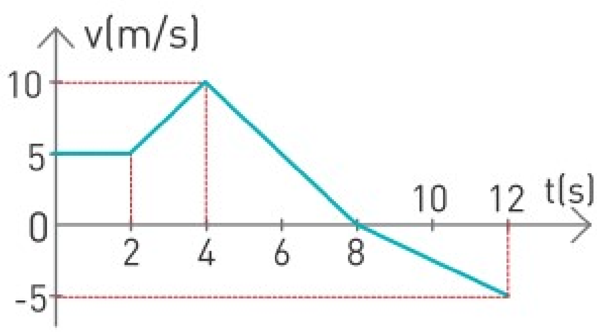
Then t_1 equals to 14+10 = 24 seconds from the beginning. If you find areas A_1, A_2, A_3 under the line on v-t graph and add them, you can find the total distance travelled.

Example

The velocity-time graph of a car at a initial position x_0 =5 m at t $_0$=0 is shown in the figure.

a) What is the acceleration of the car between 2 and 8 seconds?

b) What is the total displacement in 12 s?

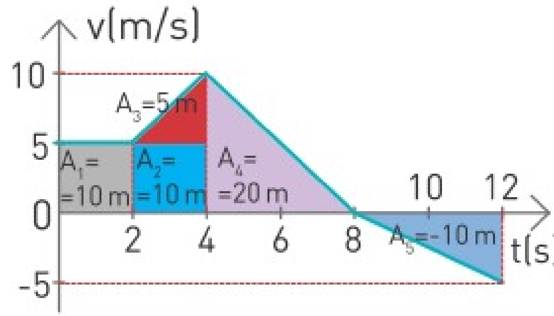


Solution:
a) Between 2nd and 8th seconds, the car has 2 different accelerations.

$$a_1 = \frac{\Delta v}{\Delta t} = \frac{10-5}{4-2} = 2.5\ \text{m/s}^2$$

$$a_2 = \frac{\Delta v}{\Delta t} = \frac{0-10}{8-4} = -2.5\ \text{m/s}^2$$

b) The area between time axis and line gives us displacement.



Total displacement = $A_1 + A_2 + A_3 + A_4 + A_5$ = 10 m + 10 m + 5 m + +20 m +(-10 m) = 35 m
A_5 is negative because velocity is negative. Displacement (s) is 35 m, but distance (d) travelled is 45 m.

Fact

Pilobolus crystallinus (“Fungus cannon”) can accelerate to approximately 200 000 m/s^2.

Terminology

acceleration - үдеу / ускорение
deceleration - тежеу / торможение
from the rest - тыныштық күйден / из состояния покоя

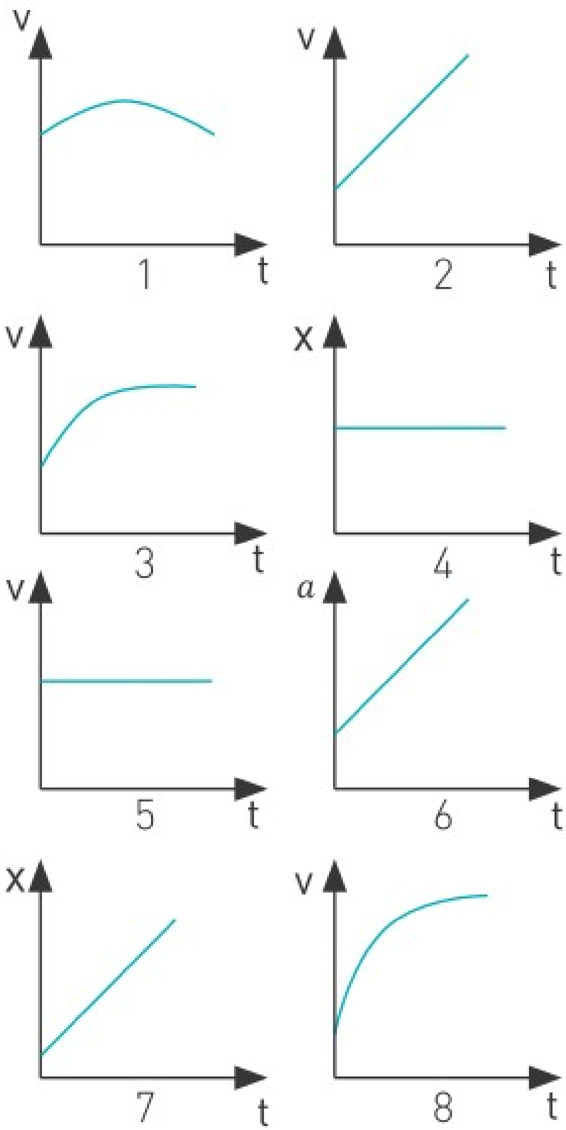
straight - түзу / прямо
stationary - қозғалмайтын/ неподвижный
constant - тұрақты, өзгермейтін / постоянный, неменяющийся

Research time

Make v-t and x-t graphs of your home-school route.

Activity

Complete the table by indicating the graph(s) that represents the motion described in the first column.



Description of motion	Graph(s)
moving at the constant speed	
accelerating to a constant speed	
changing speed	
stationary	
moving faster	
speeding up, then slowing down	
moving with constant acceleration	
moving at steady speed	

Art time

Show acceleration and deceleration with your voice.

Literacy

1. Draw v-t graph of the fastest car in the world.
2. Draw a-t graph of the fastest car in the world.
3. Draw displacement-time graph of the fastest car in the world.

4. Find the ratio between acceleration of the fastest car in the world and gravitational acceleration $g=9.8\ m/s^2$.

1.4 EQUATIONS OF MOTION

You will

- apply formulas of velocity and acceleration for solving problems with linear accelerated motion;
- apply formulas of position and displacement for solving problems with linear accelerated motion;

Question

What if all cars lose the ability to accelerate or decelerate for one hour? What will happen?

Remember the formula for average speed $x = \upsilon_{av} \cdot t$, we can use it for accelerated motion. Combining this with formula of accelerated motion, we can get the following new formulas.

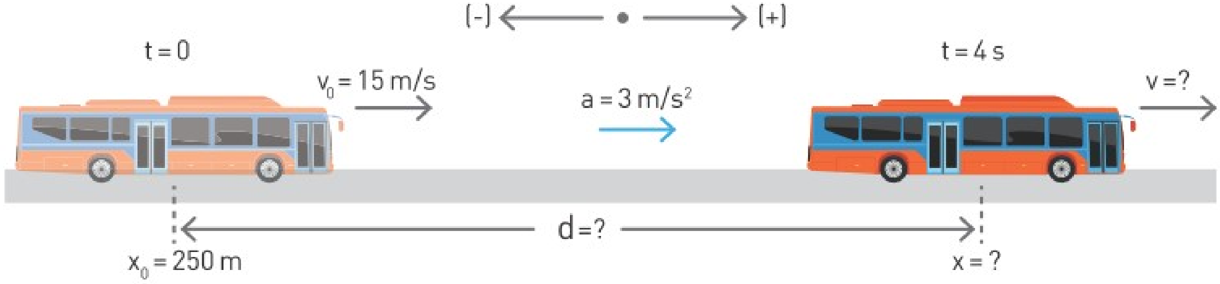
There are 3 main formulas for motion with constant acceleration. In each formula: "+" when speed increases, and "-" when speed decreases.

$x = x_0 + v_0t + \frac{1}{2}at^2$	$v = v_0 + at$	$v^2 = v_0^2 + 2ad$
x - final position [m] *x_0 -initial position [m]* *v_0 - initial velocity [m/s]* *a - acceleration [m/s²]* *t - time taken [s]*	*v - final velocity [m/s]* *v_0 - initial velocity [m/s]* *a - acceleration [m/s²]* *t - time taken [s]*	*v - final velocity [m/s]* *v_0 - initial velocity [m/s]* *a - acceleration [m/s²]* d - *distance [m]*
Example: A car moves with speed v_0. At initial position x_0 it starts to accelerate with a. In time t, it reaches position x.	Example: A car moves with speed v_0. Then, it starts to accelerate with a. After time t, it has speed v.	Example: A car moves with speed v_0. Then, it starts to accelerate with a. After it travels distance d, it has speed v.

This topic is about new formulas, so the best way to understand them is one big example.

Example 1

The bus moves with speed 15 m/s. When it is at x_0 = 250 m, it accelerates with 3 m/s^2 for 4 seconds. Then the bus needs to stop in 10 seconds.



Calculate:
a) Velocity after 4 seconds.
b) Position after 4 seconds.
c) Distance travelled.
c) Deceleration so the bus can stop in 10 seconds.
d) Displacement during deceleration.

Solution:

a) $v = v_0 + at$ $\quad v = 15 + (3 \times 4) = 27$ m/s

b) $x = x_0 + v_0 t + \frac{1}{2} at^2$ $\quad x = 250 + (15 \times 4) + (1/2 \times 3 \times 4^2) = 334$ m

c) $d = x - x_0$

$d = 334 - 250 = 84$ m

You can do this section by $v^2 = v_0^2 + 2ad$ as well.

$27^2 = 15^2 + 2 \times 3 \times s$

$d = 84$ m

d) $v = v_0 + at$

When the bus stops, its final speed is zero.

$0 = 27 - a \times 10$

$a = 2.7$ m/s^2

e) $v^2 = v_0^2 + 2ad$

$0^2 = 27^2 - 2 \times 2.7 \times s$

$d = 135$ m

Example 2

A car starts moving when the green light is on. It speeds up with a constant acceleration of 5 m/s 2 for 8 seconds. Find the final velocity.

Solution:

Initial velocity is zero, the velocity it gains after 8 s is found using the equation:

$$v_1 = v_0 + at$$

$$v_1 = 0 + 5 \times 8 = 40\ m/s$$

Activity

Design three problems that use formulas of kinematics. Let other students solve them.

Literacy

1. You walk at 1 m/s. How many kilometres do you walk in one hour?
2. Your car can decelerate at 5 m/s 2 . You drive at 80 km/h. How many meters does it need to stop? In how many seconds does it stop?
3. An olympic sprinter runs 100 meters in 10 seconds. Estimate the acceleration and maximum speed.

Fact

Maximum upward acceleration that sitting person can withstand is about 5g or 49 m/s^2.

Art time

Make a group “mime” (silent show) that shows acceleration.

Terminology

to estimate - шамалап санау / подсчитывать приблизительно
to speed up - жылдамдықты арттыру / увеличивать скорость
initial - бастапқы / начальный
distance - жол / путь
displacement - орын ауыстыру / перемещение
ability - қабілет / способность
to accelerate - жылдамдықты арттыру / ускоряться
to decelerate - тежелу / тормозить

1.5 Free fall

You will

use equations of kinematics to describe free fall;

Question

After 1 second skydiver's speed is about 10 m/s. What can the speed be after 2 sec, 3 sec, 4 sec?

When we release a stone and a feather in air, the stone falls faster. This is because of air resistance. Air decreases speed of the feather. However, in vacuum, Figure 1, they fall together with the same acceleration of 9.8 m/s^2.

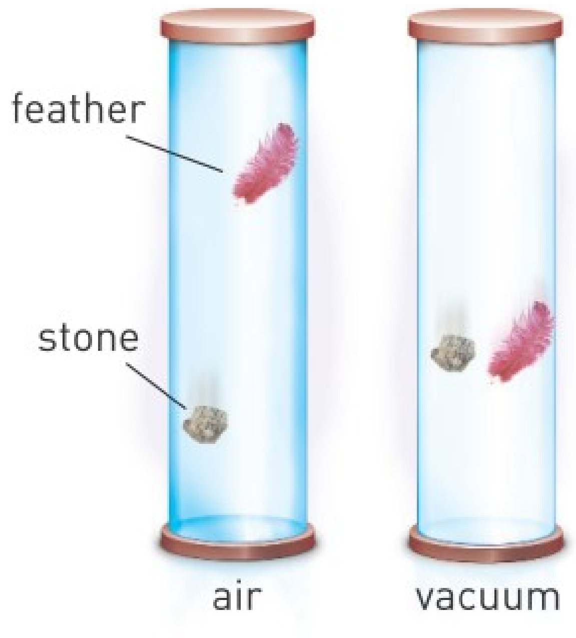


Figure 1

This motion is called free fall. The acceleration during free-fall is called "gravitational acceleration" and noted as "g". In fact, g is near to 9.8 m/s^2 . However, for simplicity we use g as 10 m/s^2.

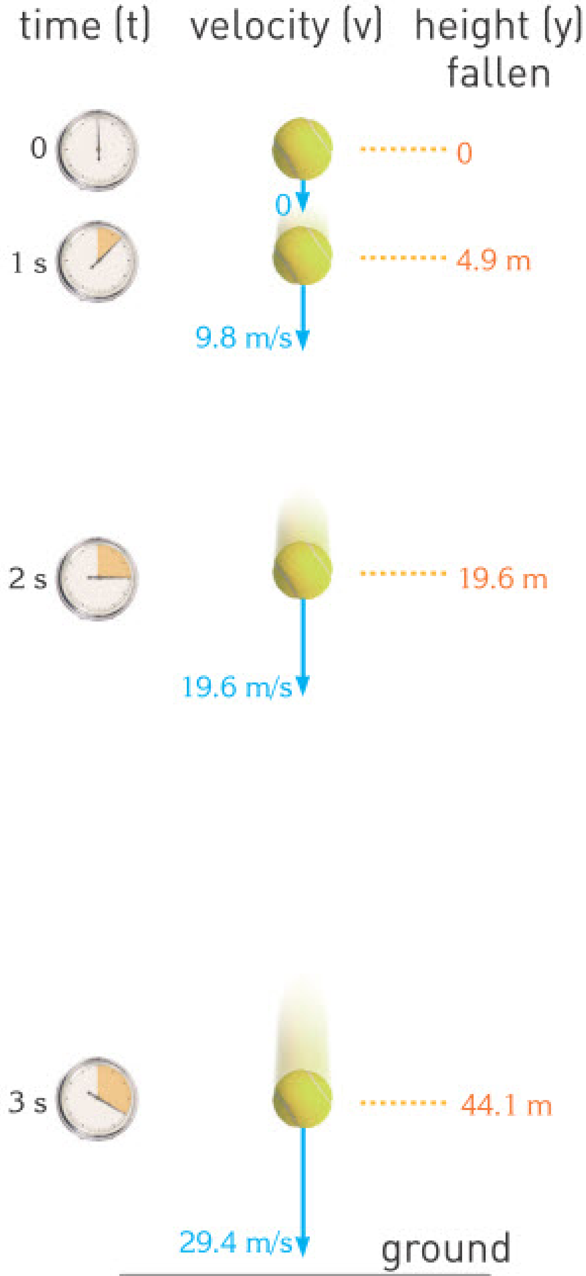


Figure 2

Free fall is a motion with zero initial speed. In each next second an object travels greater distance, Figure 2. We can use 3 kinematics formulas, but with a slight change.

Main formula	Free fall formula	Explanation
$x = x_0 + v_0t + \frac{1}{2}at^2$	$h = \frac{1}{2}gt^2$	A released object passes vertical distance h in t seconds.
$v = v_0 + at$	$v_y = gt$	A released object has a downward speed v_y after t seconds.
$v^2 = v_0^2 + 2ad$	$v_y^2 = 2gh$	A released object has a downward speed v_y after it passes vertical distance h.

Example

A stone is dropped from the top of Bayterek, which is 97 m high. (Assume there is no air resistance and $g = 10\ m/s^2$)
a) What is the displacement after 3.0 s?
b) At what speed does the stone hit the ground?

Solution:

a) Vertical displacement (h=Δy):

$$\Delta y = \frac{1}{2} \times g \times t^2 = \frac{1}{2} \times (10\, m/s^2) \times (3\, s)^2 = 45\, m$$

b) Final velocity of the stone

$$v_y^2 = 2 \times g \times \Delta y = 2 \times 10\, m/s^2 \times 97\, m \;\Rightarrow\; v_y^2 = 1940\, m^2/s^2$$

Take square root of both sides

$$v_y = 44.04\, m/s$$

Terminology

free fall - еркін түсу / свободное падение

downward - төмен / вниз

to release - жіберу / отпустить

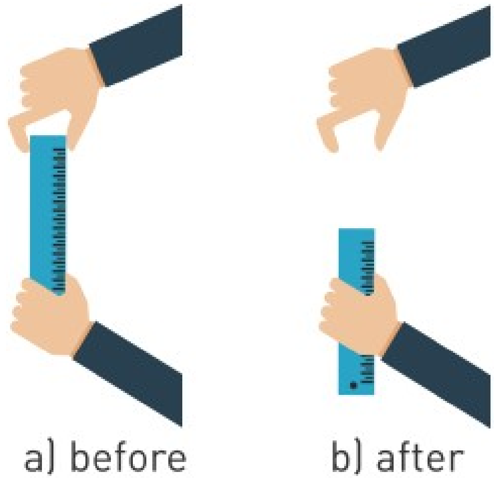
square root - квадраттық түбір / квадратный корень

slight - кішкене / немного

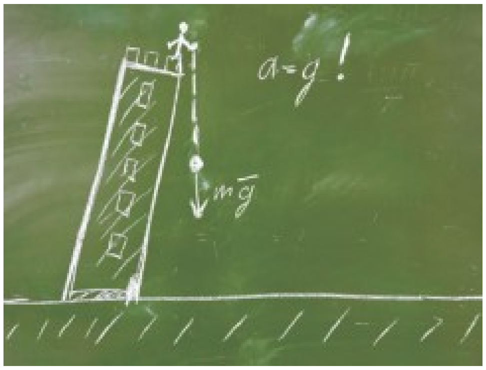
to investigate - зерттеу / исследовать

Activity

“Reaction time” Ask a friend to release a ruler as on picture. You need to stop the ruler as fast as you can. Repeat for several times and find your average reaction time.



Research time



Does the time of free fall depend on a mass? Investigate it. Two meter height is enough for this task.

Literacy

1. How many meters does skydiver fall in 1 sec, 2 sec, 3 sec, 4 sec?
2. You drop stone from the 320 m high cliff. How many seconds later do you hear its sound? Speed of sound is 320 m/s.
3. What will be final velocity of raindrops falling from 8 kilometers height. Assume there is no air resistance. Could we survive under these conditions?
4. Why do stone and feather fall with same acceleration in vacuum?

Art time

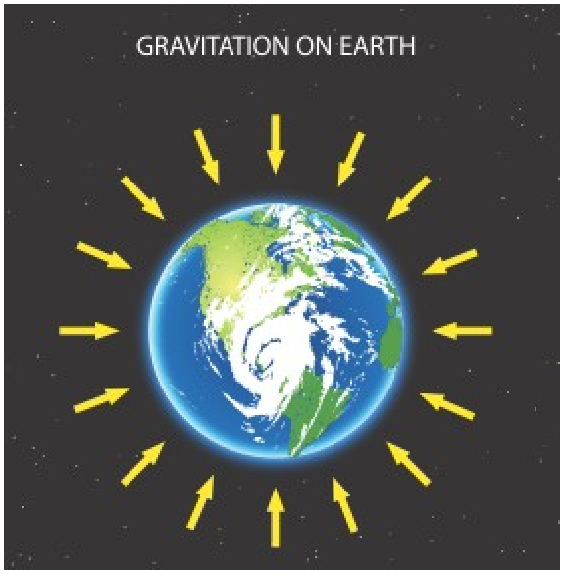
Make "calligram" about free fall.

Fact

Search "free fall in vacuum" in internet.

Fact

At different points on Earth, objects fall with an acceleration between 9.764 m/s^2 and 9.834 m/s^2 depending on altitude and latitude, with a conventional standard value of exactly 9.80665 m/s^2 .


GRAVITATION ON EARTH

1.6 MOTION OF BODY THROWN HORIZONTALLY

You will

- describe motion of an object thrown horizontally by using equations of uniform motion and equations of accelerated motion;
- determine velocity of an object thrown horizontally;

Question

Why does javelin thrower run before he throws a javelin?

Three balls start moving at the same time, Figure 1. Ball 1 - free fall. Ball 3 - horizontal motion on the ground. Ball 2 - launched from the same height as Ball 1 and have same horizontal speed as Ball 3.

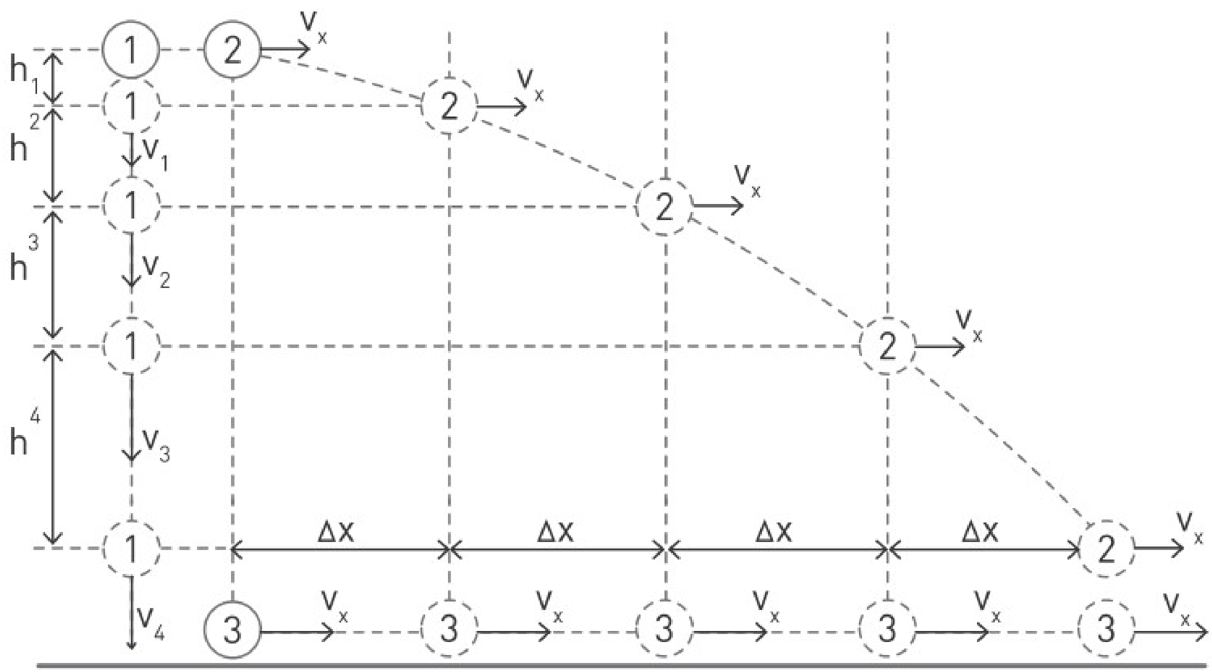


Figure 1

We neglect air resistance and friction on the ground. Then, Ball 2 and Ball 1 have the same vertical positions during the motion. Ball 2 and Ball 3 have the same horizontal positions during the motion. Motion of Ball 2 is a mixture of:

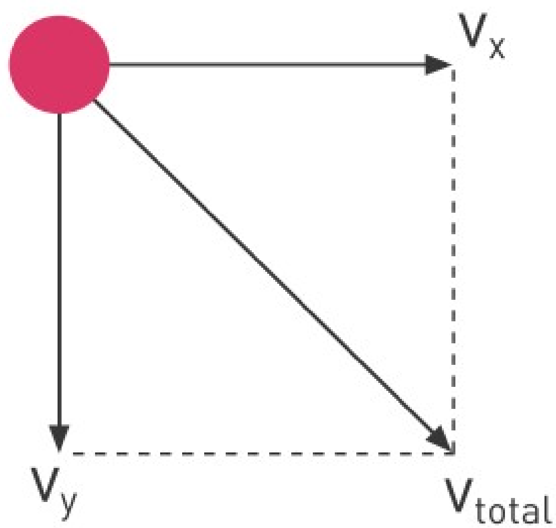
1) horizontal motion with constant speed υ_x

2) free fall with constantly increasing speed υ_y

Let us summarise this in a simple table.

Horizontal part	Vertical part
Speed v_x is constant	Speed v_y is increasing by the time
Formula: $x = v_x t$	Formulas: $h = \frac{1}{2}gt^2$ $\quad v_y = gt \quad v_y^2 = 2gh$

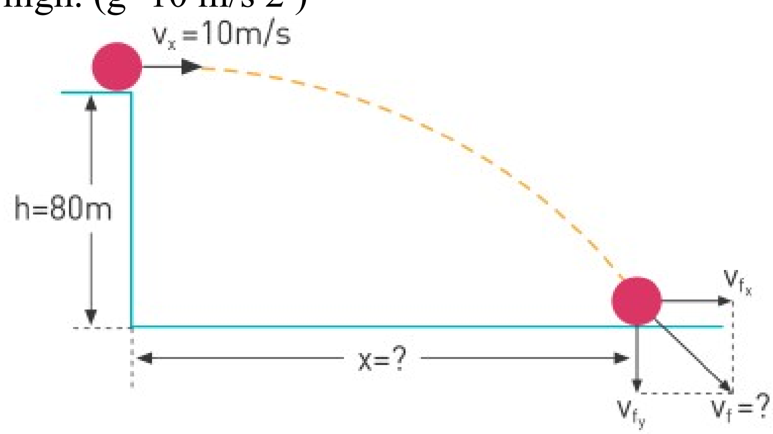
We can find total speed of an object launched horizontally by Pythagorean theorem.



$$v_{total} = \sqrt{v_x^2 + v_y^2}$$

Example

A ball is thrown at 10 m/s horizontally from the top of the building, 80 m high. (g=10 m/s 2)



Find:
a) The time of flight of the ball.
b) The horizontal distance x(range).
c) The final speed when it reaches the ground.

Solution:

a) the initial vertical velocity of the ball is zero

$$h = \frac{1}{2}gt^2; \quad t = \sqrt{\frac{2h}{g}}; \quad t = \sqrt{\frac{2 \times 80}{10}} = 4\,s;$$

b) The range is found by

$$x = v_x t$$
$$x = 10 \cdot 4 = 40 \text{ m}$$

c) The horizontal component: $v_x = 10$ m/s

The vertical component: $v_y = gt \rightarrow v_y = 10 \cdot 4 = 40$ m/s

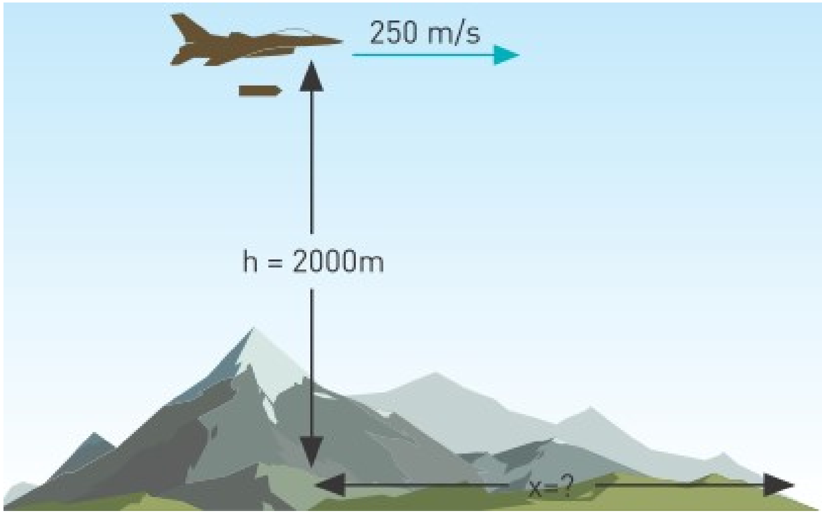
Total speed $v_{total} = \sqrt{10^2 + 40^2} = 41.2$ m/s

Activity

There are heights and velocities of different waterfalls in the table. Fill in the blanks.

№	Name of the waterfall	Height	Range	Time	Initial speed
1	Angel Falls	979 m			3 m/s
2	Niagara Falls	51 m			10 m/s
3	Iguazu Falls	82 m			7 m/s
4	Takakkaw Falls	260 m			5 m/s
5	Yumbilla Falls	896 m			8 m/s
6	Gocta Falls	771 m			4 m/s

Literacy



1. Talgat Jakypbekuly Bigeldinov was pilot of Ilyushin IL-2. IL-2 flies at 250 m/s speed and 2000 m height. At what distance does he need to drop aid box directly to target?
2. You throw stone horizontally with 44.72 m/s from the 320 m high cliff. How many seconds later do you hear its sound? Speed of sound is 320 m/s.

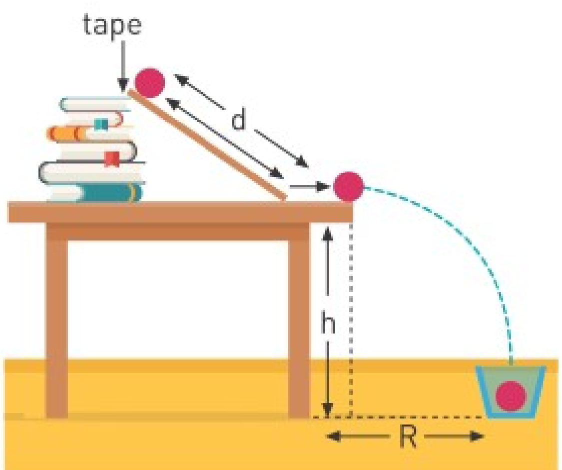
Terminology

javelin - найза / метательное копье
air resistance - ауа кедергісі / сопротивление воздуха
to launch - ұшыру / запускать
range - ұшу қашықтығы / дальность полета
waterfall - сарқырама - водопад
ski jumping - шаңғымен трамплиннен секіру / прыжки на лыжах с трамплина
aid - көмек / помощь
target - нысана / мишень

Fact

Anders Fannemel set official world record for the longest ski jump in 2015. He jumped 251.5 m

Research time



Find the relationship between range and initial velocity of the ball.

Art time

Make “ebru art” about Talgat Bigeldinov and IL-2.

1.7 Circular motion

You will

describe uniform circular motion by using linear and angular physical quantities;

Question

How do hammer throwers and discus throwers move?

A toy car moves in a circular path with constant linear speed, Figure 1a. This type of motion is called circular motion.

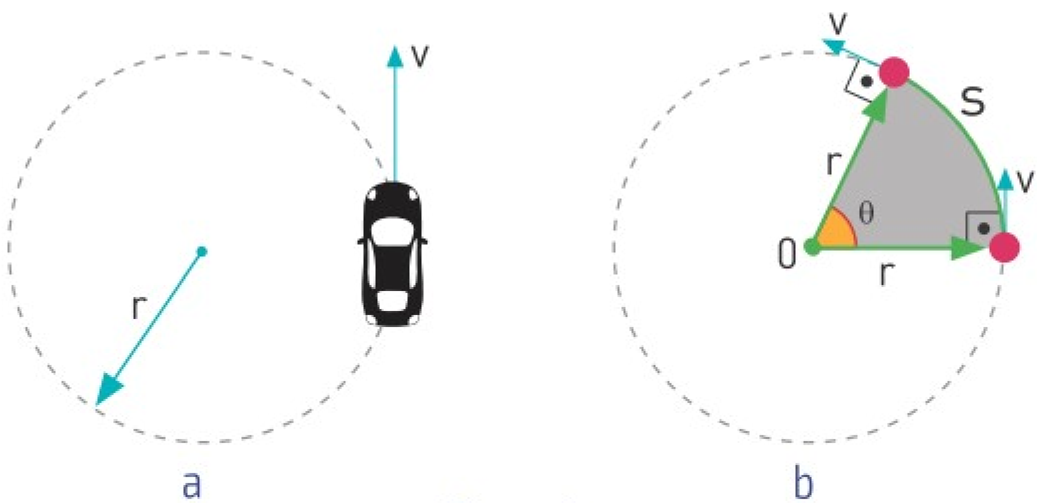


Figure 1

Imagine that the toy car sweeps the angle θ in a time interval t, Figure 1b. This angle depends on the radius (r) and arc length (S). This relation is in the formula:

$$\theta = \frac{S}{r}$$

θ - 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 in radian 2π or 6.28. That's why we can write

$$360^0 = 2\pi \text{ radians} \quad => \quad 1 \text{ radian} = \frac{360^0}{2\pi} \approx 57.3^0$$

Since the linear speed is constant, we can write the relationship between t, υ, and S - length of the arc as

S = υ × t. When toy car makes one complete revolution, it travels distance S = 2πr. We can write the new formula as

2πr=υt

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

We call υ as "tangential speed" because it makes 90° with the radius, Figure 2.

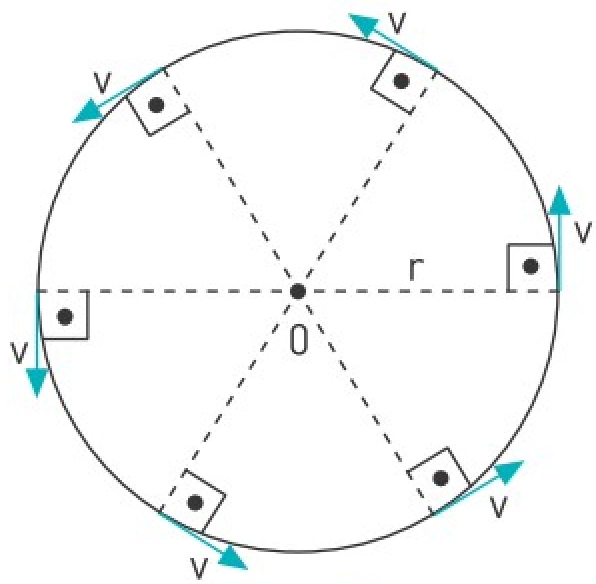


Figure 2

The time T is called period of rotation. Unit of the period is second. Period means "a time required to make one revolution". Some examples of periods are in the table below:

Example	Period in seconds
Earth	365.25 days = 31 557 600
"Shymkent Altyn Eye" ferris wheel	900
Elevator motor	0.6
Car's wheel at 72 km/h	0.12
Crankshaft of a car at rest	0.04

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 ≈ 8.33 revolutions. The relation of period and frequency is in the formula

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

ν- frequency [1/s] or [Hz] - Hertz

T- period [s]

Example

The drum of a washing machine rotates 1200 times in 1 minute. What is the period and frequency of the drum?

Solution:
1 minute is 60 s, period is time needed for 1 rotation
1200 rotations - 60 s
1 rotation - T
If you do cross multiplication, you get:

$$1200\ \times T\ = 1 \times\ 60\ s\ \ \Rightarrow\ T = \frac{60s}{1200} = 0.05\ s$$

Frequency is amount of rotations in 1 s
1200 rotations - 60 s
ν - 1 s
Again after cross multiplication you get:

$$60\ \times \nu = 1200\ rotations \Rightarrow \nu = \frac{1200\ rotations}{60} = 20\ rotations\ in\ 1s$$

$$\nu = 20\ s^{-1} = 20\ Hz$$

Activity

Which of the statements below are examples of circular motion?

1. A race car turning in a curve on a circular racetrack
2. Girl running on a straight road
3. An athlete performing a hammer throw
4. The moon orbiting the earth
5. Drops falling from the roof
6. An aircraft moving in a loop
7. Children playing football
8. Writer is writing a novel
9. Boy drying his hair with a hairdryer

Literacy

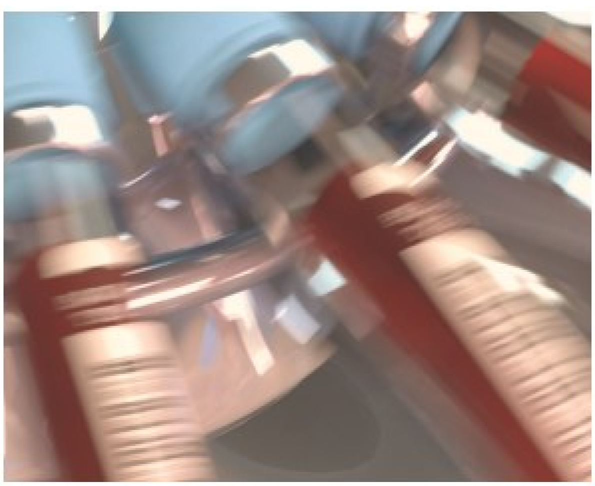
1. Earth rotates around Sun at distance of 150 000 000 km. Calculate tangential speed of Earth. Period of rotation of Earth is 1 year. Why do not we feel this speed?
2. Discus throwers throw discus with a rate of 20 m/s. Length of arm is about 1 m. Calculate period and frequency of thrower. How many turns does he make in 3 seconds?

Activity

Jumping with a skipping rope.

Find the period and the frequency of each student. Make a rating with these results.

Fact



Centrifuge is used in medicine to separate red blood cells from plasma by centrifugal force.

Art time

Make “concrete poetry (shape poetry)” about Earth that rotates around Sun.

Terminology

hammer throw - балға лақтыру / метание молота
circular motion - шеңбер бойымен қозғалыс / движение по окружности
linear speed - сызықтық жылдамдық / линейная скорость
arc length - шеңбер доғасының ұзындығы / длина дуги окружности
frequency - жиілік / частота
rotation - айналу / вращение
discus throw - диск лақтыру / метание диска
tangential speed - жанама жылдамдық / касательная скорость
revolution - айналым / оборот
period - период / время одного вращения
racetrack - жарыс трегі / гоночный трек
skipping rope - секірмек / скакалка
tachometer - айналу жиілігін өлшейтін құрал / прибор измеряющий частоту вращения

Research time

You can make a device that calculates a frequency of rotation. It is called tachometer. Make tachometer.

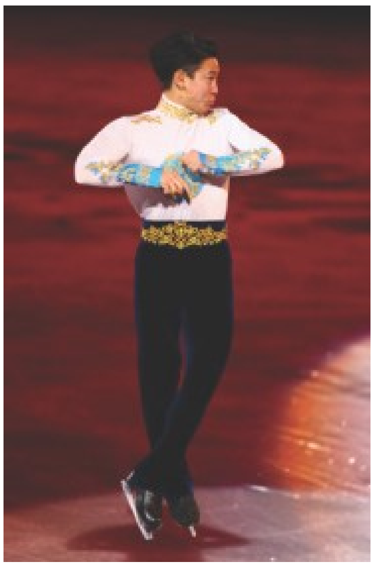
1.8 ANGULAR SPEED

You will

apply formula that shows relationship between angular speed and linear speed;

Question

Why do figure skaters try to rotate as fast as possible?



Three balls are attached to the rigid rod. In time t the rod turns by angle θ around the point O, Figure 1. In this time, each ball travels different linear distance. The relation is $S_3 > S_2 > S_1$. That's why we can say that their speeds have the relation $v_3 > v_2 > v_1$.

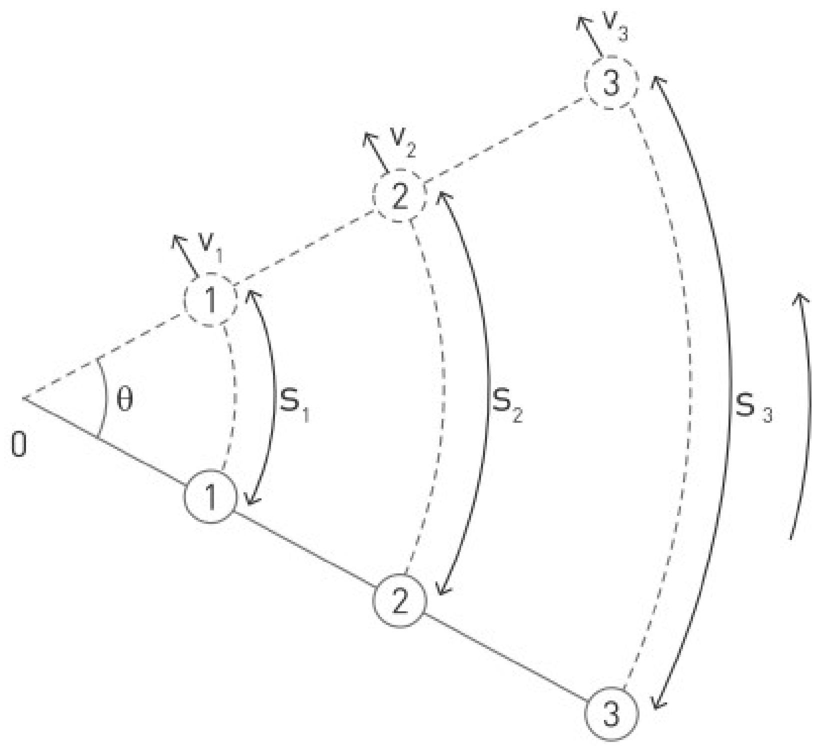


Figure 1

In the example above objects travel same angular displacement at the same time. Thus angular displacement divided by time is called angular speed. The formula of angular speed is:

$$\omega = \frac{\theta}{t}$$

θ - angle [rad]
t - time interval [s]
ω - angular speed [rad/s]

When an object makes one complete revolution, it travels angle 2π radians. Angles must be in radians, not in degrees (°). We can write it in the formula as:

$$\omega = \frac{2\pi}{T}$$

ω - angular speed [rad/s]
T - period [s]

In the Figure 1 all balls travel the same angle θ in equal time interval t. That's why their angular speeds are same.

It is clear that the greater the radius, the greater the linear speed of an object. The relation between linear speed and angular speed is:

$$\upsilon = \omega r$$

υ- linear speed [m/s]
ω - angular speed [rad/s]
r - radius of rotation [m]

Example

Ferris wheel in Shymkent city is one of the biggest in Central Asia. It is 50 m high and takes 15 minutes to make one revolution.
a) What is the tangential velocity of cabines? (π=3)
b) What is the tangential speed of the point 10 m from the centre?

Solution:

a) First we find the period:

$$T = 15\,min = 15 \times 60\,s = 900\,s$$

Then we use the formula for tangential velocity:

$v = \frac{2\pi R}{T}$, the Radius is the half of diameter, so R=25m.

$v = \frac{2\times3\times25\,m}{900\,s} \approx 0.17 m/s$

b) Angular speed:

$$\omega = \frac{2\pi}{T}$$

$$\omega = \frac{2\times3}{900} = \frac{1}{150} rad/s$$

Linear speed:

$$v = \omega r$$

$$v = \frac{1}{150} \times 10 \approx 0.067\,m/s$$

Activity

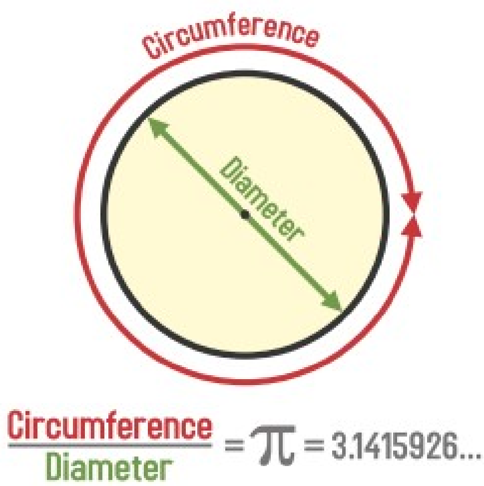
Make a bottle flip challenge in class. What should you do to improve your success? Make a rating with these results.

Literacy

1. Figure skater rotates 5 times in one second. Calculate his angular speed. Why do jury like fast rotations?
2. A person throws hammer at speed of 20 m/s. Length of hammer is 120 cm and length of arm is about 1 m. Calculate angular speed of thrower. Does thrower rotate faster or slower than figure skater?

Fact

π(Pi) is circumference divided by diameter.



Art time

Make a poster that shows examples of circular motion in nature and industry.

Terminology

skater - коньки тебуші / конькобежец
rigid - қатты / твердый
concept - түсінік / понятие
interval - аралық / промежуток
circumference - шеңбер периметрі / периметр окружности
angular speed - бұрыштық жылдамдық / угловая скорость
ferris wheel - шолу дөңгелегі / колесо обозрения

Research time

What factors does angular speed depend on?

1.9 CENTRIPETAL ACCELERATION

You wil

apply formula of centripetal acceleration for problem solving;

Question:

Why don’t people fall on rollercoaster “loop-the-loop”? Can you pass “loop-the-loop” in a car, on a bicycle or running?

When object performs the uniform circular motion, its linear speed is constant. There is no tangential acceleration. However, velocity is changing! This is because direction of the velocity vector is continuously changing, Figure 1. This means there must be different acceleration that can change the direction, but cannot change the magnitude of the velocity. This type of acceleration is called centripetal acceleration. It is always perpendicular to the velocity vector and directed towards the centre of rotation, Figure 1. This type of acceleration exists when something can keep an object in a rotation. For example, you can rotate a stone on a rope. The formula of centripetal acceleration is

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

a_c-centripetal acceleration [m/s^2]
υ-speed of an object [m/s]
R- radius of rotation [m]

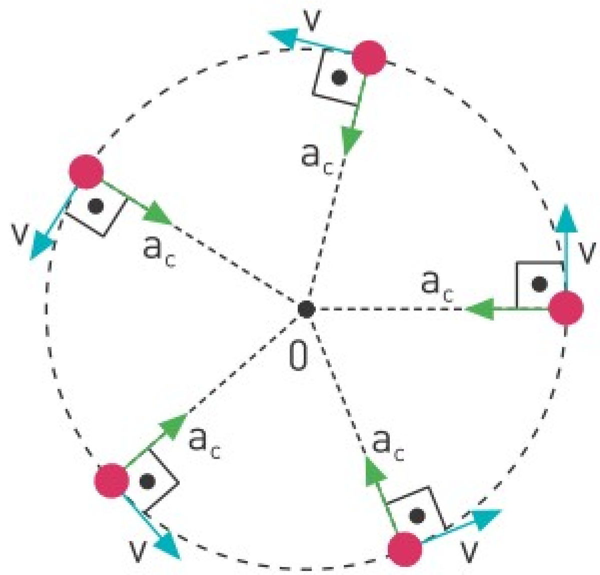


Figure 1

Let's summarise the difference between linear and centripetal acceleration in one table.

Tangential acceleration	Centripetal acceleration
Changes magnitude of velocity	Changes only direction of the velocity
$\vec{a} = \frac{\Delta\vec{\upsilon}}{\Delta t}$	$a_c = \frac{\upsilon^2}{R}$

Example

A car with υ=36 km/h follows a green line in picture. What is its centripetal acceleration?

Solution:

First we have to convert linear velocity into m/s

$$36\ km/h = \frac{36\ km}{1\ h} = \frac{36 \times 1000\ m}{3600\ s} = \frac{10\ m}{1s} = 10\ m/s$$

Next we use formula for centripetal acceleration:

$$a_c = \frac{v^2}{R} \rightarrow a_c = \frac{(10)^2}{30} = 3.33\ \mathrm{m/s^2}$$

Activity

Find the centripetal acceleration of the clock hands in your classroom or home.

Literacy

1. You pass “loop-the-loop” on a bicycle. Its radius is 5 m. What is your speed at the top so that you pass it?
2. Astronauts that go to space from Baikonur do “High-G training” in a centrifuge. The centrifuge has the radius of 18 m. Astronauts experience 8g acceleration. What are tangential speed, angular speed, period and frequency of centrifuge?

Fact

Bacteria has flagellum (tail) that rotates clockwise or counterclockwise to move.

Art time

Write “QR code poem” about feelings of astronaut in centrifuge.

Terminology

magnitude - сандық мәні / величина
centripetal acceleration - центрге тартқыш үдеу / центростремительное ускорение
clockwise - сағат тілінің бағыты бойынша / по часовой стрелке
counterclockwise - сағат тілінің бағытына қарсы / против часовой стрелки

LAB WORK #1

Title: Acceleration

Goal:

Determine acceleration of object rolling from inclined plane.

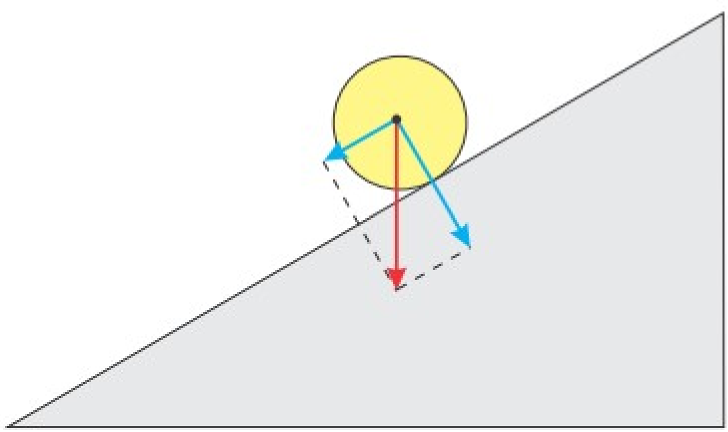
Equipment:

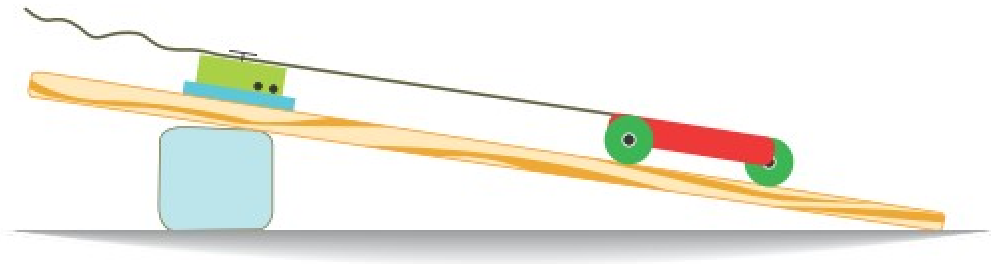
1. inclined plane,
2. stopwatch
3. ruler

Safety:

1. Tie back long hair, secure loose clothing, and remove loose jewelry to prevent their getting caught in moving or rotating parts. Put on goggles.

2. Attach masses securely. Falling or dropped masses can cause serious injury.





Theory:

$$x = v_0 t + \frac{1}{2} a t^2 \qquad v_0 = 0$$

$$x = \frac{1}{2} a t^2$$

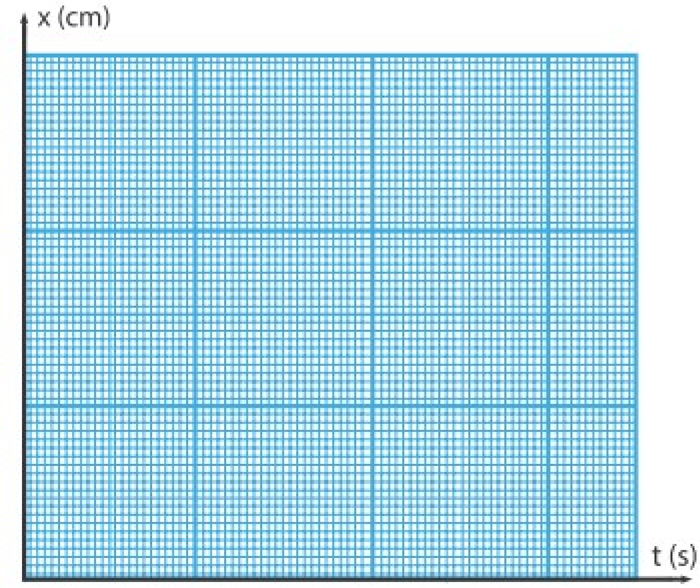
$$a = 2x / t^2$$

What is x? What is its unit?
What is a? What is its unit?
What is t? What is its unit?

Procedure:

1. Release object from inclined plane
2. Measure positions at different time intervals and write it into table
3. Calculate acceleration
4. Plot the graph

	x, m	t, s	a, m/s²
1			
2			
3			
4			
5			



Conclusions:

1. Explain factors, which affect on the result of experiment
2. How would result be affected if the initial mass of the object increase?
3. Explain why theoretical and experimental values of acceleration are different.

LAB WORK #2

Title: Horizontal flight

Goal:

Determine initial velocity of horizontally thrown object.

Equipment:

1. light object
2. table
3. ruler

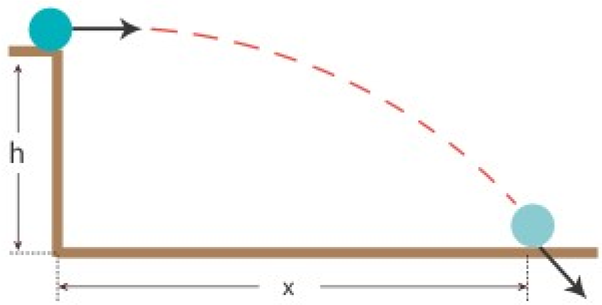
Safety:

1. Tie back long hair, secure loose clothing, and remove loose jewelry to prevent its getting caught in moving or rotating parts. Put on goggles.

2. Perform this experiment in a clear area. Falling or dropped masses can cause serious injury.

Theory:

Object thrown horizontally follows two motions. In vertical direction initial velocity is zero and acceleration is 9.8 m/s^2. That means in vertical direction object performs free fall. In horizontal direction motion is steady. So you use equations separately for vertical and horizontal direction.



$$x = v_0 t$$

$$h = \frac{1}{2} g t^2$$

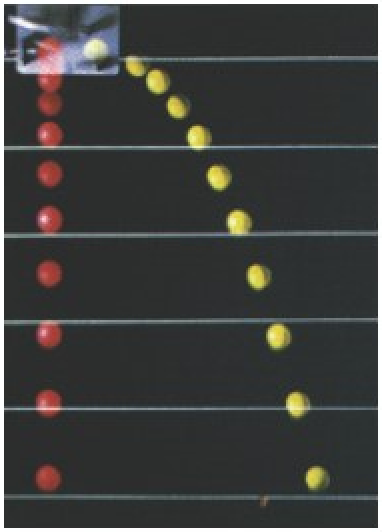
$$v_0 = x\sqrt{g}/\sqrt{2h}$$

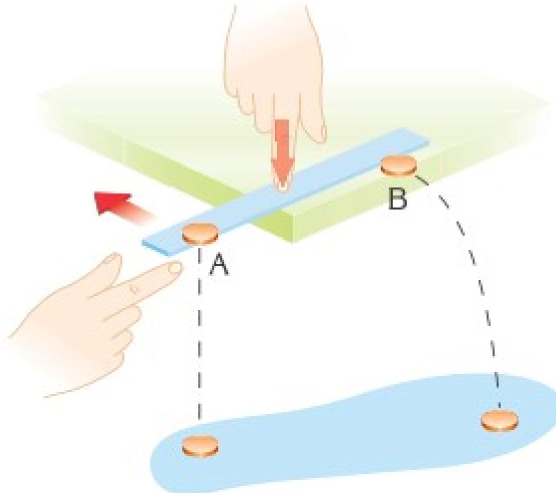
Procedure:

1. Push object horizontally along a table and calculate initial velocity and other parameters using only ruler.
2. Measure height of table
3. Give horizontal velocity to object (may be eraser) along table
4. Measure horizontal distance of falling object
5. Do same procedure and fill in the table
6. Calculate initial velocity of your object

	h, m	x, m	v_0, m/s
1			
2			
3			
4			
5			

Theory states that object thrown horizontally and free falling object fall at the same moment. Photo shows this effect. You can check this by taking two objects, like a coin and do process shown in second picture.





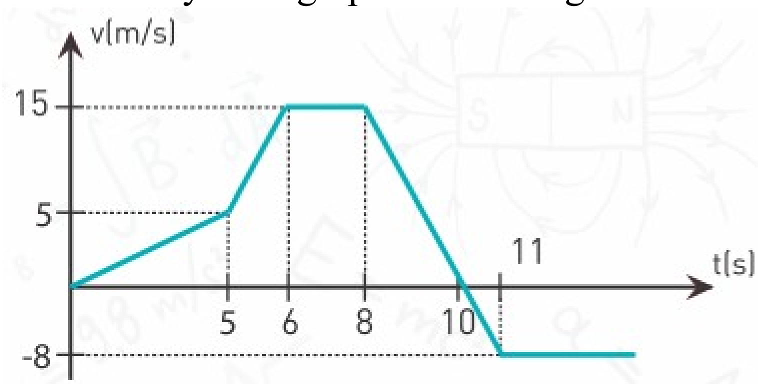
Conclusions:

1. What is initial velocity?
2. Did your classmates get the same result? Discuss.
3. Does horizontal flight have something common with free fall?

PROBLEMS

Example 1

The velocity-time graph of a car is given.



1. What do the graph lines mean?
2. Plot the acceleration-time graph.

Solution:

1. Let's analyse each time interval.

0-5 s: the car accelerates
5-6 s: the car accelerates with greater acceleration
6-8 s: the car moves with constant velocity
8-10 s: the car decelerates and reaches 0 velocity
10-11 s: the car accelerates in opposite direction
after 11s: the car moves with constant velocity in opposite direction

2. We can find acceleration at each time interval by using formula

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

0-5 s: $a_1 = \frac{5}{5} = 1\ m/s^2$

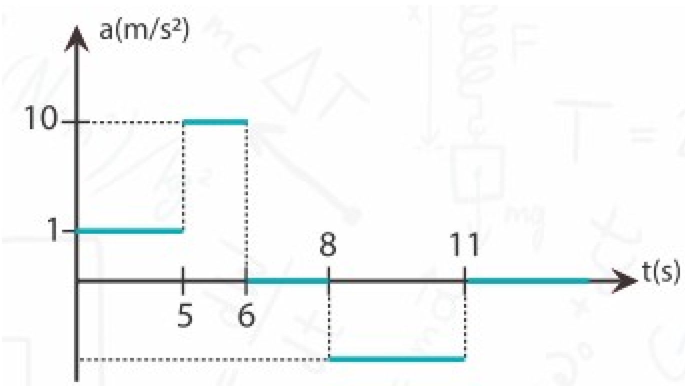
5-6 s: $a_2 = \frac{15-5}{6-5} = 10\ m/s^2$

6-8 s: $a_3 = 0\ m/s^2$

8-11 s: $a_4 = \frac{-8-15}{11-8} \approx -7.7\ m/s^2$

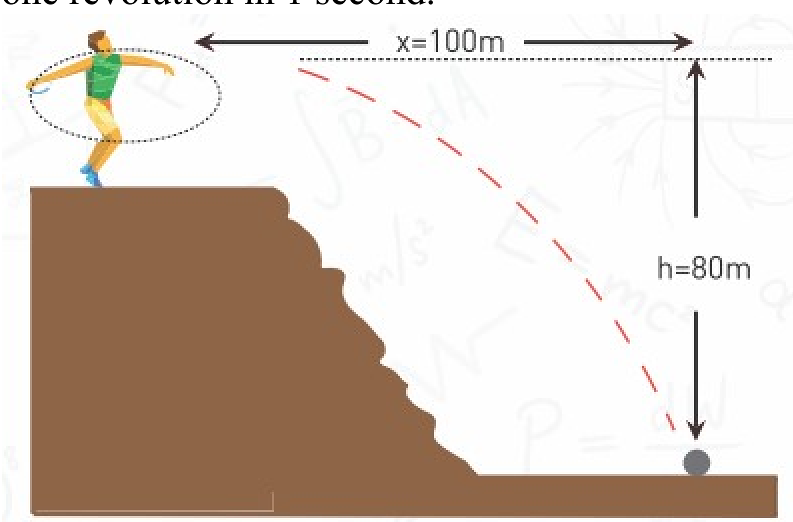
after 11s: $a_5 = 0\ m/s^2$

We can draw the graph now.



Example 2

An athlete spins the ball and then throws it from a cliff. Before throwing, he increases the speed of the ball by 4 m/s in each revolution. Athlete performs one revolution in 1 second.



a) How many seconds is the ball in motion?

b) How many complete revolutions did athlete perform?

Solution:
a) The ball has 2 stages of its motion.
1^{st} : rotating, 2^{nd}: falling.
We know the height, then we can find time of 2^{nd} stage.

$$H = \frac{1}{2}gt^2$$
$$80 = \frac{1}{2} \times 10 \times t^2$$
$$t = 4\ s$$

We know that X=100m, then we can find the launch speed of the ball.

$$x = vt$$
$$100 = v \times 4$$
$$v = 25\ m/s$$

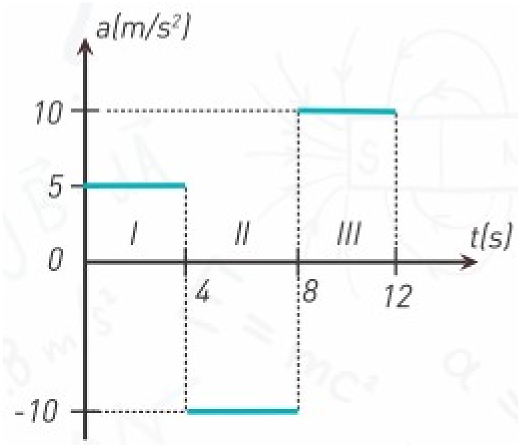
If athlete increases the speed of the ball by 4 m/s in each second, this means that he accelerated the ball for

$$\frac{25}{4} = 6.25\ second$$

The ball is 6.25 s in athlete's hands and 4 s in the air.
Therefore, the total time of ball's motion is 6.25 + 4 = 10.25 s.
b) The ball is 6.25 s in athletes hands. This means that the ball performed 6.25 revolutions (6 and a quarter). However, we need to know the number of complete revolutions. The answer is 6.

Exercise 1

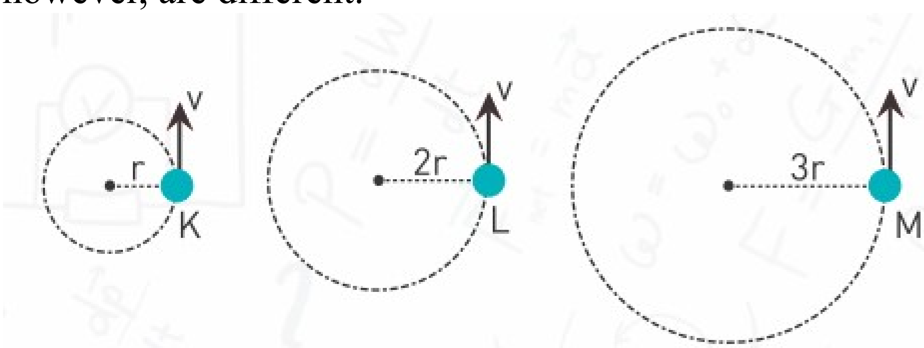
A car initially moves with 5 m/s. Then, it start to move with different accelerations according to a(t) graph.



a) What are the final velocities at the end of each time interval?
b) Draw the v(t) graph according to part a.

Exercise 2

Three balls perform circular motion with the same speeds. The radii, however, are different.

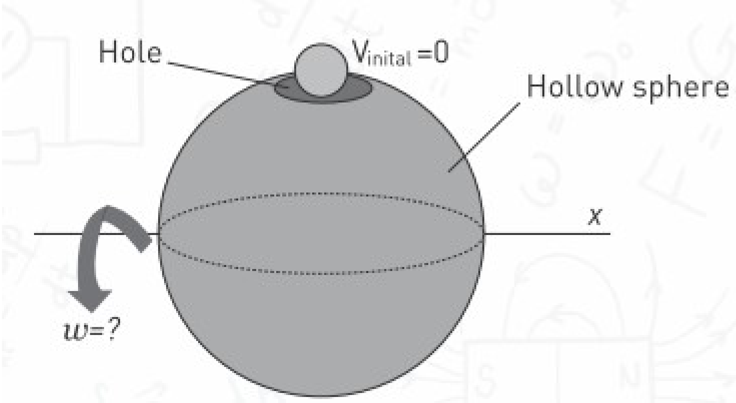


a) Compare their angular speeds and periods of rotation
b) You were given the task that each ball must have same period. How would you achieve this goal?

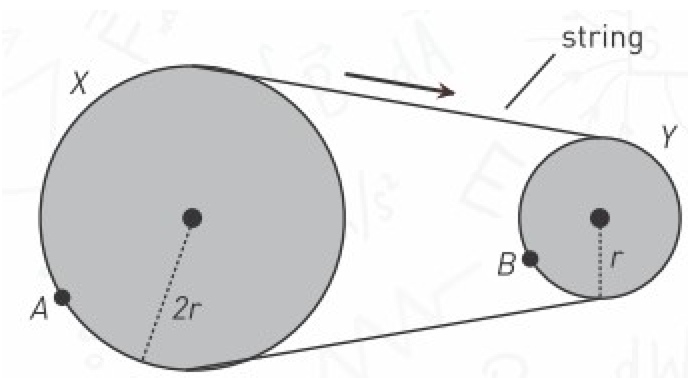
Exercise 3

The hollow sphere of radius R = 2.5 m can rotate around x axis. There is a hole in the sphere. A small ball freely falls into the hole.
a) What angular speed should the sphere have so the ball can pass through the sphere without touching it?

b) Can be there more than one answer for part a?



Exercise 4
This is the string transmission. When a larger wheel rotates once, the smaller wheel rotates more than once. In this exercise, when one of them rotates once, another will rotate twice.



a) Why does one of the wheels rotate more than once in string transmission?
b) Which of the wheels A or B will rotate twice? Why?
c) You have infinite number of different wheels and strings. What if you need to add wheel(s) that rotate(s) counterclockwise? How would you add extra wheel(s) to A and B wheels ?

Art time

Draw mind-map of chapter 1 (Motion). What central concept (idea) can you use?

Terminology

complete - толық / полный
radii - радиустар / радиусы
transmission - мотор мен дөңгелектерді байланыстыратын механизм / механизм связывающий мотор и колеса
infinite - шексіз / бесконечный
mind-map - ой, ұғым және идеялар арасындағы байланысты көрсететін диаграмма / диаграмма показывающая связи между идеями и мыслями

SUMMARY

1.1. If we can neglect the dimensions of an object, we can imagine it as a small point - point object.

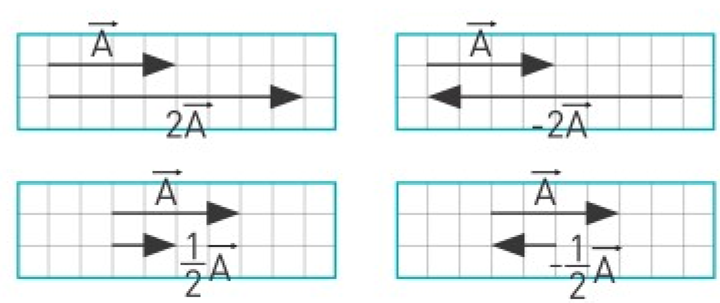
When you look at other bodies, they will have different speeds. In physics this is called relativity of motion.

When we find speeds relative to a certain body, we call that body as reference system.

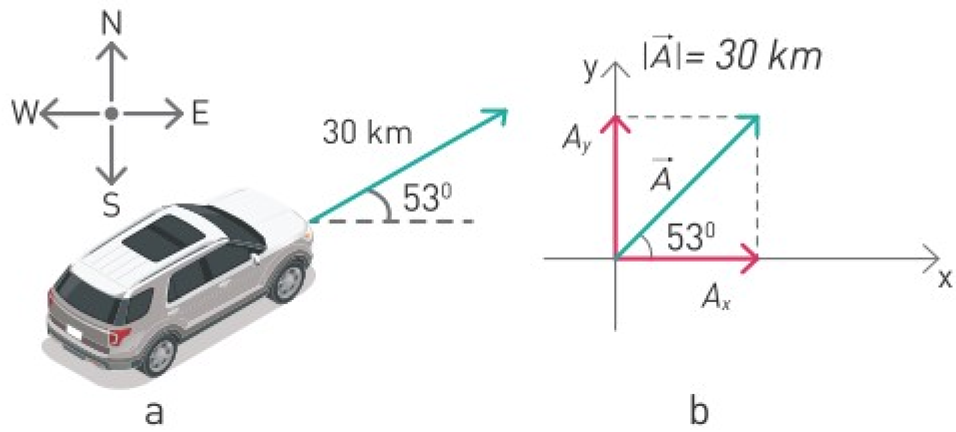
1.2. All quantities in physics can be divided into 2 groups.

Scalars	Vectors
have magnitude, but don't have direction. Example: 5 kilograms.	have both magnitude and direction. Example, 20 m/s to the East.

We can add, subtract, and multiply vector by scalar:



Vectors can be divided into components:



$$|A_x| = 30 \times \cos 53 = 30 \times 0.6 = 18 \text{ km}$$
$$|A_y| = 30 \times \sin 53 = 30 \times 0.8 = 24 \text{ km}$$

1.3. Acceleration is the change of velocity in the unit time:

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$$

$\vec{a}$ - acceleration [m/s^2]
$\Delta \vec{v}$ - change in speed [m/s]
Δt - time interval [s].

Negative acceleration is deceleration (slowing down).

1.4

$x = x_0 + v_0 t + \frac{1}{2}at^2$	$v = v_0 + at$	$v^2 = v_0^2 + 2ad$
x - final position [m] x_0 -initial position [m] v_0 - initial velocity [m/s] a - acceleration [m/s^2] t - time taken [s]	v - final velocity [m/s] v_0 - initial velocity [m/s] a - acceleration [m/s^2] t - time taken [s]	v - final velocity [m/s] v_0 - initial velocity [m/s] a - acceleration [m/s^2] d - distance [m]

1.5

Main formula	Free fall formula	Explanation
$x = x_0 + v_0 t + \frac{1}{2}at^2$	$h = \frac{1}{2}gt^2$	A released object passes vertical distance h in t seconds.
$v=v_0+at$	$v_y = gt$	A released object has a downward speed v_y after t seconds.
$v^2 = v_0^2+2a\Delta x$	$v_y^2 = 2gh$	A released object has a downward speed v_y after it passes vertical distance h.

Horizontal part	Vertical part
Speed v_x is constant	Speed v_y is increasing by the time
Formula: $x = v_x t$	Formulas: $h = \frac{1}{2}gt^2$ $v_y = gt$ $v_y^2 = 2gh$

$$v_{total} = \sqrt{v_x^2 + v_y^2}$$

1.7. The unit of angle in this formula is radians. One complete revolution is 360°. The same measurement in radians is 2π or approximately 6.28

$$360^0 = 2\pi \text{ radians} \Rightarrow 1 \text{ radian} = \frac{360^0}{2\pi} \approx 57.3^0$$

$$\theta = \frac{S}{r}$$

θ - angle [rad]

S - length of arc [m]

r - radius [m]

Since the linear speed is constant, so S = v × t. When an object makes one complete revolution, it travels distance S = 2πr. So,

$$2\pi r = vT$$

Frequency means “how many times an object revolves in 1 second”.

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

1.8. Angular speed

$$\omega = \frac{\theta}{t}, \ \omega = \frac{2\pi}{T}$$

θ - angle [rad]

t - time interval [s]

ω - angular speed [rad/s]

T - period [s]

The relation between linear speed and angular speed is

$$v = \omega r$$

υ - linear speed [m/s]

ω - angular speed [rad/s]

r - radius of rotation [m]

1.9. Centripetal acceleration is always perpendicular to the velocity vector, and directed towards the center of rotation.

Tangential acceleration	Centripetal acceleration
Changes magnitude of velocity	Changes only direction of the velocity
$a = \frac{\Delta v}{\Delta t}$	$a_c = \frac{v^2}{R}$

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

a_c- centripetal acceleration [m/s^2]

υ- speed of an object [m/s]

R - radius of rotation [m]

PROBLEMS

1. Identify whether each of the following examples involves a vector or a scalar quantity.

a) The force applied by one boxer on another

b) The number of pages in a book

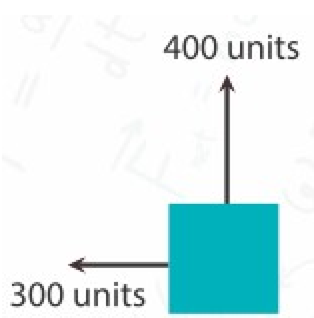
c) The volume of some milk

d) The distance that a ball travels

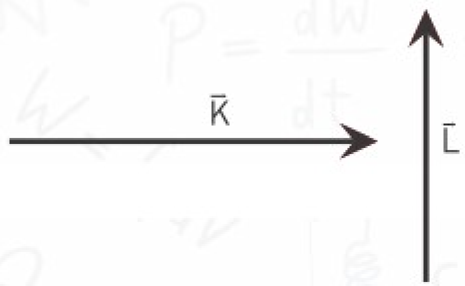
e) The velocity of a bullet

2. Vector $\vec{P}$ has a magnitude of 10 units. Vector $\vec{Q}$ has a magnitude of 8 units. Find the largest and smallest values possible for the resultant vector $\vec{R} = \vec{P} + \vec{Q}$

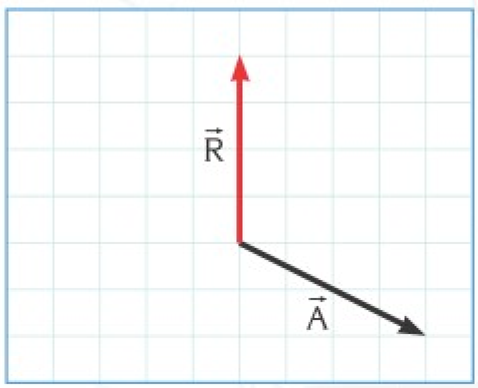
3. A heavy box is pulled by two ropes. One rope pulls it with a force of 300 units due west. The other pulls it with a force of 400 units due north. Draw a vector diagram and calculate the magnitude and direction of the resultant force.



4. Vectors $\vec{K}$ and $\vec{L}$ of magnitudes 8 units and 6 units, respectively, are as shown in the figure. Calculate the magnitude and direction of the resultant vector $\vec{R}=\vec{K}+\vec{L}$.



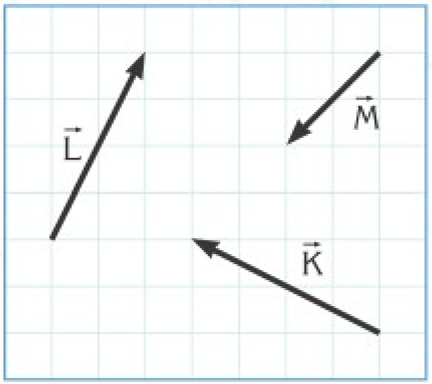
5. $\vec{R}$ is the resultant of two vectors, $\vec{A}$ and $\vec{B}$. ($\vec{R}=\vec{A}+\vec{B}$). The vectors $\vec{R}$ and $\vec{A}$ are shown in the figure, find the vector $\vec{B}$.



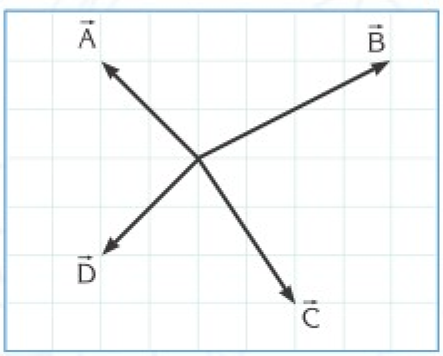
6. Vectors $\vec{K}$, $\vec{L}$ and $\vec{M}$ are as shown in the figure. Draw the resultant vectors given below.

a) $\vec{R} = \vec{K} + \vec{L} - \vec{M}$

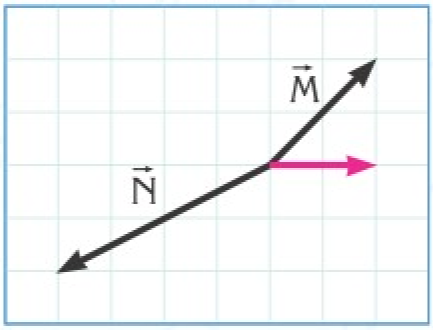
b) $\vec{R} = \vec{K} - \vec{L} - \vec{M}$



7. Draw the resultant of vectors $\vec{A}$, $\vec{B}$, $\vec{C}$ and $\vec{D}$ placed as shown in the figure.

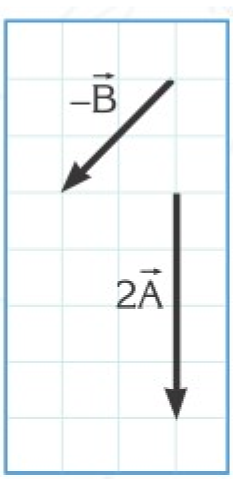


8. The resultant of vectors $\vec{M}$, $\vec{N}$ and $\vec{P}$ is $\vec{R}$. The vectors $\vec{M}$, $\vec{N}$ and $\vec{R}$ are shown in the figure, find vector $\vec{P}$.

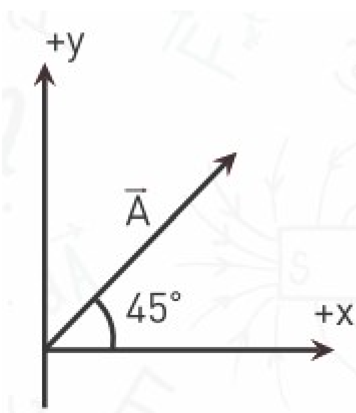


9. Under what condition can the sum of three vectors of equal magnitude be zero?

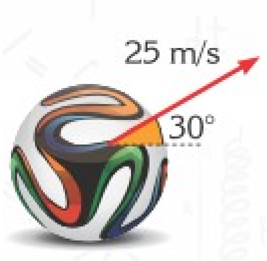
10. Vectors $2\vec{A}$ and $-\vec{B}$ are as shown in the figure. Draw the resultant vector $\vec{R} = \vec{A} + \vec{B}$.



11. If a vector makes an angle of 45º with the +x axis, what can you say about the magnitudes of its components?



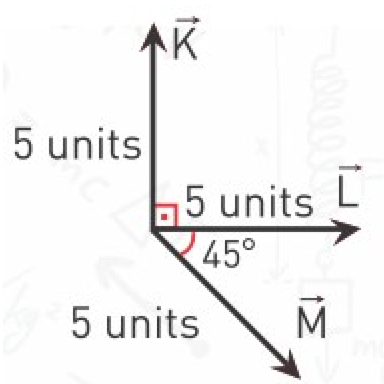
12. A ball is kicked at a speed of 25 m/s at an angle of 30º to the ground. What are the horizontal and vertical components of its initial velocity?



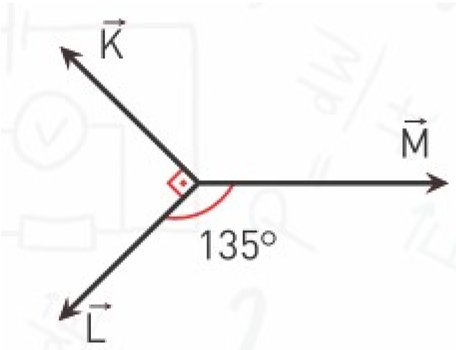
13. A force vector of $\vec{A}$ has a positive x component of magnitude 5.0 units and a negative y component of magnitude 8.0 units.
a) Calculate the magnitude and direction of vector $\vec{A}$.
b) When another force vector $\vec{B}$ is added to vector $\vec{A}$ it gives a resultant vector of magnitude 2.0 units in the positive x direction. Find vector $\vec{B}$.

14. $\vec{A}$ and $\vec{B}$ are two perpendicular vectors. What can you say about the component of $\vec{B}$ along the direction of vector $\vec{A}$?

15. Vectors $\vec{K}$, $\vec{L}$ and $\vec{M}$ are shown in the figure. Find the magnitude and direction of their resultant vector.

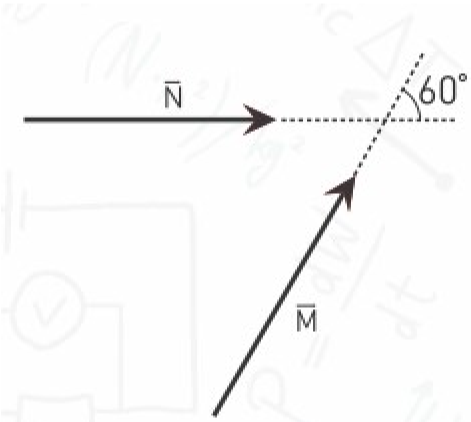


16. The resultant of vectors $\vec{K}$, $\vec{L}$ and $\vec{M}$ is zero. The magnitudes of vectors $\vec{K}$ and $\vec{L}$ are both 5 units. Find the magnitude of the vector $\vec{M}$.



17. Vectors $\vec{A}$ and $\vec{B}$ have x and y components as follows:
Ax=+3 units Bx=–5 units
Ay=+6 units. By=+4 units
If $\vec{B} - \vec{A} + 2\vec{C} = 0$, what are the components of vector $\vec{C}$?

18. Vectors $\vec{M}$ and $\vec{N}$, having the same magnitude of 5 units, are given in the figure. Calculate the magnitude and direction of the resultant vector
$\vec{R} = \vec{M} + \vec{N}$.



19. A plane flies to Karagandy 500 km due east from the airport. Then it flies from Karagandy to Astana 225 km northwest. Draw a vector diagram and determine the straight-line distance and direction from the airport to Astana.

20. Explain the difference between displacement and distance.

21. What do we pay for when we travel by taxi? Distance or displacement? What about when we travel on an airplane?

22. a) Discuss whether distance can be smaller than displacement.

b) Does the kilometre indicator in a car display its distance or displacement?

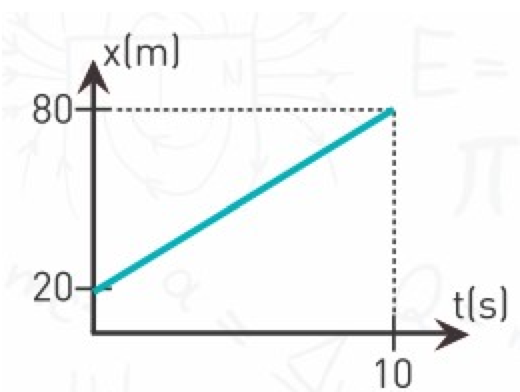
23. Convert the following units

a) 72 km/h into m/s

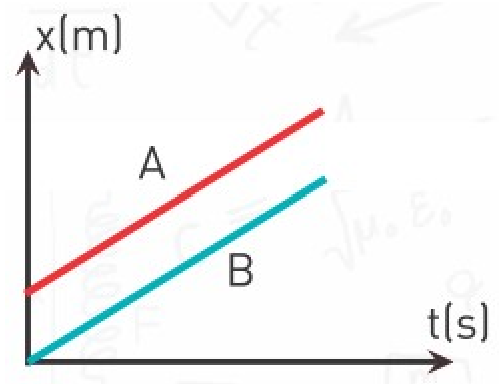
b) 27 cm/s into m/s

c) 15 m/s into km/h

24. What does the slope of a line in a position-time graph mean?



25. The position-time graph of a car moving along the x axis is given in the figure. What is the speed of the car in m/s?



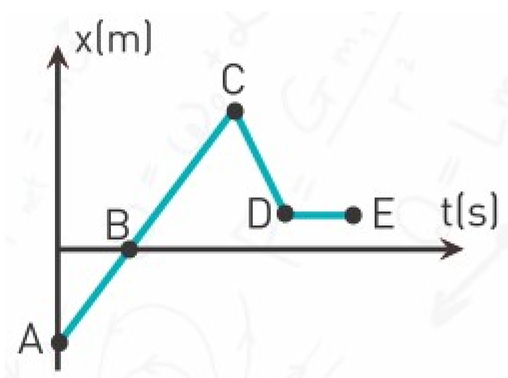
26. According to the x-t graph in which direction (positive or negative) is the object moving between points

a) A and B

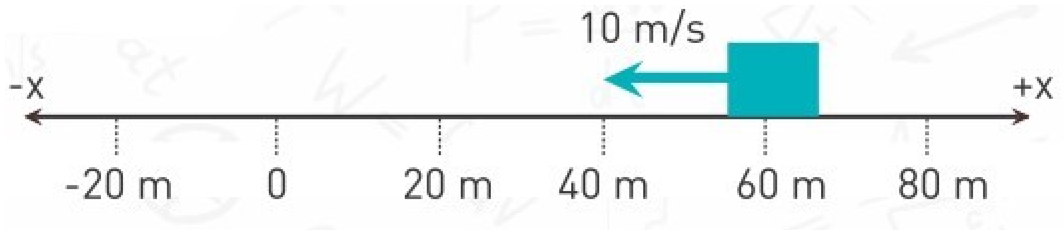
b) B and C

c) C and D

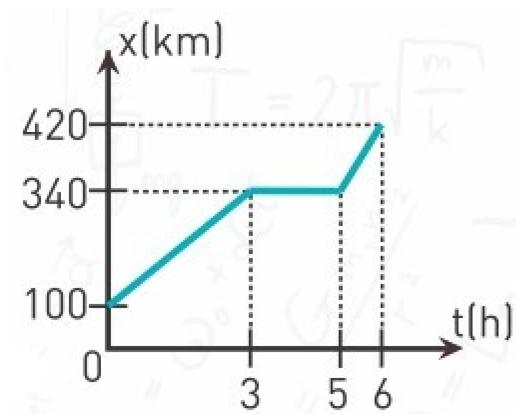
d) D and E



27. A diagram of an object moving along the x-axis taken at a time t=0 is given. Draw the position-time graph of the object for the next 7 seconds, if the velocity of the object is 10 m/s in the given direction and it is constant.



28. The position-time graph of a car moving along the x-axis is given.



a) Draw the velocity-time graph.

b) What is the displacement of the car in the first 5 hours?

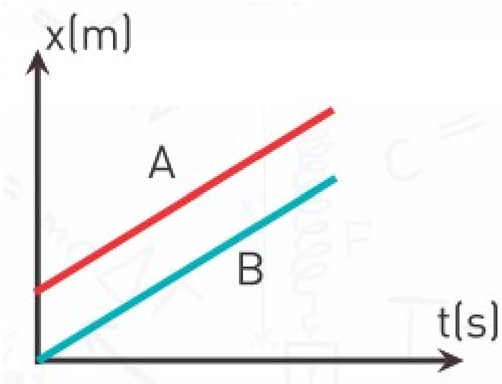
29. In astronomy the light-year is used as a unit of distance. It is the distance that light can travel in one year. (For instance, our galaxy, the Milky Way, is about 150 000 light-years across). If light travels at a constant speed of 300 000 km/s,

a) Calculate 1 light-year in km.

b) Calculate how many years it takes for the light to reach us from our closest star (Proxima Centauri) which is about 4.0 x 10^{13} km away.

c) Logically, Proxima Centauri is the first destination for interstellar travel. If the fastest man-made spacecraft, the Helios II, has a speed record of 70.2 km/s, how long would this journey take?

30. The position-time graphs of two objects A and B, are shown in the figure. Which object is faster?



31. Two vehicles move in opposite directions to each other with constant speeds of 20 m/s and 30 m/s, as shown in the figure. If the initial distance between the vehicles is 100 km, how many seconds later do they meet?

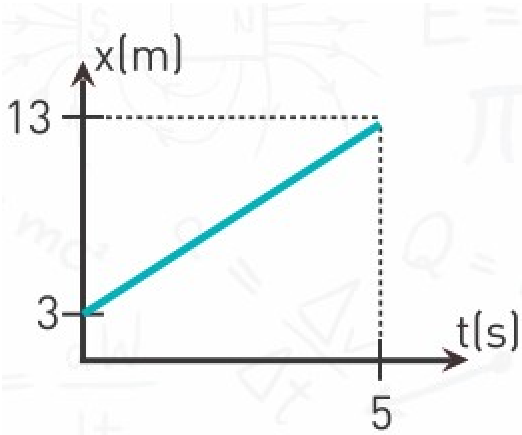
32. Assume that Kayrat and Yerbol can run at constant speeds of 8 m/s and 5 m/s, respectively. They finish a 400 m race together, since Kayrat starts after a time interval Δt seconds later than Yerbol. Find the time interval Δt.

33. A police car moving at 140 km/h is chasing a lorry moving at 120 km/h. If the initial distance between them is 500 m, how many minutes later and at what distance from its initial position does the police car catch the lorry?

34. A car travels from city A to city B at a constant speed of 60 km/h. A bus leaves city A 1h after the car and catches it as it enters city B. The distance between the cities is 240 km. What is the speed of the bus (assumed to be constant) during its journey?

35. How long does it take a train of length 120 m moving at a constant speed of 36 km/h to completely pass over a bridge of length 200 m?

36. The position-time graph for an object is given in the diagram. Write the equation for its position as a function of time, x(t).



37. Two objects travel according to the equations:

$x_1(t) = 600 + 20t$ (in metres)

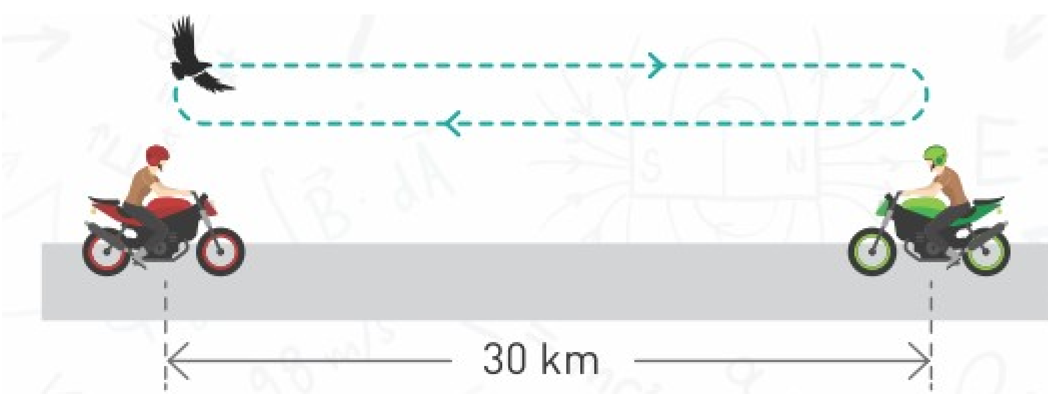
$x_2(t) = 1400 – 30t$ (in metres)

a) What is the velocity of each object?

b) What is the initial position (at t=0) of each object?

c) Determine where (x=?) and when (t=?) they meet?

(Hint: One way of finding their common meeting point is by setting $x_1=x_2$ and solving the equation for t)



38. Two motorcyclists are moving towards each other at a constant velocity of 15 km/h. When the distance between them is 30 km a bird, above the red motorcyclist, starts to fly at a velocity of 25 km/h towards the blue motorcyclist, as shown in the figure. As soon as the bird reaches the blue motorcyclist, it turns back and flies towards the red motorcyclist at the same speed. After flying backwards and forwards between the two motorcyclist in this way, how many km of distance will the bird have flown when the motorcyclists meet?

39. In which type of motion is the average velocity of an object equal to its instantaneous velocity?

40. The cyclist in the figure starts cycling at point A. He reaches point C in 80 s, returns and comes to rest at point B in 20 s.

Calculate the cyclist's

a) Average speed and average velocity in 80 s.

b) Average speed and average velocity in 100 s.

c) Average speed and average velocity, if the cyclist does not stop at point B but returns again to point A, from point C, in a total time of 100 s.

41. An object is thrown vertically upwards. After it reaches a maximum height, it falls back to its initial position. What can you say about its average velocity?

42. In big cities, traffic lights occurring in series on a street are programmed according to a given average car speed. In this system called green wave, cars passing a green light, and moving with this average speed between two

traffic lights continue to meet green. Let's say the distance between two successive traffic lights is 900 m. If the time difference between green lights is 1 minute, what is the average speed of a car which continues meeting green lights?

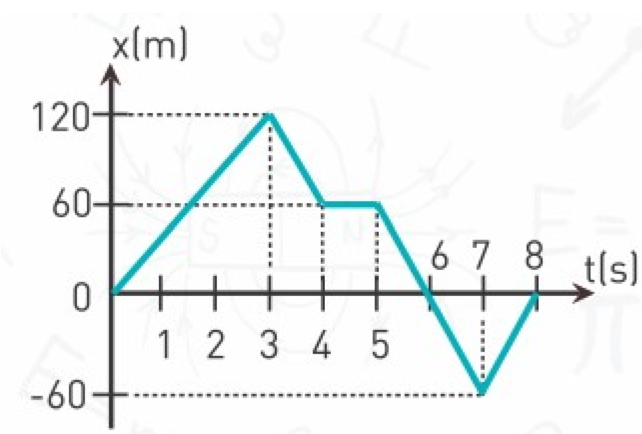
43. Usain Bolt set a new world record in the 100 m race with a time of 9.86 s.

a) Calculate his average velocity.

b) If a cheetah, the fastest of all land animals, with an average speed of 29 m/s

took place in the same race, how many seconds before Usain would it finish the race?

44. Find the magnitude of average velocity



a) From 0 to 3 s

b) From 0 to 4 s

c) From 3 to 5 s

d) From 3 to 7 s

e) From 0 to 8 s

45. A student walks to school from his home with a velocity of 6 m/s and returns home with a velocity of 4 m/s. Find the student's

a) Average speed

b) Average velocity.

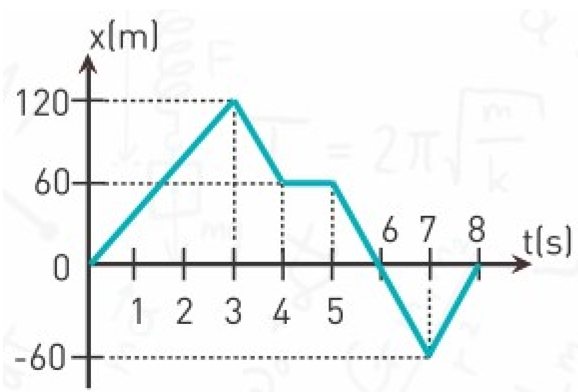
46. Find the instantaneous velocity

a) At 2.5 s

b) At 3.5 s

c) At 4.5 s

d) At 7.5 s



47. Car starts from rest with an acceleration of 2 m/s^2 and achieves maximum velocity of 20 m/s. In how many seconds does it travel 1000 m?

48. a) Describe a situation where an object has zero acceleration but non-zero velocity?

b) Describe a situation where an object has zero velocity but non-zero acceleration?

49. A car is moving eastward but accelerating westward. Is this possible? How?

50. A car accelerates from rest to 108 km/h in 6 seconds. What is the acceleration of the car?

51. A particle has a velocity υ_0=48 m/s at t=0. Between t=0 and t=12 s, the velocity decreases uniformly to zero. What is the acceleration of the particle? What is the significance of the sign in your answer?

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

53. 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?

54. 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?

55. The velocity of an object at t=0 is measured as υ=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.

56. 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?

57. 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).

58. When the driver of a car which moves with a velocity of 90 km/h brakes, he can stop in 50 m. Calculate

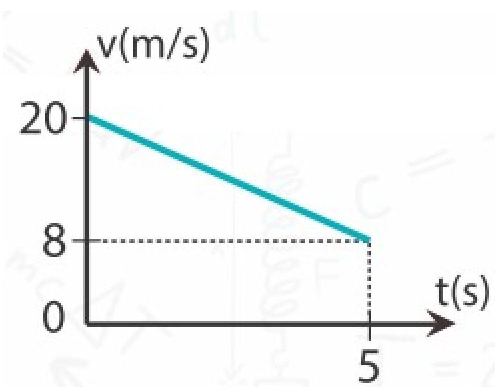
a) The deceleration of the car

b) The time elapsed before he stops.

59. The velocity-time graph for an object is given on the right.

a) Plot its a-t graph.

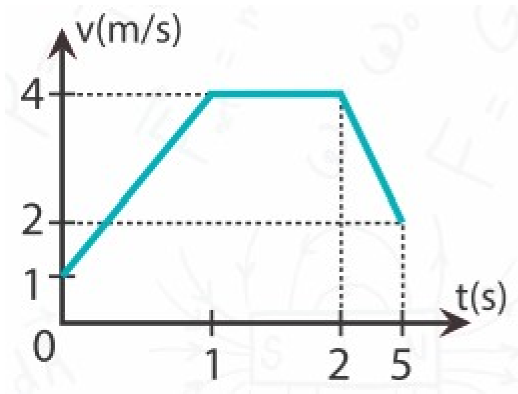
b) In which direction is the object moving?



60. 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.

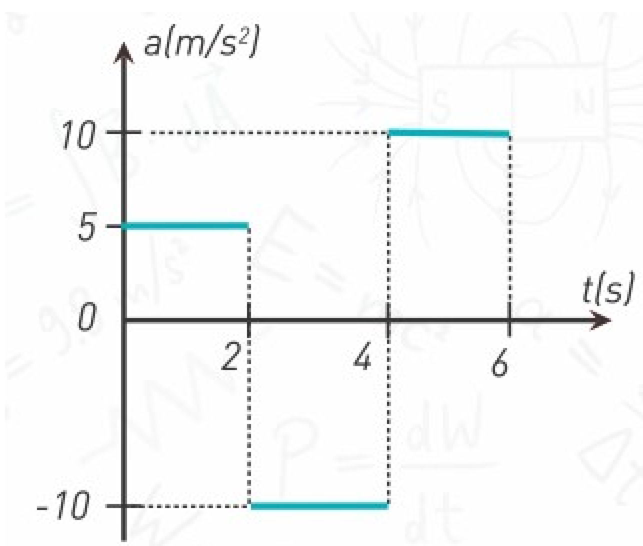


61. The figure shows the acceleration - time graph for an object moving on a straight line. Draw the velocity - time graph

a) Taking υ_o=0,

b) Taking υ_o=8 m/s

c) Taking υ_o=–30 m/s.



62. A machine gun projects a bullet through its barrel, of length 41.5 cm, at a muzzle velocity of 616 m/s. At what acceleration and for how many seconds is the bullet moving in the barrel?

63. An airplane can take off when it reaches a speed of 360 km/h. If the runway is 2 km long, what is the minimum value of acceleration required

for the plane to be able to take off?

64. 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.

65. On a straight road a lorry and a car are at rest at a fixed distance apart. The lorry then starts moving with an acceleration of 3 m/s^2 and the car starts moving with an acceleration of 4 m/s^2. After the lorry travels 96 m, the car overtakes the lorry.

a) How many seconds later will the car overtake the lorry?

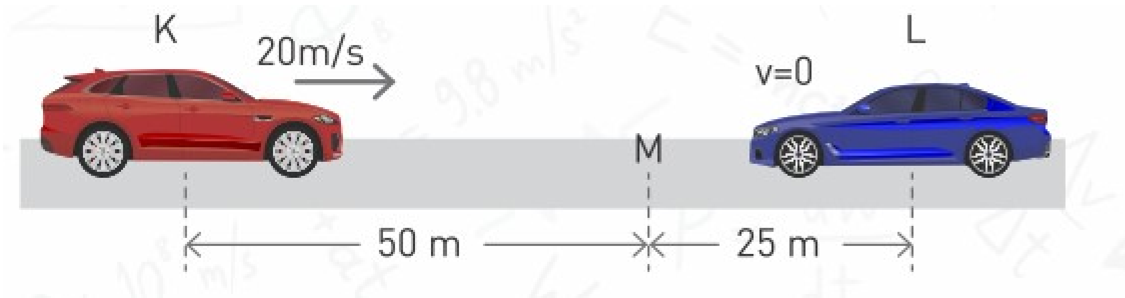
b) How many metres is the car behind the lorry at the start?

c) What are the velocities of the two vehicles when the car overtakes the lorry?

d) Draw the velocity-time, position-time, and acceleration- time graphs of each vehicle on the same coordinate axis. (Take the initial position to be zero for both of the vehicles.)

66. Vehicle L is at rest, and vehicle K is moving at a velocity of 20 m/s. When the distance between the vehicles is 75 m, K starts to slow down at a constant deceleration and, at the same instant,

L starts to speed up at a constant acceleration towards K. If vehicle K stops when the two vehicles meet at point M, as shown in the figure, what is the velocity of vehicle L at this point?



67. Ruslan and Veronica are two runners in a longdistance race. They are both moving at 4 m/s when Veronica is 18 m behind Ruslan. When Ruslan is 72 m away from the finish line, Veronica accelerates but Ruslan keeps moving at 4 m/s. What minimum acceleration is required by Veronica to overtake Ruslan and win the race?

68. Are the distances that a freely falling body travels, in equal time intervals of 1 s, equal?

69. If there were no air resistance, what sort of danger would await us on rainy days? If there were no air resistance, at what velocity would a rain drop strike the ground from a cloud of height 1200 m above the ground?

70. A stone is released freely from a tower of height 80 m.

a) How long does it take to reach the ground?

b) At what velocity does it strike the ground?

c) Calculate its velocity and height after 2 s.

71. An object, thrown upwards at υ_0, reaches a maximum height of 100 m.

a) Calculate the initial velocity υ_0.

b) Calculate the total flight time.

c) Calculate the height of the object when υ=30 m/s.

72. 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.

73. A stone is thrown upwards at 20 m/s from a bridge 60 m above sea level.

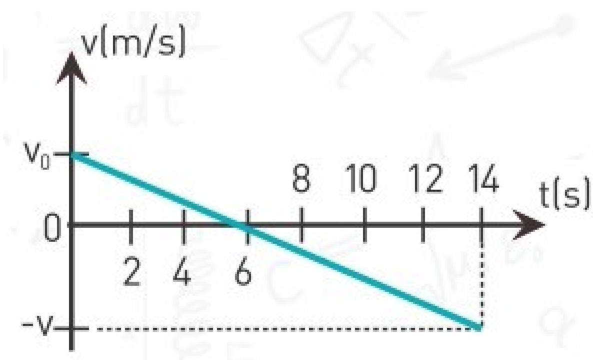
Calculate

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

74. The velocity-time graph of a stone thrown from the top of a building and striking the ground is as shown in the figure. How many metres high is the building?



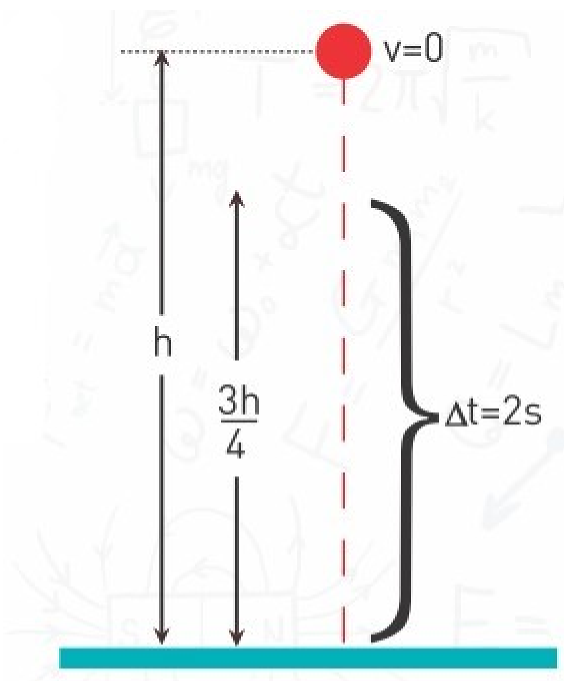
75. You can calculate a friend's reaction time in a simple experiment as follows: Hold a banknote (or a ruler) between your friend's fingers, just over his hand. Then ask your friend to catch it when you release it. What is the maximum reaction time possible to catch a 16 cm banknote?

76. A hot air balloon is rising at a constant speed of 10 m/s, as shown in the figure. An object is released from the balloon and falls freely. If the object falls to the ground in 8 s, find

a) The height of the balloon from the ground at the moment the object is released.

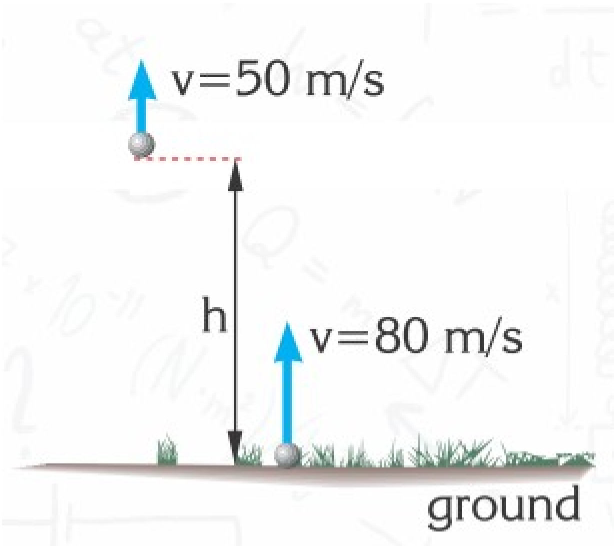
b) The velocity of the object at the moment it strikes the ground.

77. 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?

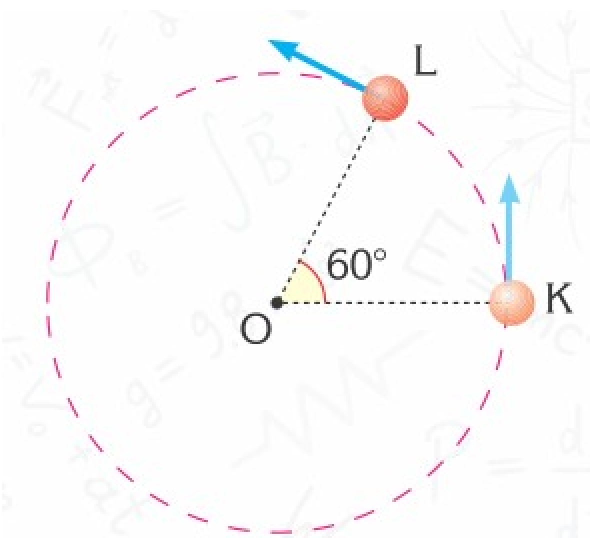


78. Two objects are released from the same height within a time interval of 1 s. How many seconds after the second object is released will the distance between the two objects be 20 m?

79. Two objects are thrown vertically upwards at the same time at speeds of 50 m/s and 80 m/s, as shown in the figure. What should the height, h, be so that both objects land at the same time?



80. An object exhibiting uniform circular motion, as shown in the figure, travels from point K to point L in 1s. Find the following parameters of circular motion



a) Period

b) Frequency

c) Angular speed

d) What is the tangential speed of the object if the radius of the circular motion is 0.5m? (Take π to be 3)

81. An engine rotates 3600 times per minute. Calculate the

a) period in seconds

b) frequency in Hertz

c) angular speed (Take π to be 3)

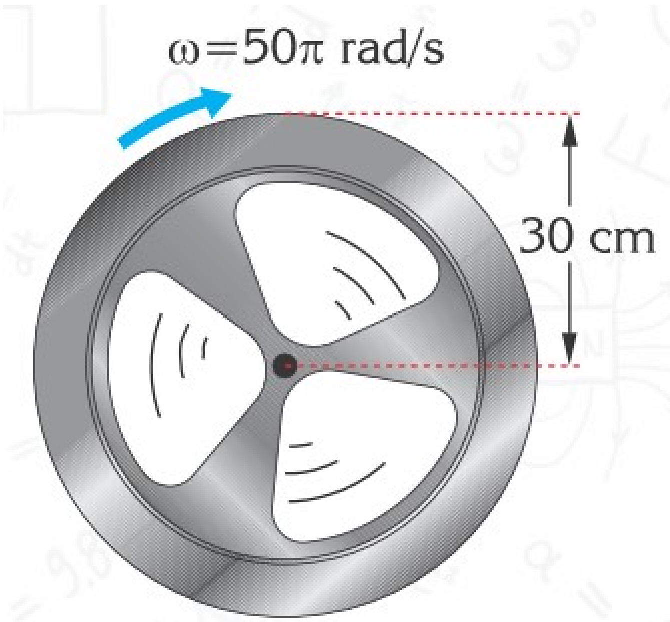
82. Calculate the periods and the frequencies of all hands (the hour hand, the minute hand and the second hand) of a table clock?

83. An iron wheel of radius 30 cm is rotating about an axis at an angular speed of 50 π rad/s, as shown in the figure, find

a) The frequency and the period of the wheel.

b) The tangential speed of a point 10 cm away from the axis of rotation

c) The tangential speed at the rim of the wheel. (Take π to be 3)



84. A drum of washing machine rotates with frequency of 800 rpm (revolutions per minute). Find:

a) period

b) frequency in Hertz

c) angular speed

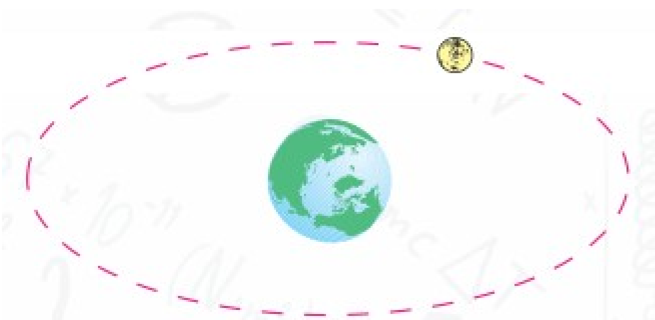
d) tangential speed if diameter of drum is 60 cm. Take $\pi=3$.

85. 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)

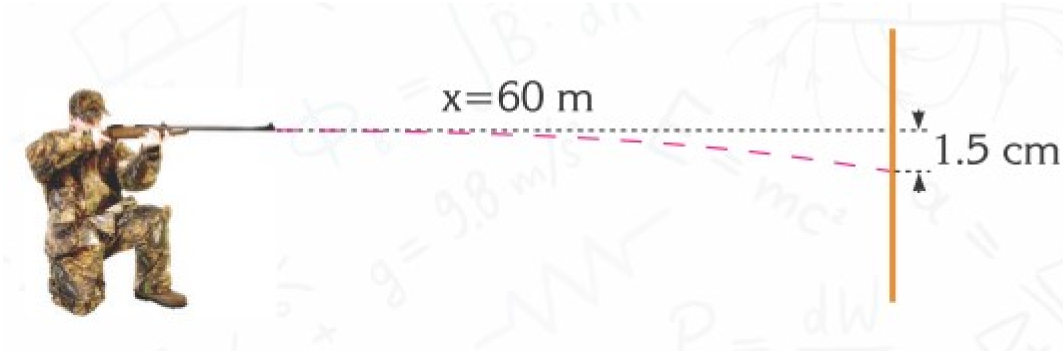
86. The period of the Moon orbiting the Earth is 27.3 days. If the Moon is 384 000 km away from the Earth, calculate its tangential speed. (Take π to be 3)



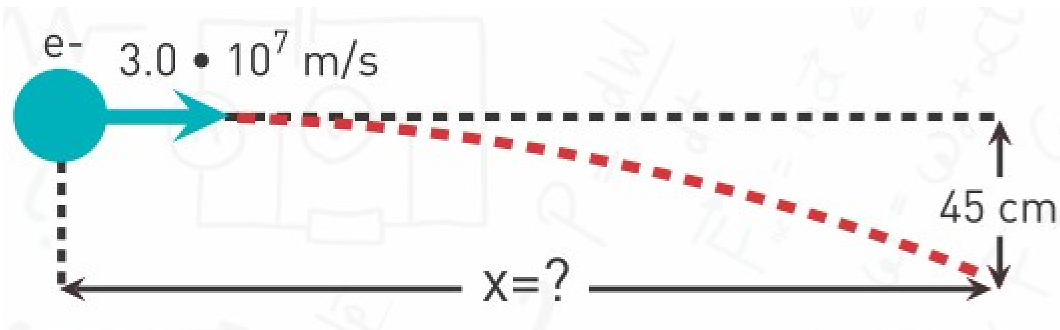
87. A rifle is aimed horizontally at a point 60 m away, as shown in the figure. The bullet misses the target and strikes the wall 1.5 cm below the target point. If the effects of air resistance are neglected

a) Calculate the time that the bullet remained in the air.

b) Find the bullet's muzzle velocity.

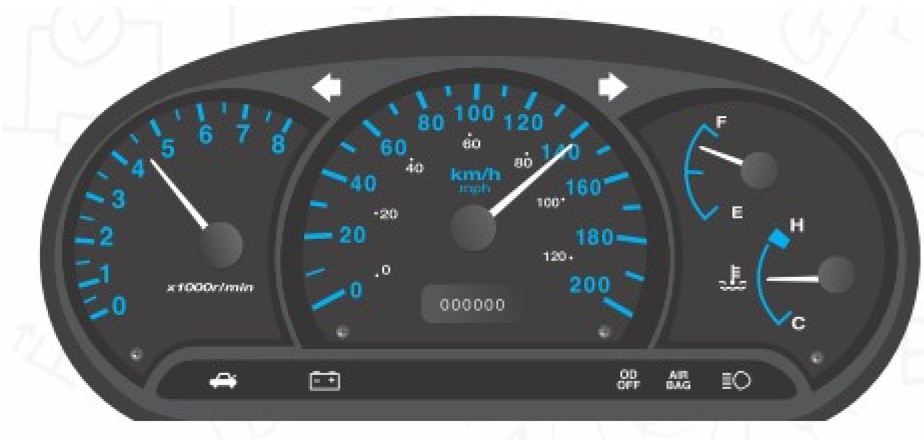


88. An electron is launched at a horizontal velocity of 3 · 10 7 m/s, as shown in the figure. How many metres should the electron travel in the horizontal direction in order to have a declination of 45 cm?



PHYSICS IN LIFE

1. What would happen if there were no dashboards in cars?



2. People of Botai culture were first to domesticate horses about 5400 years ago. What if they didn't have?

3. "Astana Pro Team" has one of the greatest accelerations. What is more important for "Astana Pro Team" - speed or acceleration?

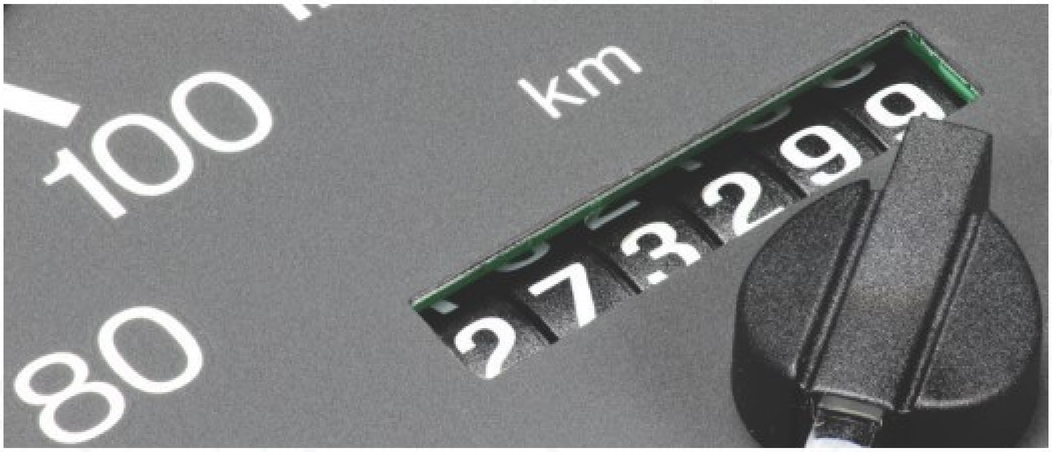
4. Smartphones have option of auto-rotation. How does it work?

5. Some cars can gain speed from 0 to 100 km/h in 3-4 seconds. Why do we measure this time?

6. The Earth moves around the Sun at a speed of about 30 000 m/s. Why don’t we feel it?

7. This device shows directions of planes. What if people didn't use these devices?

8. Odometer counts kilometres. What if it counted centimetres?



9. This road is inclined. What if it was horizontal?

CHAPTER 2. ASTRONOMY

2.1 STELLAR MAGNITUDE

2.2 CELESTIAL SPHERE

2.3 MOTION OF CELESTIAL OBJECTS. UTC

2.4 KEPLER'S LAWS. PARALLAX

2.1 STELLAR MAGNITUDE

You will

- tell the difference between absolute and apparent magnitude of a star;
- tell the factors that affect luminosity of star;

Question

How do astronomers discover new planets by using distant star's brightness?

Why are there stars in the sky? Why do stars emit light? How far away from us are stars?

These questions were asked by people from the beginning of history. By searching answers to these questions we understood many mysteries of world. We calculated age of
Universe, sent people into space and built space stations.

Astronomers study stars and other objects in the sky. Astronomers sort stars by colour and brightness. There are two types of brightness: apparent magnitude and absolute magnitude.

Apparent magnitude is the brightness of star as you see it in the sky. Apparent magnitude depends on distance. Near stars have higher apparent magnitude than the same but distant
stars.

Absolute magnitude is the true brightness of star. Absolute magnitude depends on temperature and area of star. If temperature and area of star are large then absolute magnitude is high.

Star is 2.5^1 times brighter than other star if difference between their apparent magnitude is 1.

Star is $2.5^2 = 6.25$ times brighter than other star if difference between their apparent magnitude is 2.

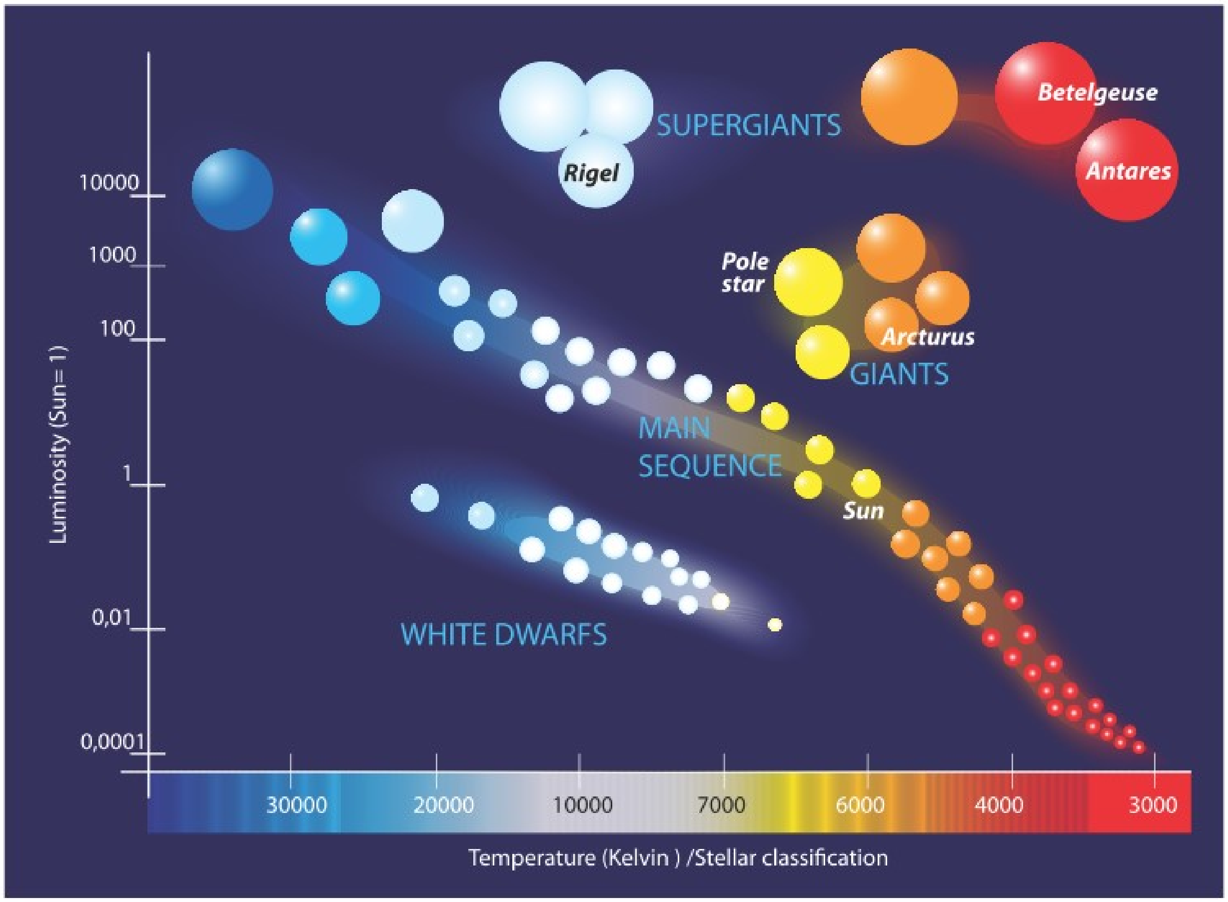
In the table there are apparent magnitudes from the brightest to the dimmest object.

Object in sky	Apparent magnitude
Sun	-27
Moon	-13
International Space Station	-6
Venus	-5
Jupiter	-3
Sirius (the brightest visible star in the night sky)	-1
Polaris	2
Pluto	14

Stars emit light because they burn hydrogen. The amount of light emitted by star is called luminosity. Luminosity depends on temperature of star and area of star.

Example

Compare the luminosity of Sun with Polaris in solar units.

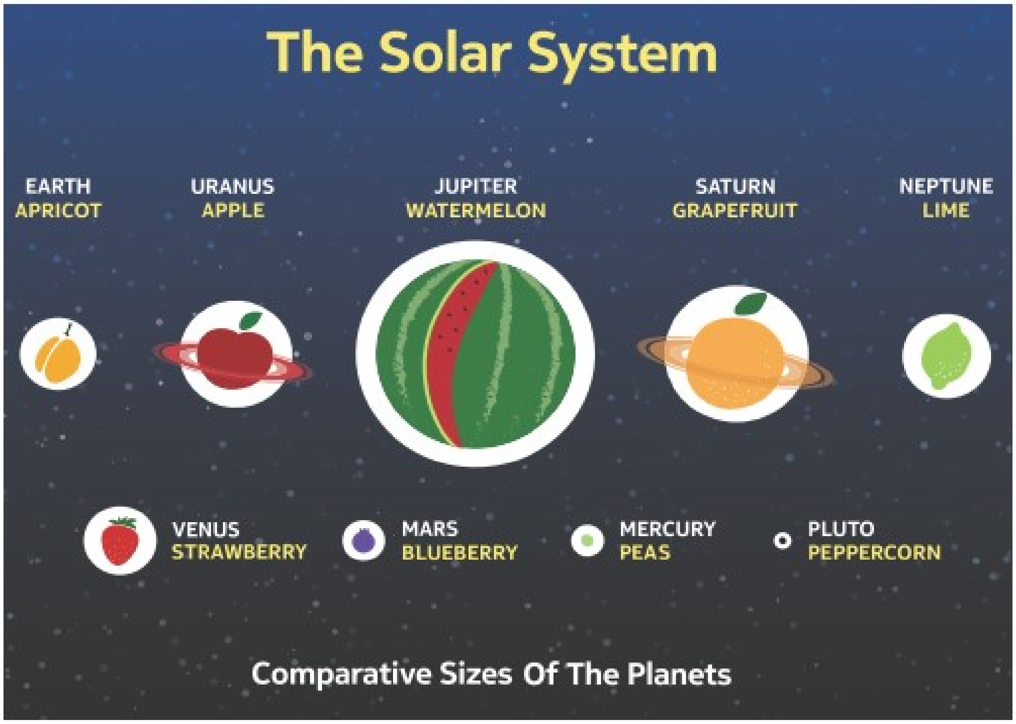


Solution:
Luminosity of Sun is 1 solar unit
Luminosity of Polaris is about 10^3 solar units
Luminosity of Polaris is nearly 1000 times greater than
Luminosity of Sun.

Activity

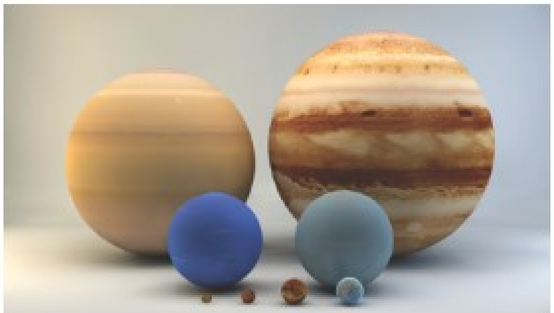
Use Stellarium to make table of apparent magnitudes of objects of Solar system and stars of “Big Dipper”. Arrange them by brightness.

Fact



Activity

Using information of our solar system make a video about “Solar system” in your school’s football stadium or in your room.



Terminology

apparent magnitude - көрінерлік жұлдыздық шама / видимая звездная величина
absolute magnitude - абсолют жұлдыздық шама / абсолютная звездная величина
luminosity - жұлдыздың жарқырауы / светимость небесного тела
contemporary - замандас / современник

Art time

Use concepts of “apparent magnitude” and “absolute magnitude” to write two opinions about Abay. One opinion by modern person and second opinion by contemporary of Abay.

Literacy

1. Why do we use “absolute magnitude” and “apparent magnitude” for stars?

2. Why do we observe and study stars?
3. Which star is brighter, Sirius or Polaris? How many times is it brighter? Apparent magnitude of Sirius is -1, apparent magnitude of Polaris is 2.
4. Why don't we see stars during day?

Research time

Make list of stars in Kazakh, Russian and English languages. Research stories about Kazakh names of stars. How do these stories relate to culture and history?

2.2 CELESTIAL SPHERE. CELESTIAL COORDINATE SYSTEMS

You will

- tell basic elements of celestial sphere;
- determine celestial coordinates by using planisphere;

Question

You can see star trails on long exposure photograph. Which star does not move in night sky? Why?

How can you find your city on the map? What numbers do GPS show?

These numbers are called latitude and longitude. They are used to denote position of any object on the Earth.

Similarly position of stars is denoted by two numbers. By using these numbers we determine position of stars in the night sky.

We use two celestial coordinate systems: equatorial and horizontal (azimuthal).

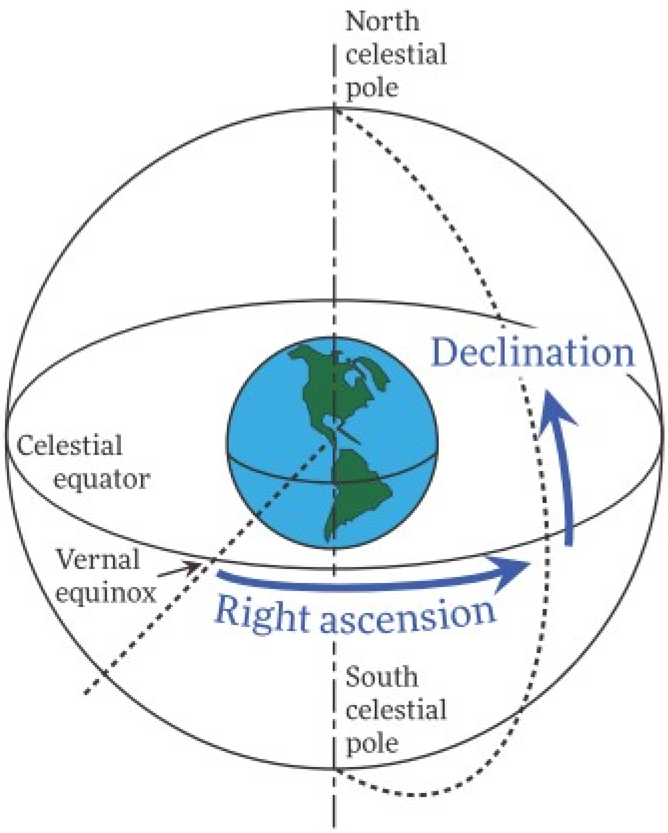
Equatorial coordinate system uses two numbers: declination (latitude) and right ascension (longitude).

Declination is 0° at equator and 90° at pole. For example, declination of Polaris is +89°. That means Polaris shows North Pole.

Right ascension is an angle from vernal equinox to the star in eastward direction. Right ascension is measured in hours, minutes and seconds.

360°= 24 hours

15°=1 hour = 60 minutes = 3600 seconds



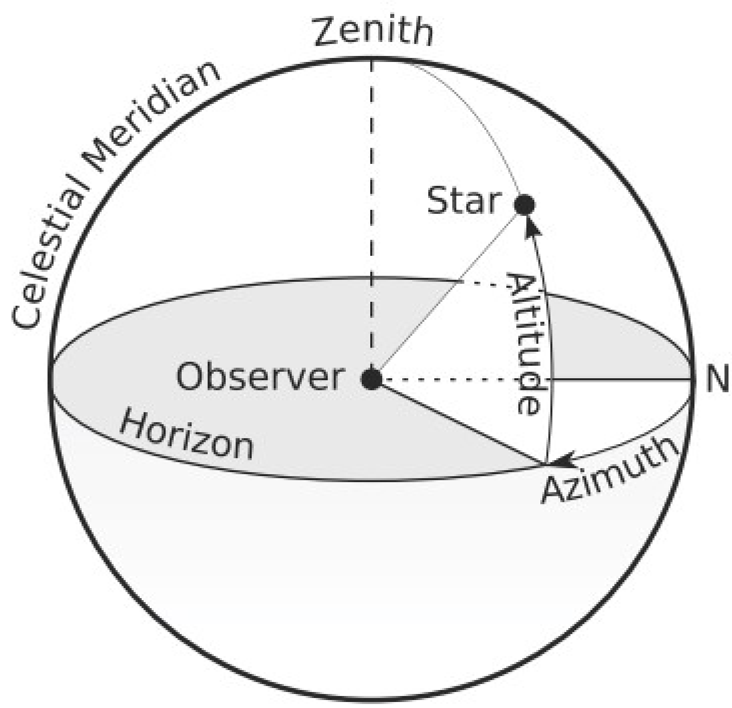
Horizontal (azimuthal) coordinate system uses two numbers: altitude and azimuth.

Altitude is 0° at horizon and 90° directly above you.

Azimuth is 0° at North and increases to the eastward direction.

Celestial coordinate systems do not consider distance to the stars. Instead, we think that all stars are located on imaginary sphere with infinite radius.

These imaginary sphere is called celestial sphere.



Example

Use Stellarium or planisphere to determine right ascension and declination of Capella, Vega and Arcturus. Also determine azimuth and altitude at the current time.

Solution:
VEGA
RA/ Dec (32000.0): 18h36m56.48s/+38°47’07.2”
Az/Alt: +54°27’52.2”/+19°25’14.3” (apparent)

Research time

What is the purpose of Fesenkov Astrophysical Institute (aphi.kz)? Why did we build Fesenkov Astrophysical Institute? What should you do to work in Fesenkov Astrophysical Institute?

Activity

Make your own "planisphere" (star wheel). Learn to use planisphere and study night sky by using planisphere.

Literacy

1. Why do we use "equatorial coordinate system" and "horizontal coordinate system"? What is difference between them? Which one is better?
2. Change "right ascension" of 6 hours 45 minutes 55 seconds to degrees, arcminutes and arcseconds.
3. Change 46 o 45'15'' to hours, minutes, seconds.
4. Use "Stellarium" software to fill this table.

Name	Apparent magnitude	Right ascension	Declination	Distance from Sun
Polaris				
Sirius				
Vega				
Sun				
Moon				
Venus				
Jupiter				
Mars				
Saturn				

5. Use table to determine the brightest object and the farthest object.

Fact

First patented telescope was made in 1608 in Netherland by Hans Lippershey.

Art time

Make “light painting” about some topic of astronomy (or long-exposure photo of night sky).

Terminology

vernal equinox - наурыз, көктемдегі күн мен түннің теңелуі / весеннее равноденствие
celestial - аспанмен байланысты / небесный
planisphere - жұлдызды аспанның жылжымалы картасы / подвижная карта звездного неба
trail - із / след
latitude - ендік / широта
longitude - бойлық / долгота
declination - еңістік / склонение
right ascension - тура көтерілу / прямое восхождение
altitude - шырақ биіктігі / высота светила
azimuth - азимут / азимут
imaginary - қияли / воображаемый

2.3 MOTION OF CELESTIAL OBJECTS. COORDINATED UNIVERSAL TIME (UTC) AND TIME ZONES

You will

- explain difference in culmination at different latitudes;
- tell the difference between local time, time zone and UTC time;

Question

How did sailors in the past navigate the oceans (without GPS and compass)?

a) Sailing without compass

Use Stellarium and look at motion of stars from the North pole, from equator and from Astana.

What is the difference between motion of stars?

Stars rise and set. Their maximum altitude is called culmination.

Sailors used maximum altitude to determine latitude of their location. Sailors used astrolabes, quadrants and sextants to measure altitude. Then latitude can be found by this formula:

$$\text{Latitude} = 90° + \text{Declination} - \text{Altitude}$$

Sailors usually sailed to correct latitude and then sailed east or west to their destination.

b) Time zones

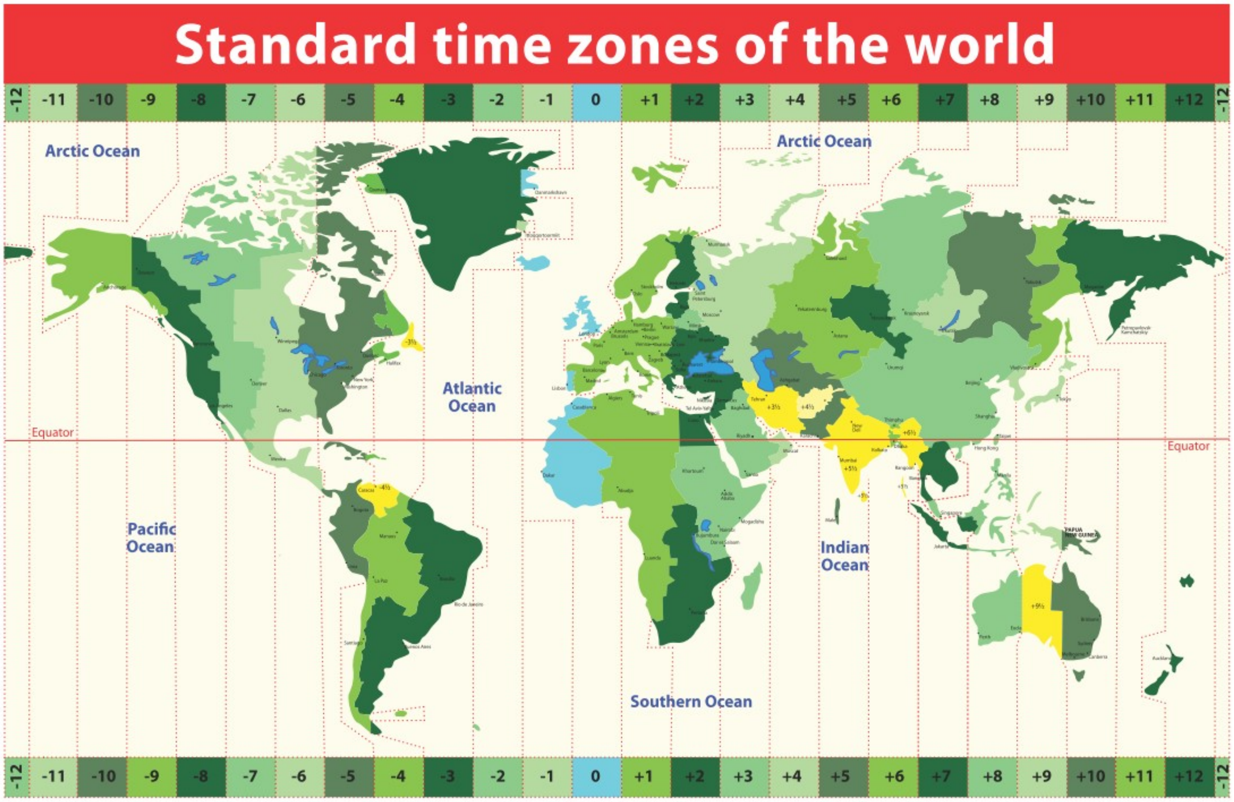
Let's say you have train ticket from Aktobe to Astana. Time of departure on the ticket is 12:30. You arrive at train station at 12:00 but train already departed. Why?

Time in Aktobe is UTC+5 and time in Astana is UTC+6. Difference between them is one hour. That means when Aktobe time is 12:00 then Astana time is 13:00.

UTC is "Coordinated Universal Time". UTC+0 is time zone of Royal Observatory in Greenwich, London. Before UTC there was GMT (Greenwich Mean Time).

On the figure you can see time zones of the world. There are two time zones in Kazakhstan: UTC+5 and UTC+6.

Aktobe, Atyrau, Mangystau and Oral are in UTC+5 time zone. Other cities of Kazakhstan are in UTC+6 time zone.



Terminology

navigate - бағыттау / направлять
destination - баратын жер / пункт назначения
departure - сапарға шығу / отъезд
royal - корольдік / королевский
mean - орташа / среднее
offset - ығысу / смещение

Activity

Install “astronomy app” on smartphone or tablet. Then use smartphone or tablet to determine positions of stars (Polaris, Sirius, Vega, etc.), planets (Venus, Jupiter, Mars, Saturn, etc.) and other celestial objects. Then at night use telescope to observe these celestial objects. Also take pictures of these celestial objects.

Example

Determine time in Astana and fill the table.

City	UTC offset	Time in that city	Time in Astana (UTC+6)
Berlin	UTC+1	10:00	
Tokyo	UTC+9	19:00	
Toronto	UTC-5	16:00	
Hawaii	UTC-10	23:00	
Lisbon	UTC+0	07:00	
Sydney	UTC+10	22:00	
Rio de Janeiro	UTC-3	05:00	
Petropavlovsk - Kamchatsky	UTC+12	03:00	

Solution:
Difference between time zones of Astana and Berlin is 5 hours. That means Astana time is 15:00 when Berlin time is 10:00.
Difference between time zones of Astana and Tokyo is 3 hours. That means Astana time is 16:00 when Tokyo time is 19:00.
Difference between time zones of Astana and Toronto is 11 hours. That means Astana time is 03:00 when Toronto time is 16:00.

Art time

Make “quadrant” or “astrolabe” and determine latitude of your home (or school). Use Internet to check your answer.

Literacy

1. You are on trip in Chicago (UTC-6). Your parents wait you to call at 20:00. At what time in Chicago do you call them?
2. Why do we use “time zones”?
3. Why do we use “Coordinated Universal Time (UTC)”? Are there any alternatives?

4. What is “altitude” of Polaris on North Pole (or on equator)?

Research time

How did railways and telegraph affect time zones? How would your life look like if there were no time zones? How would trains and airplanes travel if there were no time zones?

2.4 KEPLER'S LAWS. PARALLAX

You will

- explain motion of celestial bodies by using Laws of Kepler;
- explain parallax method of determining distances and dimensions of objects of Solar system;

Question

We did not send somebody or some device to distant stars. Then how do we measure distances to stars?

a) Kepler's Laws

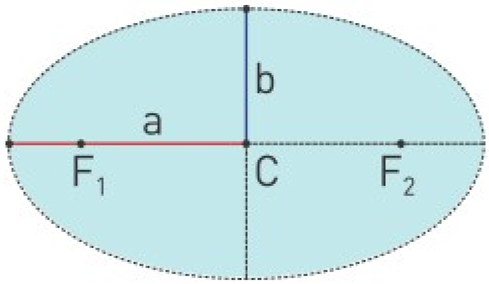
Before Johannes Kepler (1571-1630) people thought that:

1. Planets rotate around the Sun in circular path (circle)
2. Sun is at the centre of circle
3. Speeds of planets are constant.

Kepler observed night sky and studied motion of stars and planets. Then he made these corrections:

1. Planets rotate around the Sun in elliptical path (ellipse)
2. Sun is at the focal point of ellipse
3. Speeds of planets are not constant.

In the figure you see ellipse. F_1 and F_2 are focal points of the ellipse. a is semi- major axis of the ellipse. b is semi-minor axis of the ellipse.

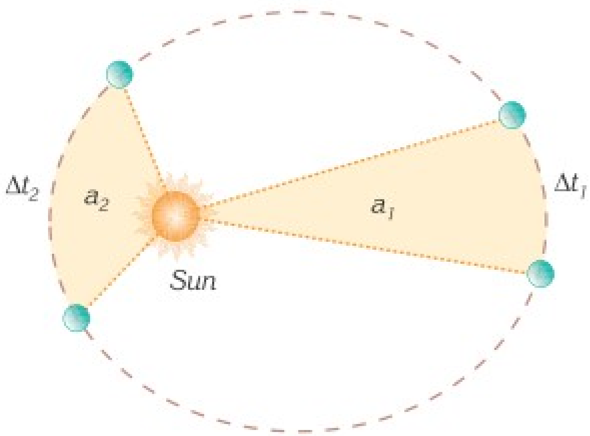


By using these corrections Kepler discovered laws of planetary motion:

1. Planets' orbits are ellipses and Sun is at the focal point of ellipse.
2. Planet covers equal areas in equal time intervals (speed is greater near Sun, speed is lower far from Sun).

$$v_1 r_1 = v_2 r_2$$

In the figure area a_1 is equal to area a_2, time Δt_1 is equal to time Δt_2.

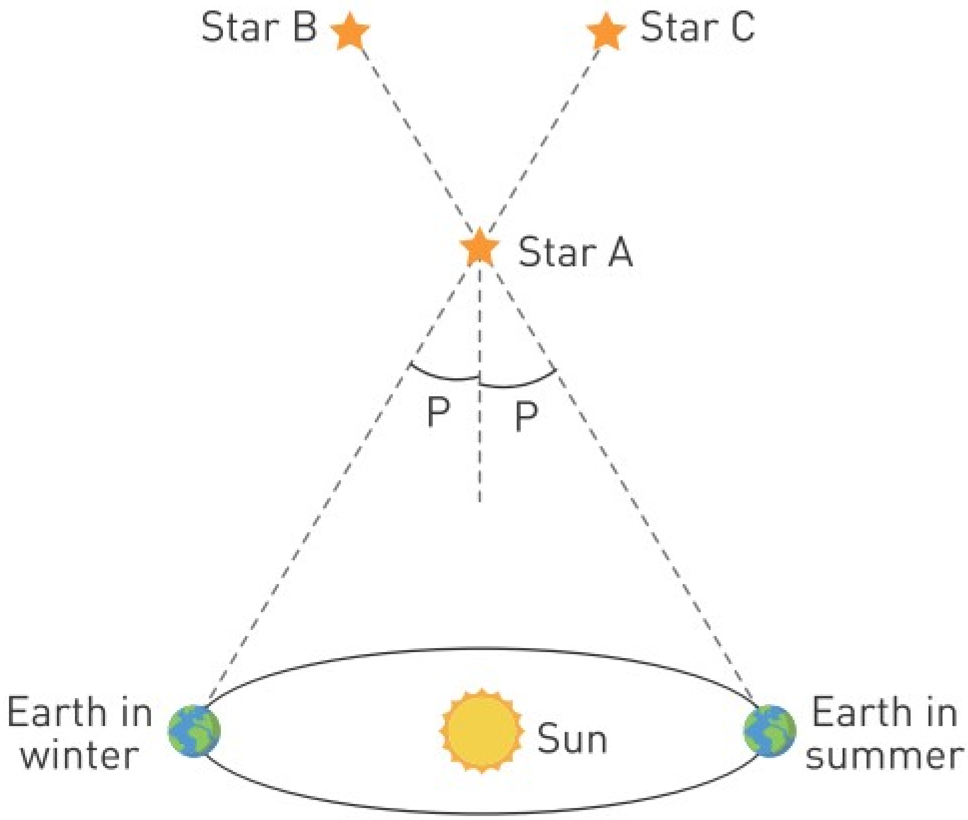


3) Square of period is proportional to cube of semi-major axis.

$$\frac{T_1^2}{T_2^2} = \frac{a_1^3}{a_2^3}$$

b) Parallax

Parallax is used to determine distance to stars. In the figure you see astronomer that looks at star A in winter. Behind star A astronomer sees star C. Then astronomer looks at star A in summer. Behind star A astronomer sees star B.



Next, astronomer measures angle of parallax p in arcseconds. 1 degree equals 3600 arcseconds (1°=3600"). Distance (d) to the star can be found by formula:

$$d\ (parsec) = \frac{1}{p\ (arcsecond)}$$

1 parsec = 1 pc = 3.09×10^{16} meters

Example

Parallax of Sirius is 0.37921". What is distance to Sirius in parsecs, light years and meters? One light year is about 9.46×10^{15} meters. One parsec is about 3.09×10^{16}meters.
Solution:

$$d = \frac{1}{p} = \frac{1}{0.37921} = 2.63706\ parsec$$

$$2.64\ \text{pc} \simeq 8.15\times10^{16}\ \text{meters} \simeq 8.6\ \text{ly}$$

Literacy

1. Use "Stellarium" software to write parallax angles of Polaris, Sirius and Vega. Determine distances to these stars in parsecs and light years. Use Internet to check your answers.
2. Use "Stellarium" software to write distances from Sun for Mars, Jupiter, Saturn and Uranus. Determine "year" for each planet.
3. What would happen to space flights and satellites if Kepler's laws were not discovered?

Art time

Make theater play about Kazakh astronomical myths.

Fact

Having two eyes help us perceive the depth and 3D.

Figure 1

Activity

Use Stellarium to write down sidereal periods of Mercury, Venus, Mars, Jupiter, Saturn, Neptune, Uranus. Then use Kepler's 3 rd law to determine orbits of planets.

Terminology

focal point - фокус / фокус
semi-major axis - үлкен жарты ось / большая полуось
sidereal period - жұлдыздармен салыстырмалы период / период относительно звезд

Research time

Research inventor of parallax method.

SUMMARY

2.1. There are two types of brightness: apparent magnitude and absolute magnitude.
Apparent magnitude is the brightness of star as you see it in the sky. Apparent magnitude depends on distance. Near stars have higher apparent magnitude than same but distant stars.
Absolute magnitude is the true brightness of star. Absolute magnitude depends on temperature and area of star. If temperature and area of star are large then absolute magnitude is high.
2.2. We use two celestial coordinate systems: equatorial and horizontal. Equatorial coordinate system uses two numbers: declination (latitude) and right ascension (longitude).Horizontal coordinate system uses two numbers: altitude and azimuth.
Celestial coordinate systems do not consider distance to the stars. Instead, we think that all stars are located on imaginary sphere with infinite radius. These imaginary sphere is called celestial sphere.
2.3. Sailors used maximum altitude to determine latitude of their location. Sailors used astrolabes, quadrants and sextants to measure altitude.
Latitude = 90°+ Declination - Altitude
UTC is “Coordinated Universal Time”.
UTC+0 is time zone of Royal Observatory in Greenwich, London. Before UTC there was GMT.
2.4. By using these corrections Kepler discovered laws of planetary motion:

1. Planets’ orbits are ellipses and Sun is at the focal point of ellipse
2. Planet sweeps equal areas in equal time intervals (speed is greater near Sun, speed is lower far from Sun)
3. Square of period is proportional to cube of semi-major axis.

Parallax is used to determine distance to stars.

$$d\ (parsec) = \frac{1}{p\ (arcsecond)}$$

P R O B L E M S

1. Knowing Earth radius (6400 km) and Moon's parallax p=57' find distance to Moon.

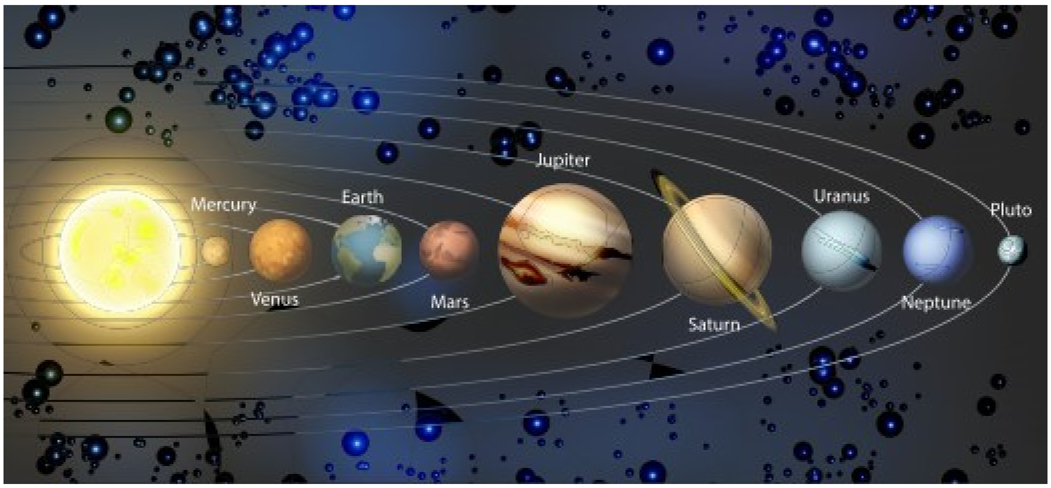
2. If Sun's and Moon's angels are the same and using parallax of them (8.8'' and 57'), find the ratio between Moon's and Sun's radiuses

3. Rings of Saturn are seen from distance of 1.3 . 10^9 km with 40'' degree. What is approximate diameter of rings?

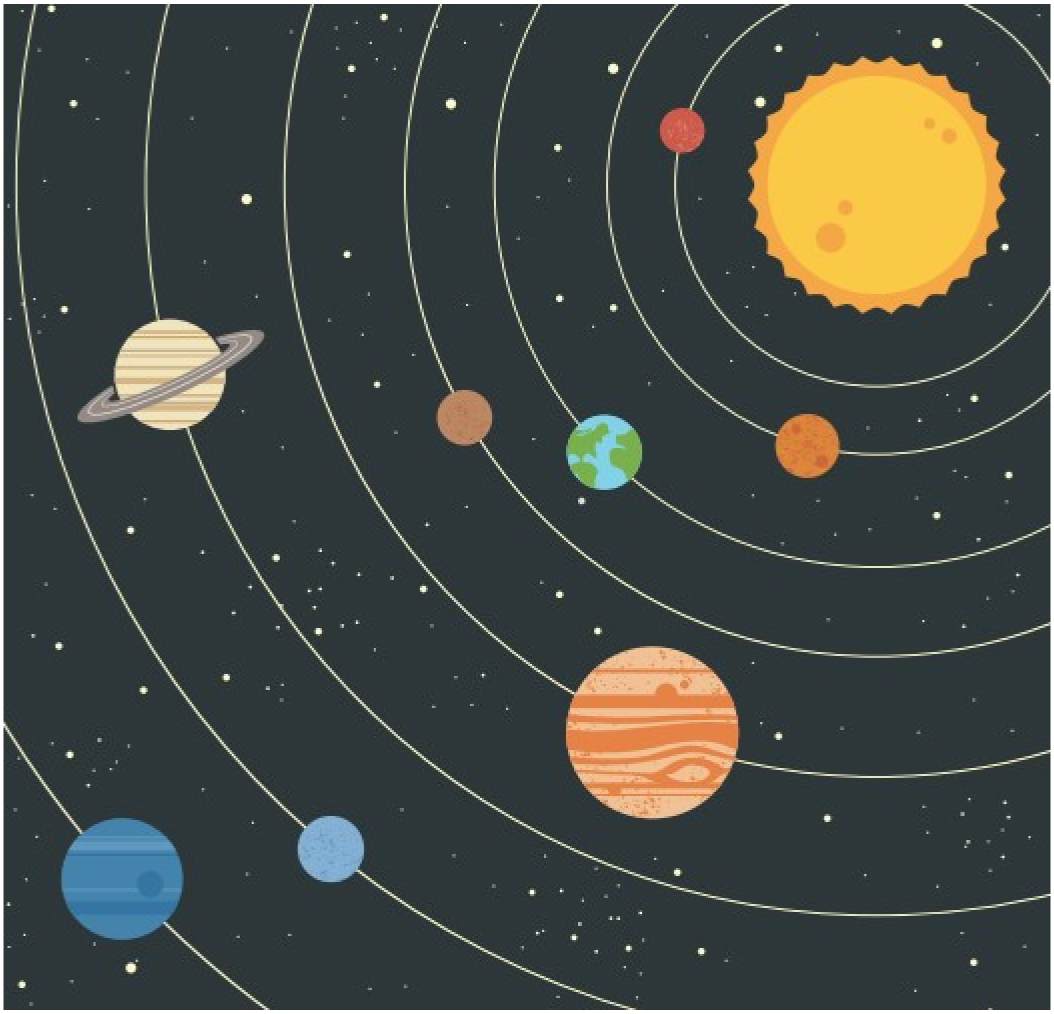
4. What is the parallax of the star if distance to star is 100 pc (parsec)?
5. What is parallax angle ?
6. What factors affect luminosity of star?
7. What is the brightest object in our solar system?
8. What is the dimmest object in our solar system?
9. What parameters determine the position of the star?
10. What kind of celestial bodies do you know?
11. Change 26°45 ’11’’ to hours, minutes, seconds.
12. Change “right ascension” of 2 hours 2 minutes 2 seconds to degrees, arcminutes and arcseconds.
13. What are Kepler's laws of planetary motion?

PHYSICS IN LIFE

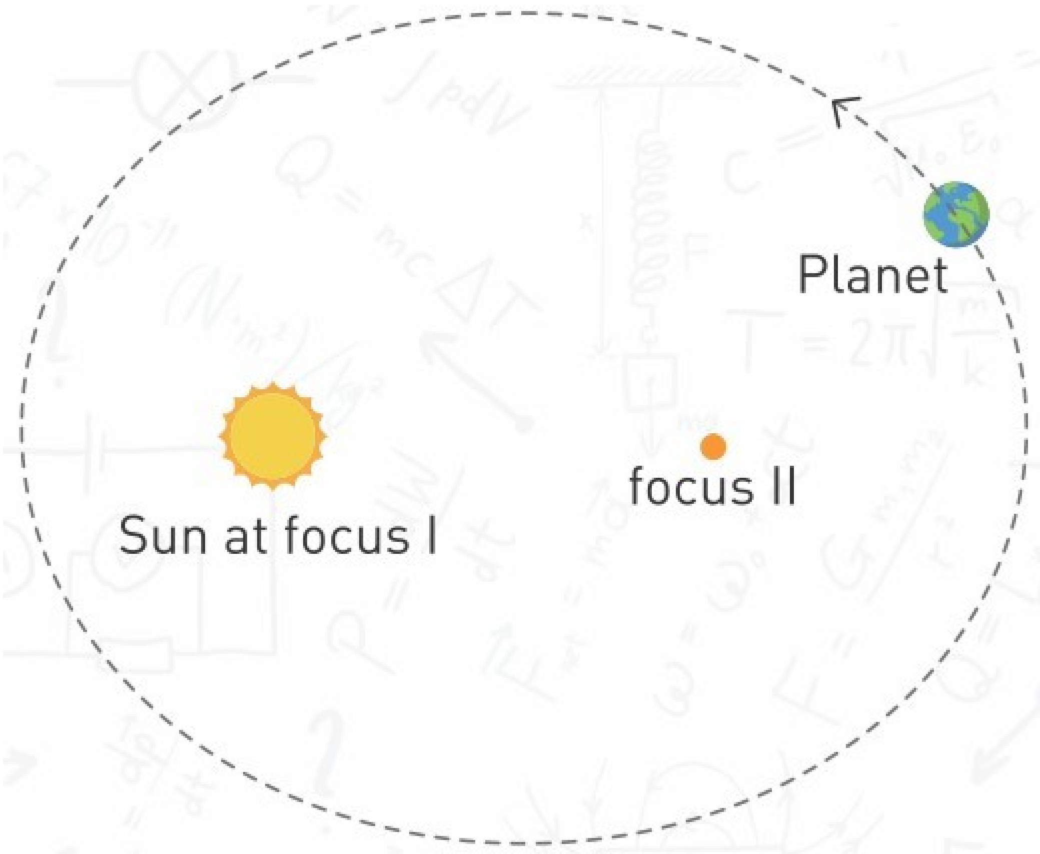
1. Mercury is closer to the Sun but colder than Venus. Explain why it so.



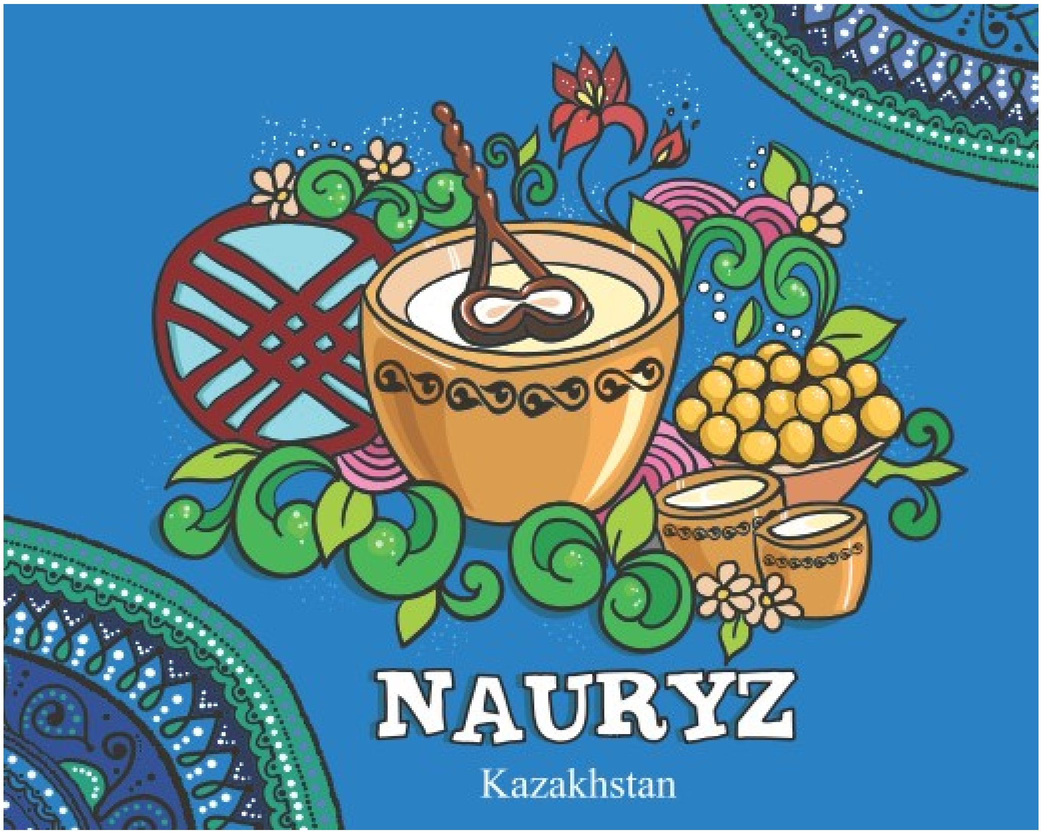
2. Even if you are not moving, you are in motion. Why is it true?



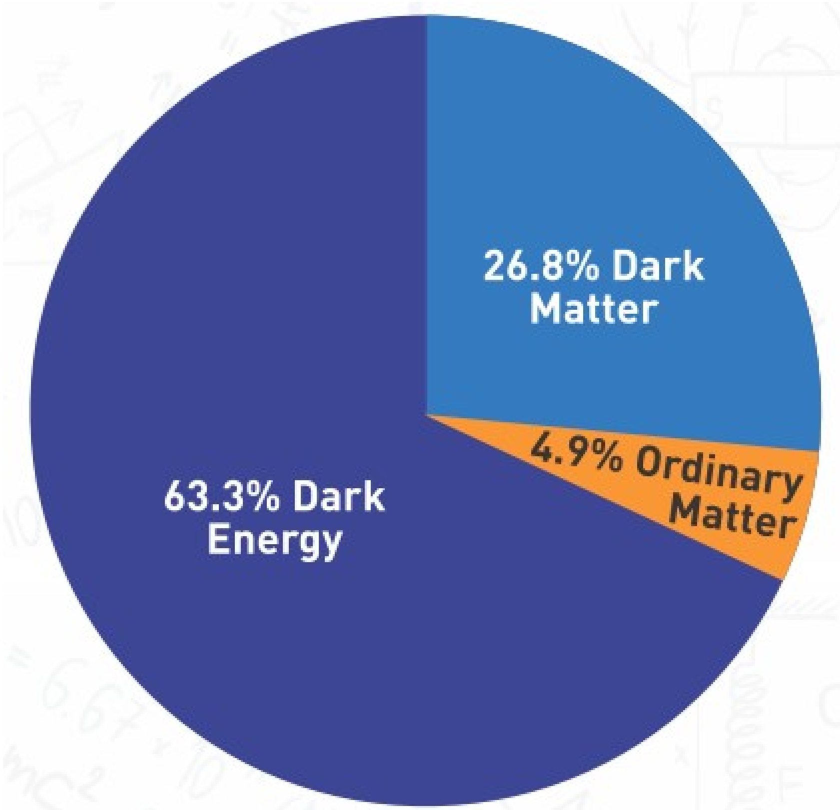
3. According to Kepler's law the Sun is not in the center of orbit. How can you prove this law?



4. Nauryz has been celebrated by many cultures of the Middle and Central Asia. Why is Nauryz on 22nd of March?



5. Dark energy is 68.3% of energy and matter. Why do we use term “dark energy”?


26.8% Dark Matter
4.9% Ordinary Matter
63.3% Dark Energy

CHAPTER 3 Force

3.1 FORCE

3.2 FIRST LAW OF NEWTON

3.3 SECOND LAW OF NEWTON

3.4 THIRD LAW OF NEWTON

3.5 APPLICATIONS OF NEWTON'S LAWS

3.6 PROBLEM SOLVING (NEWTON'S LAWS)

3.7 WEIGHT AND ACCELERATION

3.8 WEIGHTLESSNESS

3.9 UNIVERSAL LAW OF GRAVITATION

3.10 PROBLEM SOLVING

3.11 SATELLITES

3.12 MOTION OF SATELLITES

3.13 PROBLEM SOLVING

3.1 Force

You will

explain nature of weight, elastic force and friction force;

Question

What does happen if gravity disappears for one hour? Describe changes in your life.

Force is any push or pull. Unit of force is Newton [N].We use forces almost every day. For example, Figure 1.

Figure 1

There are many types of forces.
In this topic we will discuss 3 types of forces.

Gravitational force and weight

The gravitational force is the mutual force of attraction between any two objects in the Universe. The magnitude of the gravitational force acting on an object of mass m near Earth's surface is called the weight, W, of the object, given by

$$\vec{W} = m\vec{g}$$

W- weight [N]
m - mass [kg]
g - acceleration of gravity [m/s^2] or [N/kg]

On the Earth g is approximately 9.8 N/kg. For simplicity we use 10 N/kg. Gravitational acceleration is not always constant. It decreases as the distance from the planet increases, Figure 2.

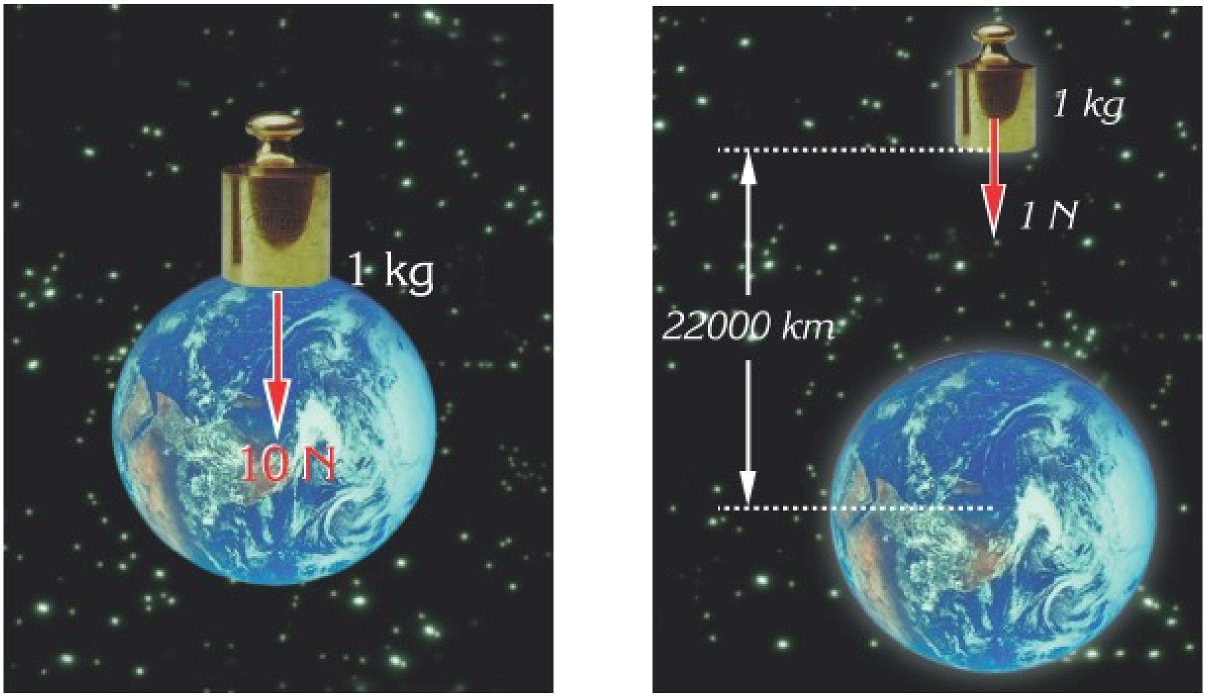


Figure 2

Gravity is unique for each planet. Each planet in the Solar system has its own g.

Elastic force

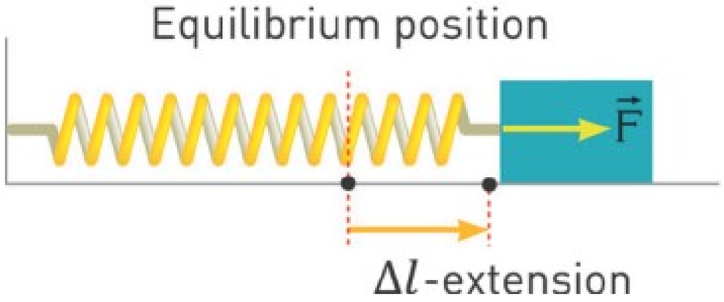
Force in elastic objects, Figure 3.

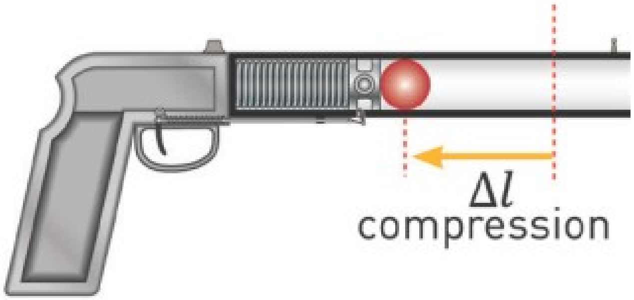
Figure 3.

Springs are commonly used in daily life. The formula of spring's elastic force is

$$\vec{F} = k\overrightarrow{\Delta l}$$

F- force of spring [N]
k - spring constant [N/m]
Δl - extension or compression of spring [m]
Minus sign indicates opposite direction to the force applied.





Friction force

This type of force is always against the motion. Friction is produced because surfaces of objects are not smooth on microscopic level, Figure 4.

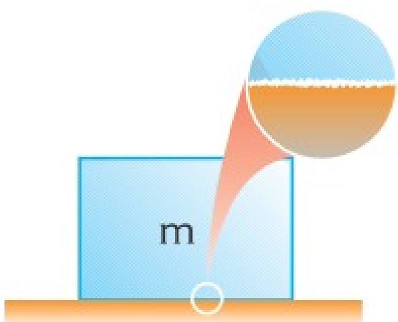
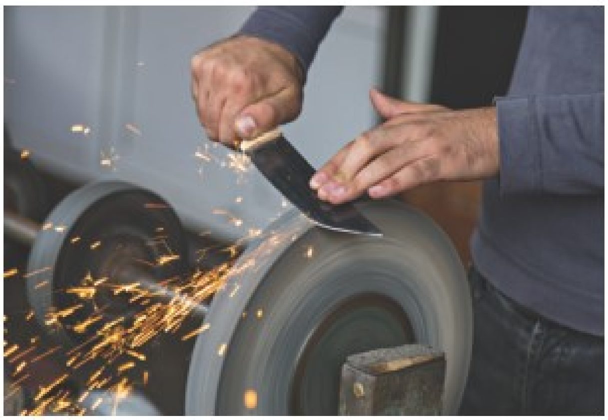


Figure 4

Sometimes friction is harmful. Mechanisms, Figure 5a, break faster because of friction. Sometimes friction could be useful. For example, knife sharpening, Figure 5b.

a



b

Figure 5

Activity

a) Match the words to their definitions.

1. Force a. to move something away from you
2. Motion b. the action of moving or changing position
3. Pull c. an object pushing on another object slowing it
4. Push d. To move or haul something towards yourself
5. Friction e. A push or a pull

b) Design a situation where weight, elastic force and friction force are involved. NOTE: don't draw 3 different cases. Draw all in one example.

c) Draw 3 examples when friction is harmful. Draw 3 examples when friction is useful.

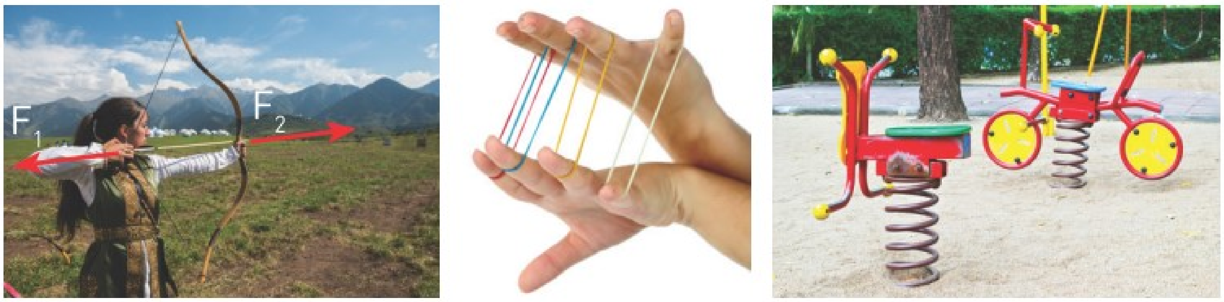


Figure 3

Literacy

1. "Friction is always against motion. It is better to live without it." What do you think about this statement? How would the world be without friction?
2. Why does Moon rotate around Earth? Why doesn't Moon fall on the Earth?

Terminology

to disappear - жоғалып кету / исчезнуть
to push - итеру / толкать
to pull - тарту / тянуть
field - өріс / поле
extension - ұзару / удлинение
compression - сығылу / сжатие
friction - үйкеліс / трение
approximately - шамалап / приблизительно
commonly - әдетте / обычно
spring constant - серіппе қатаңдығы / жесткость пружины
smooth - тегіс / гладкий

Art time

Make “micrography” (microcalligraphy) about types of forces.

Research time

Let students observe forces by going to a park, playground or natural area. How many different examples of forces can students see?

3.2 FIRST LAW OF NEWTON

You will

- explain the meaning of such concepts as inertia and inertial frame of reference;
- define Newton's first law and use it for problem solving;

Question

You drive a car. Why does not car stop immediately when you turn off motor?

When a bus suddenly starts moving, you may feel something as on, Figure 1a. When the bus suddenly stops, you may feel something as on, Figure 1b (arrow is a direction of movement).

Figure 1

This is called inertia. Inertia is a property of object to continue its existing state of motion. If resultant force acting on object is zero, then:
1. If body is at rest, it continues to be at this state.
2. If body is in motion, it continues to be at this state.
These properties also called Newton's first law of motion. Let us summarise this in a Table 1.

Resultant force acting on a body is not zero. $\vec{F}_{resultant} \neq 0$	Resultant force acting on a body is zero. $\vec{F}_{resultant} = 0$
State changes: Speed changes	State doesn't change: a) Constant speed b) Speed is zero

Table 1

Mass is measure of inertia of matter. The greater the mass, the more difficult to change the state of an object. For example, Figure 2.

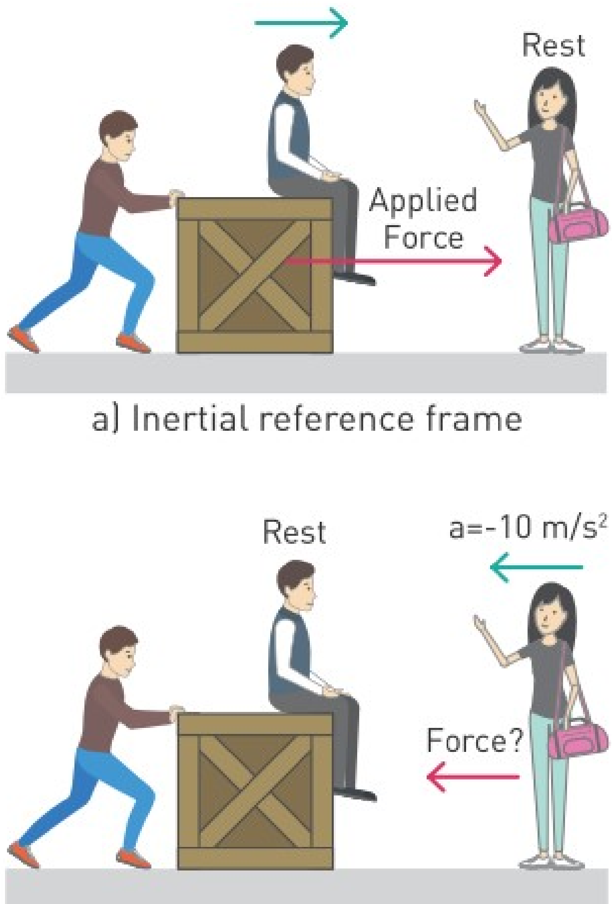
Figure 2

Inertial and Non-inertial reference frames

The man moves with acceleration of 10 m/s^2 relative to the girl standing on the ground, Figure 3a. The girl says “Hey there! You are moving with acceleration. Then, there must be a force pushing you”. The man says “Yes! You are right!”

Now let us think relative to the man: we change reference frame, Figure 3b. The man says “Hey there, you are moving with acceleration. Then, there must be force that pushes you”.

However, the girl says that “no, there is no force that pushes me”.



a) Non-inertial reference frame

Figure 3

This happens because our reference system “the man” moves with acceleration itself. Such system is called non-inertial reference frame. If system “the girl” does not have acceleration and move in straight line, as on the Figure 1a, then it is called inertial reference frame.

Example

A toy car and real train move with same speed. Which one would be easier to stop? Why?

Solution:
It would be easier to stop a toy car. Because it has much less mass than train. Mass is a measure of inertia. Hence, a toy car has small inertia. The smaller the inertia, the less force it requires to stop.

Activity

Fill in the blanks. You can use following words:
straight, inertia, motion, speed, friction, laws, force, rest.
1. One example of an outside force that slows down moving objects is ___________.
2. Newton's first law states that an object in motion will stay in ___________.
3. Newton said that a moving object will travel at a steady ___________.
4. Objects stay at rest or in motion until outside ___________ interferes.
5. When an object is not moving, it is at ___________.
6. A moving object will go in a ___________ line.
7. Isaac Newton described how objects behave with his ___________ of motion. Another name for Newton's First Law of Motion is: the law of ___________.

Research time

Investigate the motion of jars or bottles on the different surfaces.
Answer the following questions.

Race	Surface	How far did the empty jar travel?	How far did the filled jar travel?
1	Wooden Floor		
2	Carpet		
3	Linoleum		
4	Tile Floor		
5	Other (____________)		

1. Did the results depend on whether the jar was filled with sand (water)? If so, in what way?
2. Did the results depend on the type of surface you used? If so, in what way?

Literacy

1. One person pushes crate to the north with 200 Newtons. Second person pushes same crate to the south with 200 Newtons. Where does crate move?
2. Crate moves to the east with 2 m/s. In which direction do you need to push crate to stop it?

Art time

Make video that shows “First Law of Newton”.

Terminology

immediately - дереу, шұғыл / немедленно
to require - талап ету / требовать
state - күй / состояние
resultant force - теңәрекетті күш / равнодействующая сила
interfere - араласу / вмешиваться
cabin - каюта / каюта
crate - жәшік / ящик

Fact

Let us say you are in ship cabin that has no windows. You cannot feel motion of ship if ship moves with constant speed.

3.3 SECOND LAW OF NEWTON

You will

define Newton's second law and use it for problem solving;

Question

Discus has a mass of 2 kg, shot is 7.26 kg, javelin is 800 g. Which object does athlete throw as the fastest one? Why?

First law of motion: you can change the speed of an object only by force. How fast can that change be? The answer to this question is given by Newton’s second law motion. The formula of this law is

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

$\vec{F}$ - resultant force acting on an object [N]
m - mass of the object [kg]
$\vec{a}$ - acceleration of the object [m/s^2]

The meaning of the formula: acceleration is produced due to the resultant force. The greater the force, the greater the acceleration. However, if you apply same forces on a light object and a heavy object, the light one will have greater acceleration. For example, Figure 1.

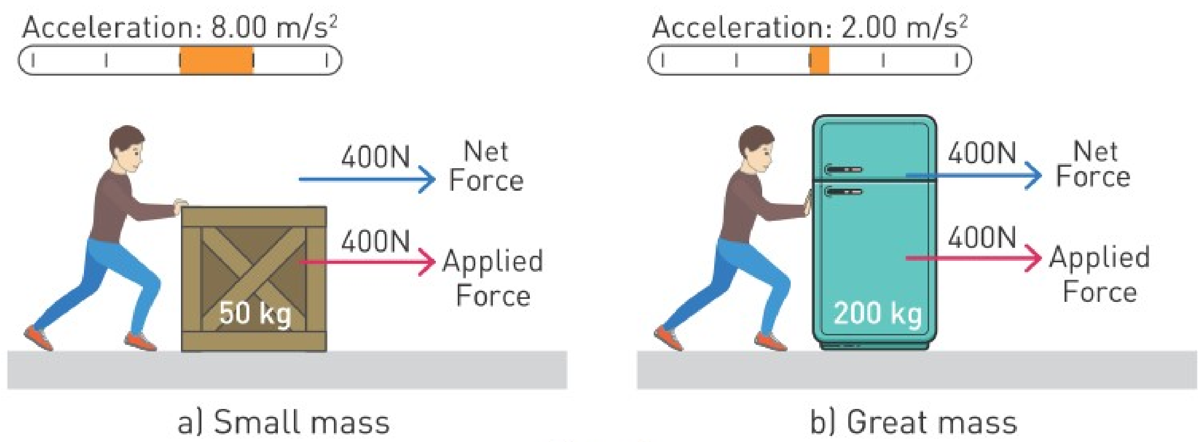


Figure 1

The resultant force means the sum of all forces. In the Figure 1 there is only one force. Sometimes you may have several forces. For example, friction, Figure 2.

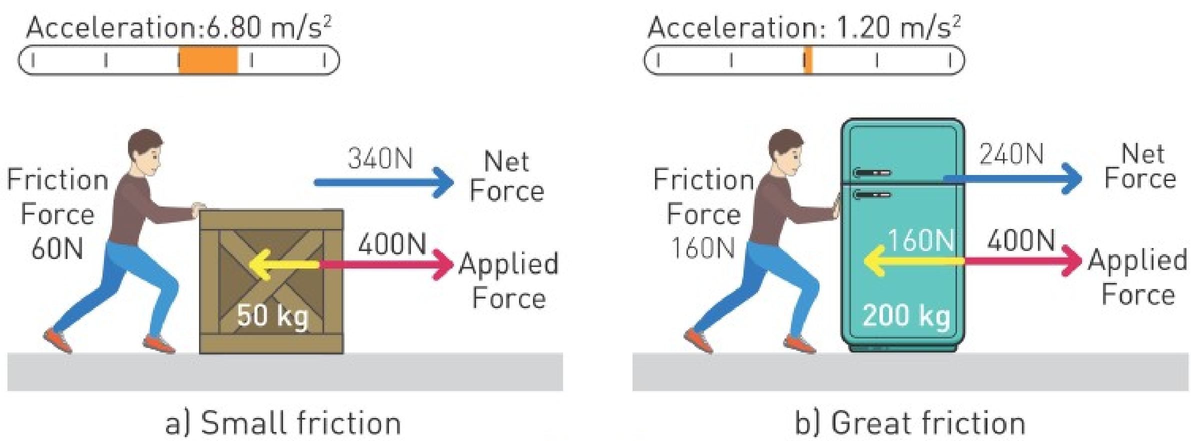
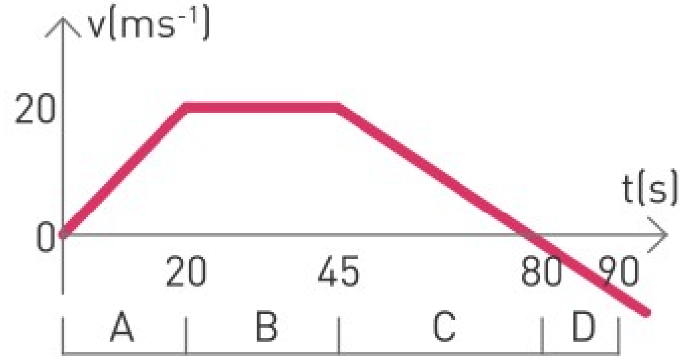


Figure 2

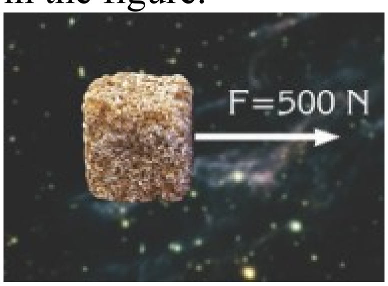
Activity

Divide into groups. You will need piece of paper to draw the graphs. An 800 kg car travels to the north initially and its velocity is shown in the following graph. Determine the magnitude and direction of the net force on the car in each of the intervals A, B, C and D. Draw F-t and a-t graph.



Example

A force of 500 N acts on a load of 250 kg which is at rest in space, as shown in the figure.



Find
a) the acceleration of the load,
b) the speed which the load reaches 5 s later.
Solution:
a) The force of 500 N is the net force acting on the object.
From the equation of the second law of motion we can find its acceleration.

$$\vec{F} = m\vec{a}; \quad a = \frac{F}{m}; \; a = \frac{500}{250}; \quad a = 2\, m/s^2;$$

b) From the equation

$$v = v_0 + at; \qquad v = 0 + 2 \times 5 = 10\, m/s;$$

Terminology

shot - ядро / ядро

light - жеңіл / легкий
heavy - ауыр / тяжелый

Literacy

1. Sport car has mass of 1700 kg and car’s engine produces 17000 Newtons. What is acceleration of car? Is acceleration bigger or smaller than gravitational acceleration?
2. How many seconds does sports car need to reach 100 km/h? Why do we build sports cars?

Research time

While riding a bicycle we have to rotate pedals constantly in order to have constant speed. Why bicycle tends to stop if pedals are not rotated?

Art time

Make “fractal art” about Second Law of Newton.

3.4 THIRD LAW OF NEWTON

You will

define Newton's third law and use it for problem solving;

Question

Why do water animals have fins and tails? How do they use fins and tails?

Look at the Figure 1a. When a man tries to pull a tree, he can actually pull himself towards it. It seems like "the tree pulls the man". In physics this is called action-reaction or Newton's third law of motion. This law says that when one object applies a force on the second object, the second object applies the same force on the first one in opposite direction. Another example is on the Figure 1b. If this man hits the punching bag, the bag "will hit the man too".

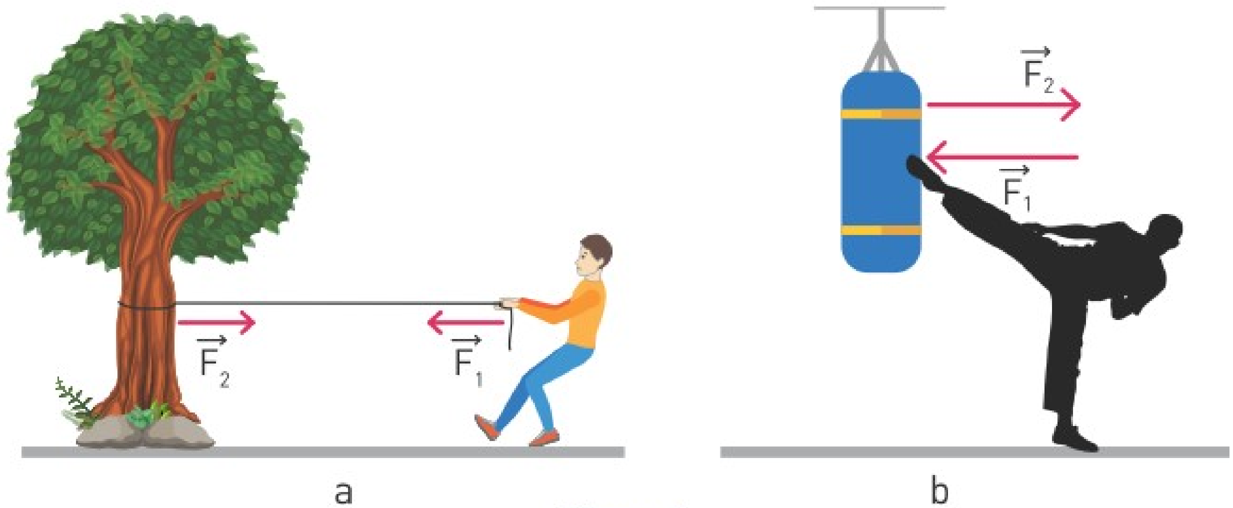


Figure 1

Fact

The formula for the Newton's third law is

$$\vec{F_1} = -\vec{F_2}$$

Sign "-" means that the forces are in opposite directions.You can see other examples of Newton's third law on the Figure 2.

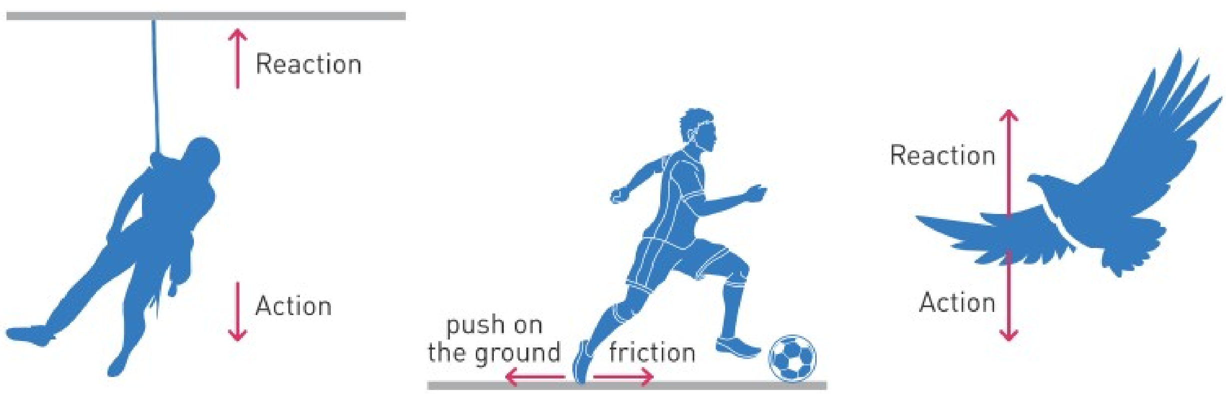


Figure 2

Normal force

When a book is on the table, Figure 3a, there is a reaction force **N** that is against the gravity. That's why the book is not falling. This reaction force is called normal force. It has such name because it always makes 90° with the surface. More examples are on the Figure 3b, 3c.

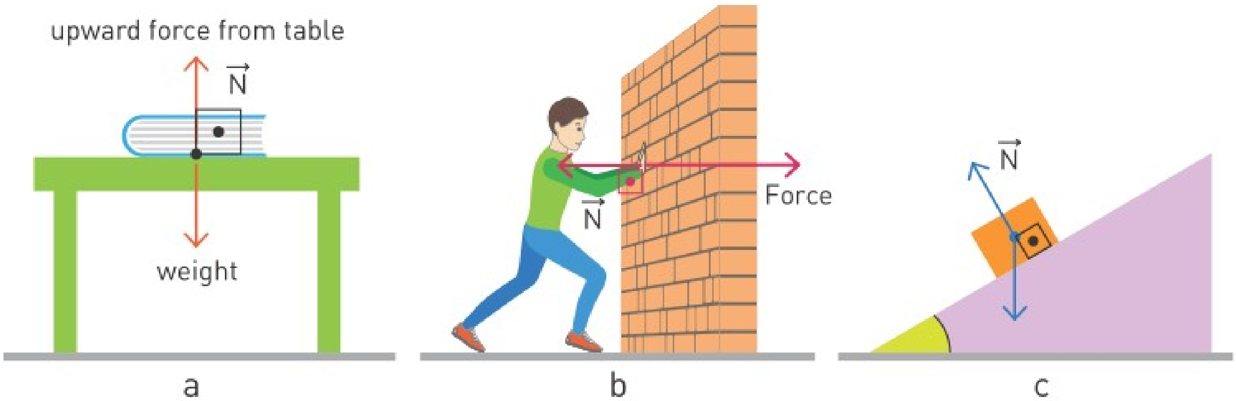
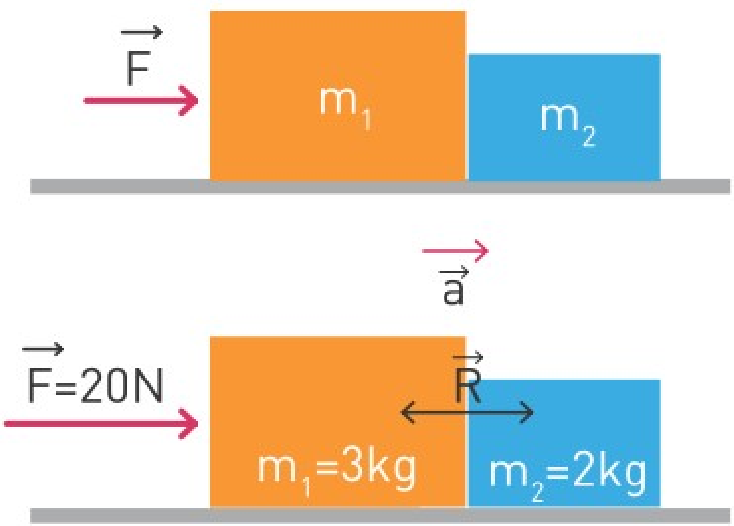


Figure 3

Example

m_1=3 kg and m_2=2 kg which are in contact with each other are pushed by a force of 20 N. What force does the m_1 apply to the m_2?



Solution:

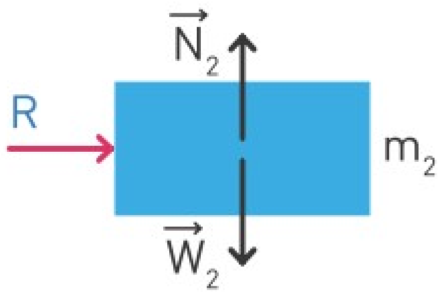
$\vec{F} = (m_1 + m_2)\vec{a}$

$$a = \frac{F}{m_1 + m_2}; \quad a = \frac{20}{3+2};$$

$a = 4\, m/s^2$

Now to find reaction force we draw free body diagram for m_2:

$\vec{F}_2 = m_2\vec{a}; \qquad F_2 = 2 \times 4 = 8\, N$



Activity

a) On the pictures below define action and reaction forces.
b) Draw an example of action and reaction force. Then, ask your classmate to find them on your picture.

Terminology

fin - жүзбеқанат / плавник
tail - құйрық / хвост
opposite - қарама-қарсы / противоположный
neighbour - көрші / сосед
classmate - сыныптас / однокласник
helicopter - тікұшақ / вертолет
weight scales - таразы / весы
to raise - көтеру / поднимать

Literacy

1. Why helicopters and planes cannot fly on the Moon?

2. How many Newtons is force of gravity that acts on you? What is its direction? Why don't you move downwards?
3. Why you cannot walk on the water?
4. You stand on weight scales. How does your weight change if you raise one leg?

Art time

Make "Pixel art" about Third Law of Newton.

Research time

Find the examples of third law of motion in Kazakh culture. Show them to classmates as a picture (or something else). Draw the direction of all forces.

3.5 APPLICATIONS OF NEWTON'S LAWS

You will

apply free body diagram in problem solving

Question

How many forces are acting on this decelerating car?

Laws of motion help us to understand why objects move or do not move. We can apply them by drawing free body diagram. This diagram includes all forces that currently act on an object. For example, Figure 1.

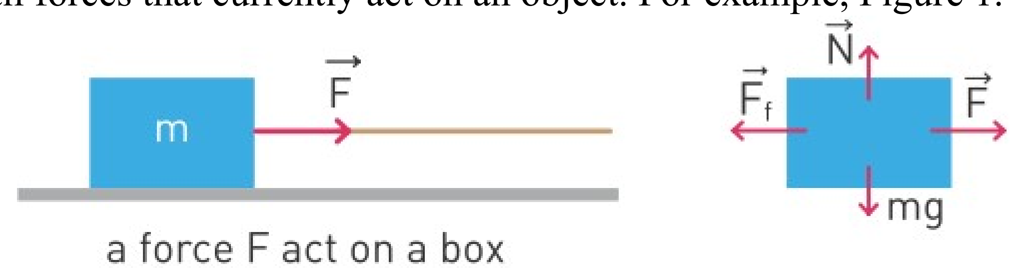


Figure 1

There are 4 forces acting on the box.

1. Pulling force of a rope - $\vec{F}$
2. Weight of the box - $m\vec{g}$
3. Normal force - $\vec{N}$
4. Friction force - $\vec{F_f}$

Let us analyse this example by Newton's laws.

a) If $\vec{F}$ is greater than $\vec{F_f}$, then the box will have acceleration. This is the second law of Newton.

b) $\vec{N}$ must be equal to $m\vec{g}$. This is the third law of Newton.

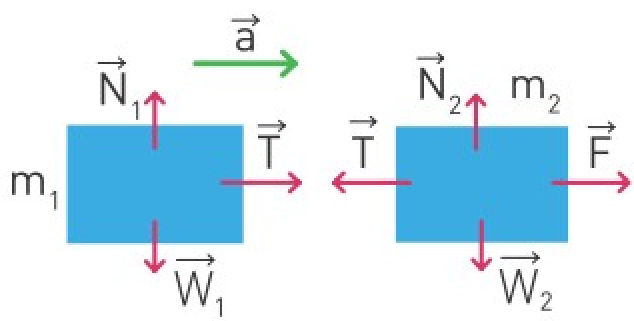
c) Initially $\vec{F}$ is greater than $\vec{F_f}$. After a while, the box will have a certain speed $\vec{v}$. Let's say that at this moment our force becomes smaller so $\vec{F}_{new} = \vec{F_f}$. From this moment, the speed will not change. It will remain as $\vec{v}$ because the resultant force is zero. This is the first law of Newton.

Example

Two boxes are attached with a string. Then, a force pulls the boxes. If m_1= 2 kg and m_2= 3 kg, what is the value of the tension in the string?

Solution:

$$\vec{F} = (m_1 + m_2)\vec{a}; \quad a = \frac{F}{m_1 + m_2}; \quad a = \frac{10}{2+3}; \quad a = 2\ m/s^2$$



The net force acting on mass m_1 is the tension T in the string. Hence, applying the second law of motion to mass m_1

$$\vec{T} = m_1\vec{a}$$

$$T = 2 \times 2 = 4\ N$$

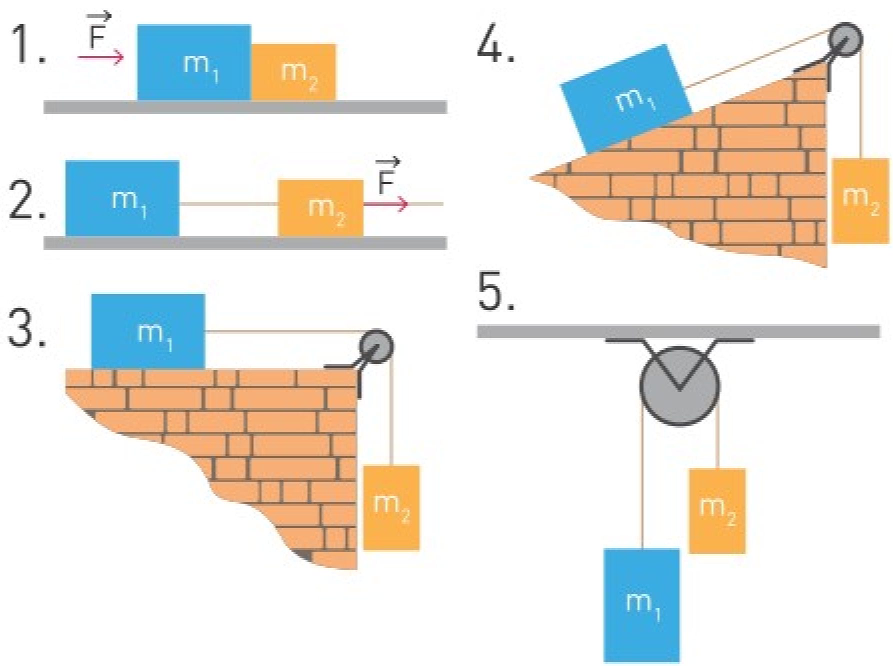
$$F - T = m_2 a$$

$$T = F - m_2 a$$

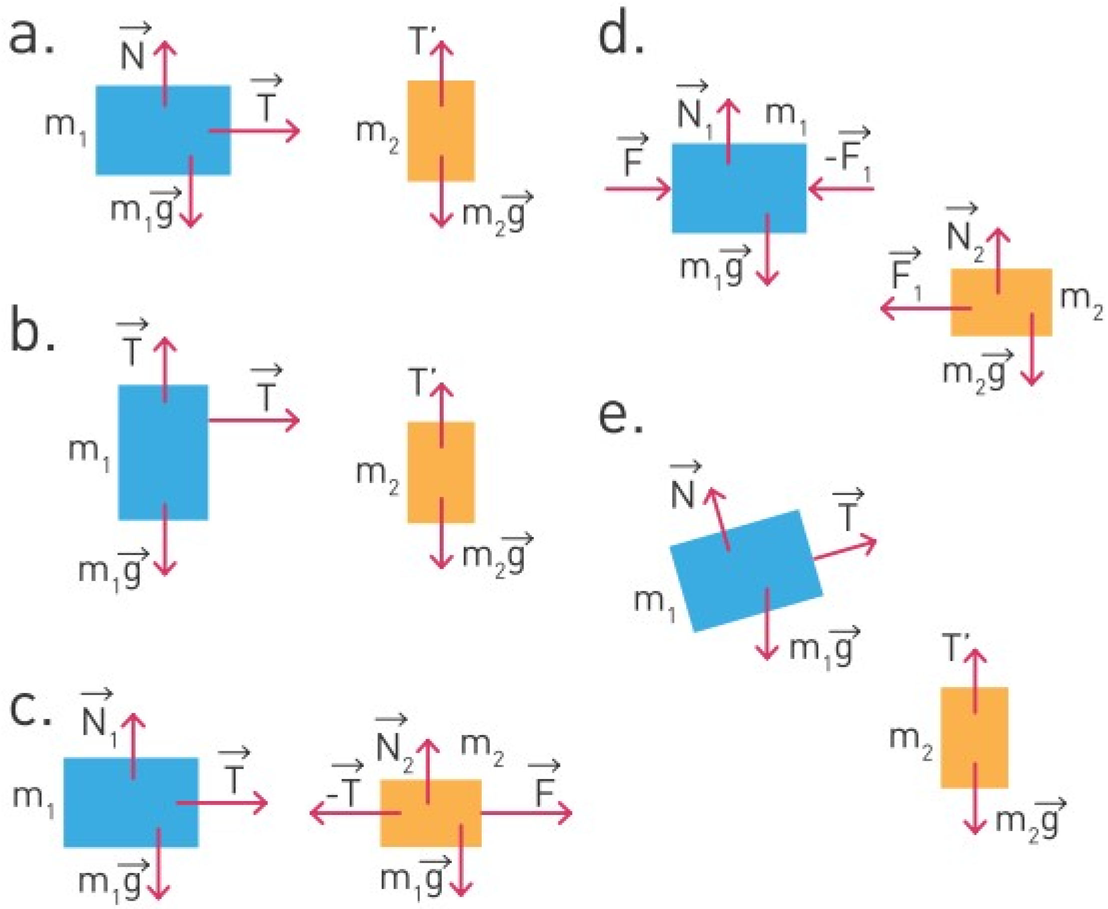
$$T = 10 - 3 \times 2 = 4\ N$$

However, the tension is the same. T=4 N

Activity

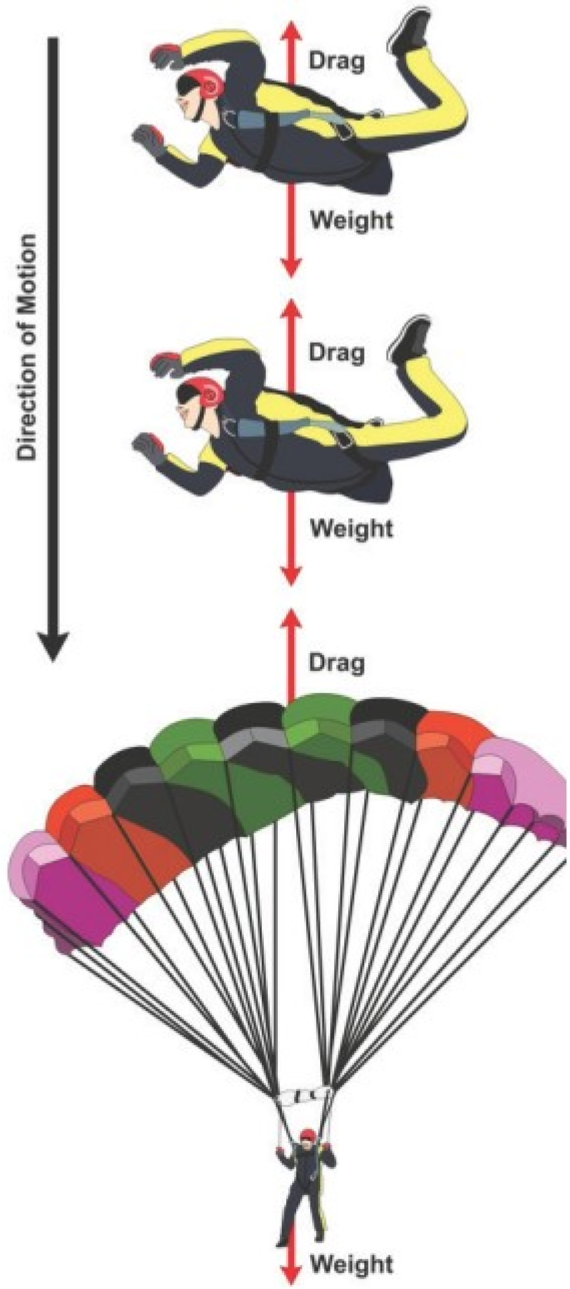


a) Match the right picture with the right diagram.
b) Now draw your own example. Design it yourself or choose from a movie, a song, a book etc. Then, give it to your neighbour. Ask him to find and draw all forces your picture has.



Fact

A force that decreases the velocity of an object is called drag.



Literacy

1. You stand on the ground. Draw all forces that act on you.
2. Draw all forces that act on a car (2000 kg) that moves on a hill road. Hill has height of 20 m and length of road is 50 m. How many Newtons is normal contact force?

Research time

"The Can" Main materials: Aluminum cans, string, water, screwdriver or nail.
Goal: You need to make can that uses third law of motion to move. How would you do that? You can use other simple additional materials.

Terminology

application - қолдану / применение
spring - серіппе / пружина
disappear - жоғалу / исчезать
currently - дәл қазір / в данный момент

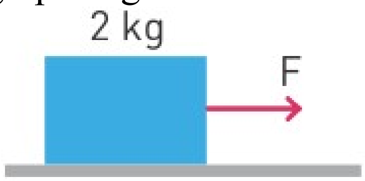
3.6 PROBLEM SOLVING (NEWTON'S LAWS)

Question

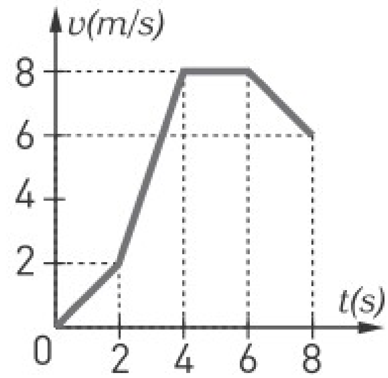
Why do we use "inclined planes"? What does happen if we do not use "inclined planes"?

Example 1

A box of 1 kg is initially at rest. Then, a changing force F acts on it. The v(t) graph is given.



a) Find the acceleration of the box in each time interval.
b) Draw F(t) graph.



Solution:

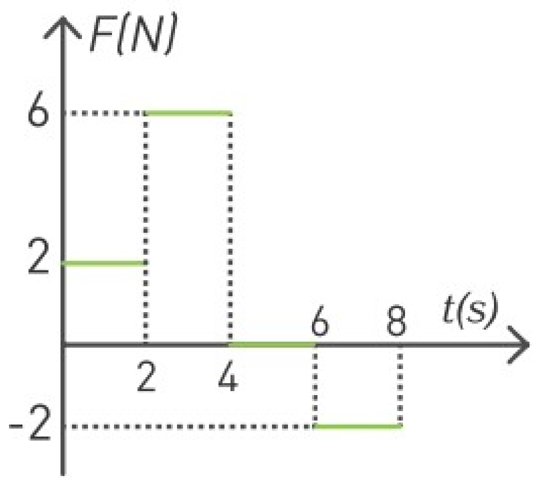
a) We need to use formula $\overline{a} = \frac{\Delta V}{\Delta t}$ for each time interval.

0-2 s : $a_1 = \frac{2-0}{2-0} = 1\ m/s^2$

2-4 s : $a_2 = \frac{8-2}{4-2} = 3\ m/s^2$

4-6 s: $a_3 = 0\ m/s^2$ because velocity is not changing

6-8 s: $a_2 = \frac{6-8}{8-6} = -1\ m/s^2$

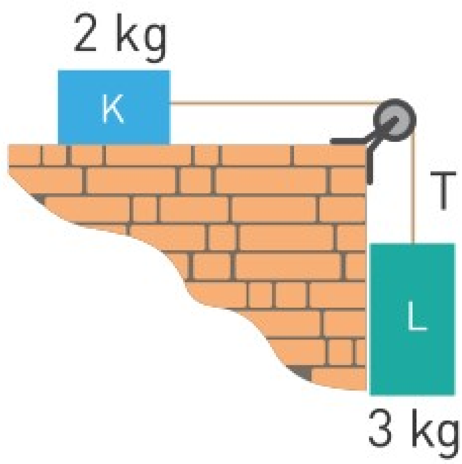


b) We need to use formula to find force on each time interval.

0-2 s : $F_1 = 2 \times 1 = 2N$
2-4 s : $F_2 = 2 \times 3 = 6N$
4-6 s: $F_3 = 2 \times 0 = 0N$
6-8 s: $F_4 = 2 \times (-1) = -2N$
The F(t) graph can be drawn now.

Exercise 1

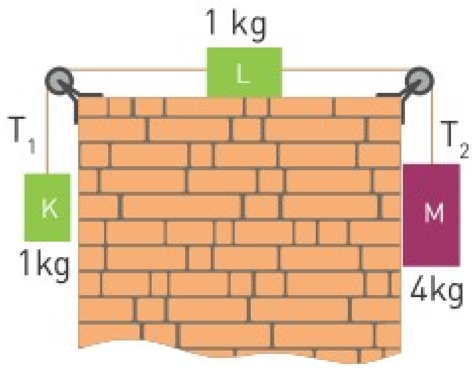
Two masses are attached to each other. There is no friction force in the system. Take g=10 m/s^2.



a) Find acceleration of masses.
b) How can you add extra mass of 10 kg so the acceleration becomes smaller (greater)?
c) What can be done so the system won't move even if you add 1000 kg to any place?

Example 2

Three masses are attached to each other. The surface of table is smooth. Pulleys are frictionless. Take g=10 m/s^2.



a) In what direction will the masses move?
b) What are their accelerations?

Solution:
a) The only force that can move masses is gravitational. Thus, the whole system will move to the right because the right side (4 kg) is heavier.
b) All masses will move with the same acceleration since they are attached to each other.
The force that pulls boxes to the right is F_1= 40 N. The force that pulls boxes to the left is F_2=10 N.

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

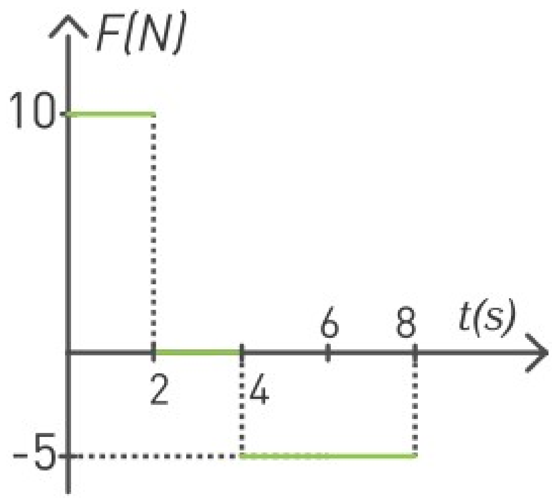
$$F_1 - F_2 = (m_1 + m_2 + m_3)a$$

We add masses because they all move together.

$$a = \frac{F_1 - F_2}{m_1 + m_2 + m_3} \qquad a = \frac{40 - 10}{1 + 1 + 4} = 5\ m/s^2$$

Exercise 2

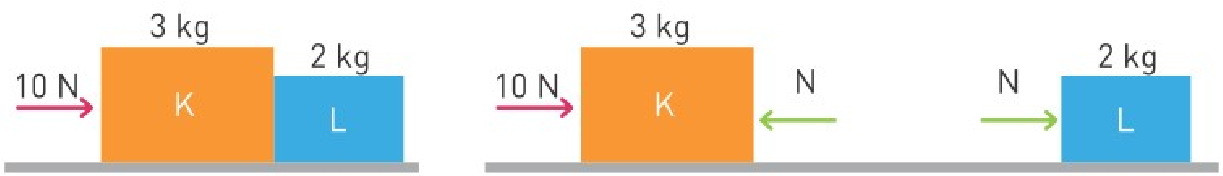
A force acts on a box of 5 kg. Initially the box is at rest. The F(t) graph is given.



a) What is the acceleration of the box in each time interval? When the acceleration is maximum?
b) What is the maximum velocity of the box?
c) What is the velocity of the box at time 8 s?
d) Does the box change its direction of motion? If yes, at what time?

Exercise 3

A force of 10 N acts on 2 boxes K and L.



a) What is the acceleration of the boxes?
b) What is the reaction force N between boxes? Hint: Use the picture and Newton's third law for help.

LIiteracy

1. Car has mass of 3000 kg and its engine produces 15 kN. Can it go up the hill that is 40 m high and has length of 70 m?
2. What is reaction force of car on the hill? Is it more or less than weight of car?

Terminology

inclined plane - көлбеу
жазықтық / наклонная плоскость
rest - тыныштық күйі / состояние покоя
initially - бастапқы күйде / в начальном состоянии
playdough - пластилин / пластилин
plasticine - пластилин / пластилин

Art time

Use playdough (plasticine or something similar) to explain “force”.

3.7 WEIGHT AND ACCELERATION

You will

determine weight of an object that moves with acceleration;

Question

Why do pilots and astronauts wear “anti-g suit”?

When a plane takes off, Figure 1, the speed of the plane increases. During this process the pilot must maintain the acceleration of the plane at a certain limit. This is because the weight of passengers increases during the acceleration.

Figure 1

Let us consider 3 examples on the Figure 2. The man stands on the scales in all cases. We can apply Newton's second law for each case.

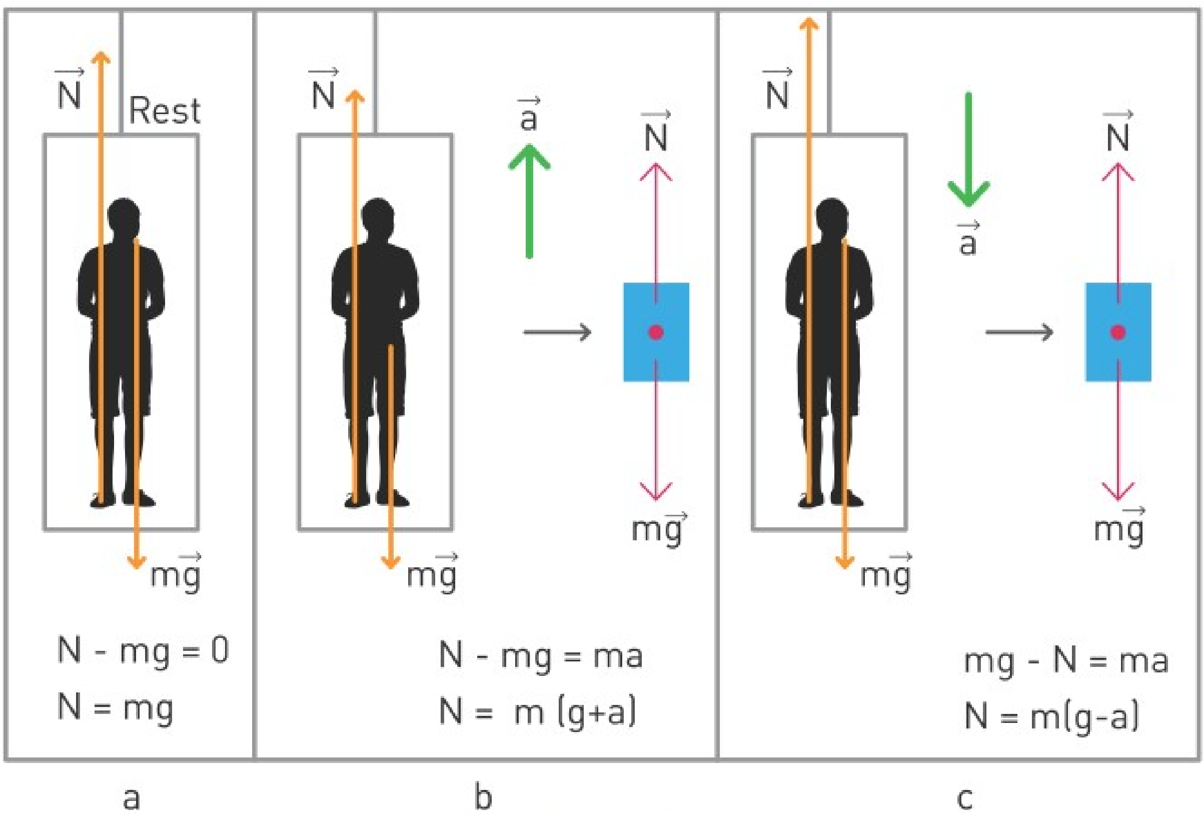


Figure 2

a. The elevator is at rest. The reaction force N = mg.
b. The elevator rises with acceleration. The reaction force N=m(g+a).
c. The elevator descends with acceleration. The reaction force N=m(g-a).

The weight of a person is a reaction force N from the surface. This example shows that weight can be changed by acceleration.

In case b, the N is greater. Therefore, the scales show more than usual: weight is greater. In case c, the N is smaller. Therefore, the scales show less than usual: weight is smaller.

This phenomenon is very important for astronauts and pilots, Figure 3.

Figure 3

The weight of an astronaut may increase up to 8 times during the launch of a rocket.

Military pilots performs quick and difficult maneuvers. Their weight may increase up to 12 times during the flight. Those jobs are not easy. Special training is required.

Load factor

It is a number by which normal weight is multiplied during the acceleration, Table 1. For example, during the takeoff of civil plane, passengers' weight increases 1.5 times.

Situation	Load factor
No acceleration	1
Civil plane takeoff	1.5
Opening parachute	up to 10
Military plane	up to 12 (short period)
Fatal for untrained person	8-9

Example

Average acceleration that astronauts experience during rocket launch is 2 times larger than the gravitational acceleration on earth. If the mass of astronaut is 100 kg, what is the weight during launch?

Solution:

$$\vec{F}_{net} = m\vec{a}$$
$$N - W = ma$$
$$N - mg = m \times 2g$$
$$N = 3mg$$
$$N = 3 \times 100 \times 10 = 3000\ N$$

Activity

Take two pieces of paper and roll one into a ball. Drop them from the same height at the same time. Do they fall at the same speed? Why?

Research time

Try to answer the following questions by doing this task below.

1. First make a ramp.
2. Take two different marbles. Line them up evenly at the top.
3. Use ruler as a gate. Lift the gate quickly so that marbles start to roll at the same time.

4. Watch the finish line closely to see if one marble comes in first or it is tie.
5. Do the race 3 or 4 times.

Questions:

1. Does one marble win the race or is it tie?
2. Are results the same for every race?
3. Explain the results of the task.

Literacy

1. What type of safety system should machines in Figure 2 have?
2. Where do you move if reaction force is smaller than weight?
3. Where do you move if reaction force is bigger than weight?
4. You are a pilot of jet aircraft that moves upwards. Reaction force is 3000 Newtons. What is your acceleration?

Terminology

weight - салмақ / вес
passenger - жолаушы / пассажир
scales - таразы / весы
elevator - лифт / лифт
descend - түсу / опускаться
phenomenon - құбылыс / явление
launch of a rocket - ракетаны ұшыру / запуск ракеты
military - әскери / военный
civil - азаматтық / гражданский
maneuver - маневр жасау, орағыту, күрделі қозғалыс жасау / сделать сложное движение, маневрировать
experience - сезу / чувствовать
ramp - еңіс / скат, трап
marble - ойыншық шыны
шарик / игрушечный стеклянный шарик
evenly - біркелкі / равномерно
jet aircraft - реактивті ұшақ / реактивный самолет

Art time

Use crayons, gravity and hairdryer to paint "weight". Search “crayon art”.

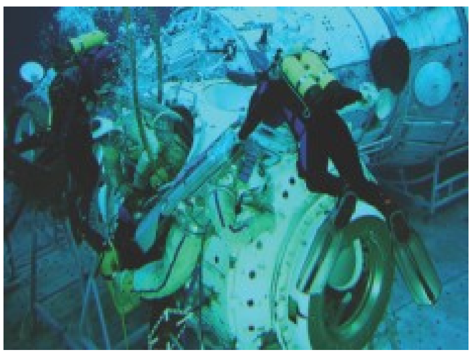
3.8 WEIGHTLESSNESS

You will

explain weightlessness;

Question

Why do astronauts train underwater?



Consider the example on Figure 1a. Let's take acceleration as $a = g = 9.81$ m/s^2.

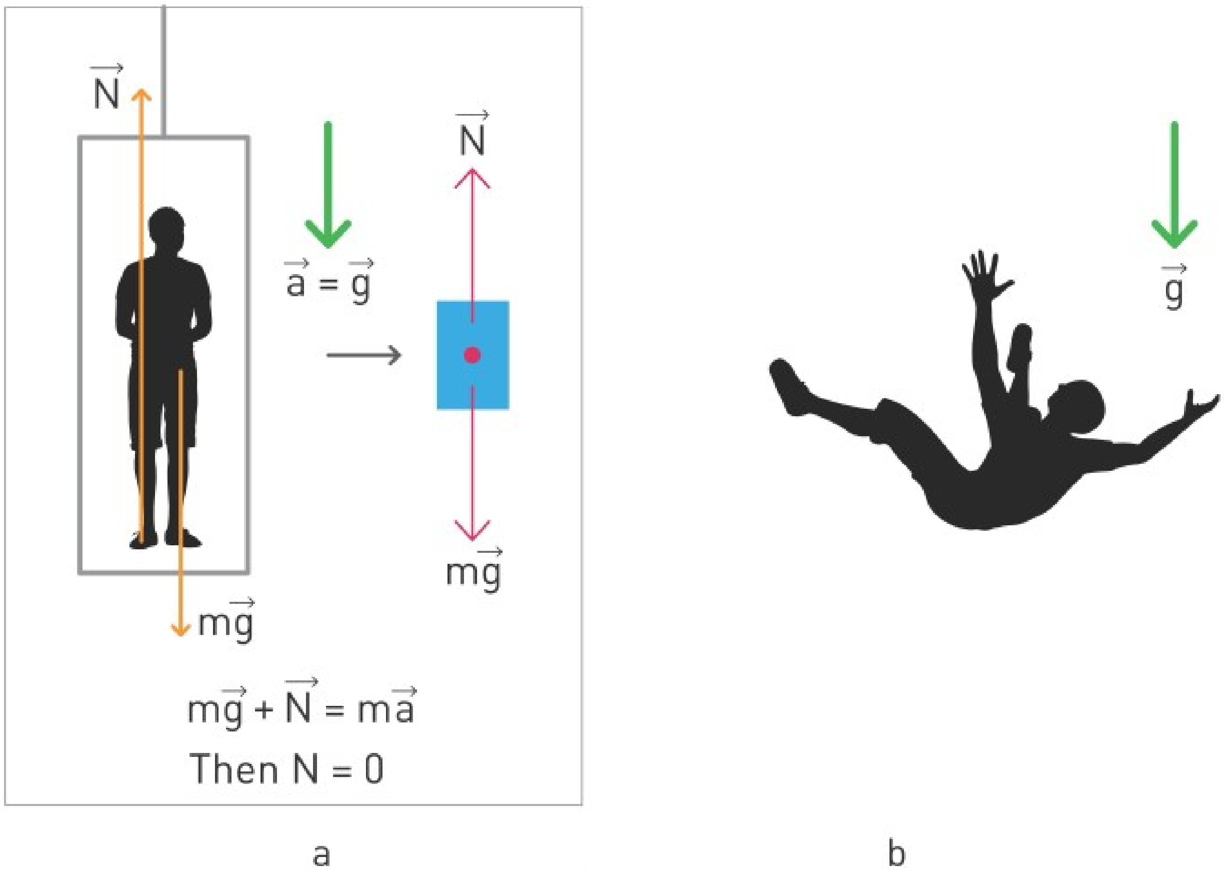


Figure 1

In this case the reaction force **N** is zero. This means that the man has no weight. When an object has no weight, we call such condition as weightlessness.

When elevator moves downward with g, it's as if a man falls downward with g, Figure 1b. During this motion a man does not feel own weight because there is no reaction force **N**.

Weightlessness in space

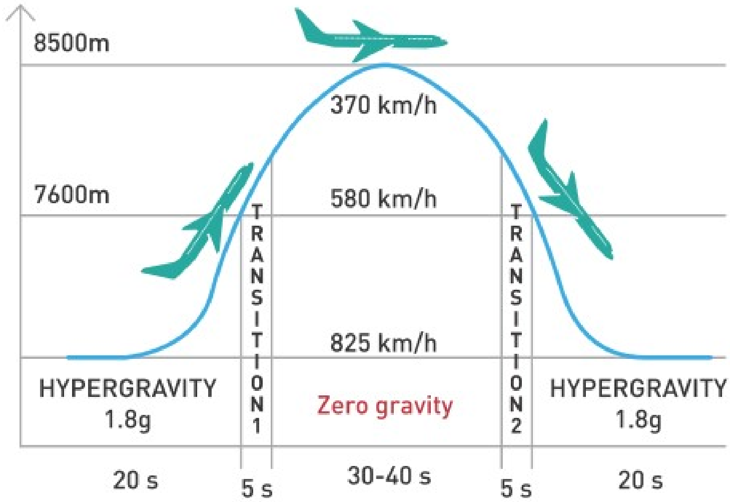
When astronauts are in space, they do not feel reaction force. They are weightless, Figure 2. All objects in spaceship float.

Figure 2

Weightlessness simulation

People can simulate weightlessness by using special plane which flies in a certain trajectory, Figure 3a. When it passes transition 1, it enters a zero gravity stage. During next 30-40

seconds people in plane are weightless, Figure 3b. Then the plane enters transition 2 and decelerates.



a

b

Figure 3

Example

Which kid feels weightlessness? Why?

Answer:
Girl feels weightlessness when she starts to fall because her acceleration will be same as gravitational acceleration.

Fact

There are three astronauts in history of Kazakhstan: Toktar Aubakirov (1^{st} mission in 1991), Talgat Musabayev (1^{st} mission in 1994) and Aidyn Aimbetov (1^{st} mission in 2015).

Activity

Astronauts live in weightlessness about 4-6 months. Astronauts cannot do some activities due to weightlessness. Imagine such activities and draw pictures of such activities.

Research time

Make two holes in the Styrofoam (or plastic, or paper) cup on opposite sides near the bottom. Fill the cup with water, so that water is pouring out of the holes. Drop the cup and look carefully what is happening. Answer these questions:

1. Why the water falls out the holes, when you're holding the cup?
2. What will happen to the water coming out of the holes while the cup falls?
3. Will the water pour faster, slower or will it come out of the top of the cup?
4. Explain logic of your answers and provide evidence for your answers.

Literacy

1. What if the elevator on the Figure 1 moves downward with acceleration of 2g, 3g, or more?
2. How do astronauts drink, eat, sleep, shower, shave, cry, clip nails in ISS (International Space Station)?
3. How can weightlessness change your bones, muscles, internal organs, eyes and brain?

Terminology

weightlessness - салмақсыздық / невесомость
consider - қарастыру / рассматривать
space-ғарыш / космос
weightless - салмақсыз / невесомый
spaceship - ғарыш кемесі / космический корабль
float -қалқу / плаватьнаповерхности

simulate - ұқсату, еліктеу / имитировать
transition - өтпелі кезең / переходный период
styrofoam - пенопласт / пенопласт
pour - құю / литься
International Space Station - халықаралық ғарыш станциясы / международная космическая станция
internal organ - ішкі ағзалар / внутренние органы

Art time

Write and sing song about your feelings in weightlessness.

3.9 UNIVERSAL LAW OF GRAVITATION

You will

define law of universal gravitation and use it for problem solving;

Question

Why does Earth attract you? Does Earth attract light? Does “black hole” attract light?

“Any object that has mass, attracts another object that has mass. If the distance between these objects increases, the attraction force decreases.”

This is called universal law of gravitation. Let us consider the example on Figure 1. Objects attract each other with the same force (Newton’s third law.) That’s why $\mathbf{F_1}=-\mathbf{F_1}$. We can

calculate that force by the formula

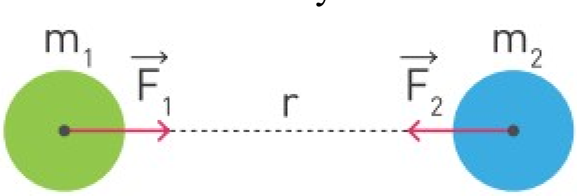


Figure 1

$$F_1 = F_2 = G\,\frac{m_1 \times m_2}{r^2}$$

F - attraction force [N]
G - gravitational constant
m_1 - mass of first object [kg]
m_2 - mass of second object [kg]
r - distance between centres of masses [meter]

Gravitational constant $G=6.67\cdot10^{-11}\ Nm^2/kg^2$. This number is very small. That is why we cannot feel the force of attraction between small masses. For example, a book and a pen. However, force of attraction is great between planets and others space objects. Their masses are great, Table1.

Name	Radius(km)	Mass (kg)
Sun	695 000	1.99×10^{30}
Mercury	2 440	3.30×10^{23}
Venus	6 052	4.87×10^{24}
Earth	6 371	5.97×10^{24}
Mars	3 397	6.42×10^{23}
Moon	1 738	7.35×10^{22}
Jupiter	71 492	1.90×10^{27}
Saturn	60 268	5.68×10^{26}
Uranus	25 559	8.68×10^{25}
Neptune	24 766	1.02×10^{26}

Table 1

Let us use this formula on a person standing on the surface of the Earth, Figure 2.

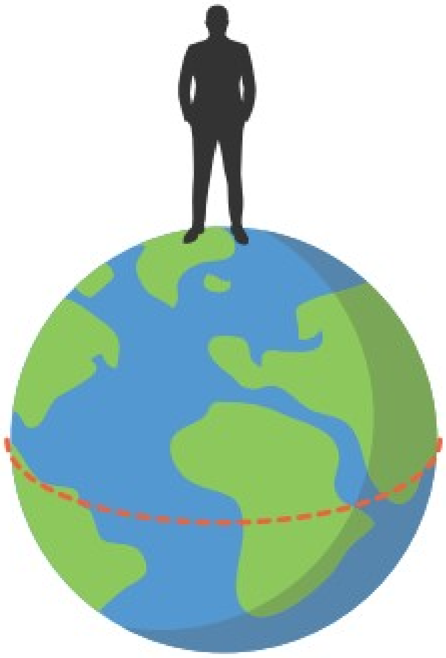


Figure 2

The Earth attracts with the force

$$F = G\frac{m_{man} \times M_{Earth}}{R_{Earth}^2}$$

We know that gravitational attraction can be found by the formula

$$F = m_{man} \times g$$

Therefore, we can equalise these formulas as

$$m_{man} \times g = G\frac{m_{man} \times M_{Earth}}{R_{Earth}^2}$$

Then, we get

$$g = G\frac{M_{Earth}}{R_{Earth}^2}$$

This expression gives formula for gravitational acceleration on the surface of any planet.

$$g = G\frac{M}{R^2}$$

M - mass of a planet [kg]
R - radius of planet [meter]

Example

Calculate the mass of the Earth by applying the law of gravitation. (Take g = 10 m/s^2, G=6.67×10^{-11} Nm^2/kg^2 and radius of Earth R_E=6.4×10^3 km)
Solution:
The weight of an object on the surface of Earth is calculated from W=mg.
Gravitational force between the object and Earth is:

$$F = G\frac{mM_E}{R_E^2}, M_E \text{ -mass of Earth}$$

When we equalise weight and gravitational force we get:

$$mg = G\frac{mM_E}{R_E^2} \Rightarrow M_E = \frac{gR_E^2}{G}$$

$$M_E = \frac{(10\ m/s^2) \times (6.4 \times 10^3\ km)^2}{(6.67 \times 10^{-11}\ Nm^2/kg^2)} \approx 6 \times 10^{24} kg$$

Fact

Baikonur Cosmodrome is the first and the largest space launch facility. Baikonur Cosmodrome is near the Tyuratam railway station in Kyzylorda Region.

Activity

Find the gravity of each object in the space. Use the table.

1. Sun : __________
2. Mercury : __________
3. Venus : __________
4. Earth : __________
5. Mars : __________
6. Moon : __________
7. Jupiter : __________
8. Saturn : __________
9. Uranus : __________
10. Neptune :__________

Literacy

1. What does happen to Universe if law of gravity is $F = G\,\frac{m_1 \times m_2}{r^3}$?
2. What does happen to Universe if law of gravity is $F = G\,\frac{m_1 \times m_2}{r}$?
3. Why can't we find "anti-gravity"? How can you use "anti-gravity"?
4. What if Earth's gravity becomes three times stronger? What does happen to you, to plants and trees, to birds, animals and fishes, to mountains, to waves?

Terminology

Universal Law of Gravitation -
бүкіләлемдік тартылыс заңы / закон всемирного тяготения
attract - тарту / притягивать
attraction - тартылыс / притяжение
expression - математикалық өрнек /математическое выражение
cosmodrome - ғарыш айлағы / космодром
space launch facility - ғарыш ракеталарын ұшыратын жер / место запускания космических ракет

Art time

Draw “gravity” and “anti-gravity”.

3.10 Problem solving

You will

define law of universal gravitation and use it for problem solving;

Question

Why did we launch International Space Station (ISS)?

Example 1

The weight of object 2 is 36% percent different from object 1. Their masses, however, are the same.
a) What does "different by 36 %" mean?
b) Calculate h.
Solution:
a) Gravitational attraction is weaker at the point where object 2 is located. Thus, the weight of object 2 is less (not greater) by 36%
To find h we will use the formula

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

$$F_1 = G\frac{m_{object\,1} \times M_{Earth}}{R^2_{Earth}}$$

Here F_1 is the weight of object 1.

$$F_2 = G\frac{m_{object\,2} \times M_{Earth}}{(R_{Earth} + h)^2}$$

Here F_2 is the weight of object 2.

We know that $F_2 = 0.64 \cdot F_1$.

Then, we get

$$G\frac{m_{object\,2} \times M_{Earth}}{(R_{Earth} + h)^2} = 0.64 \times G\frac{m_{object\,1} \times M_{Earth}}{R^2_{Earth}}$$

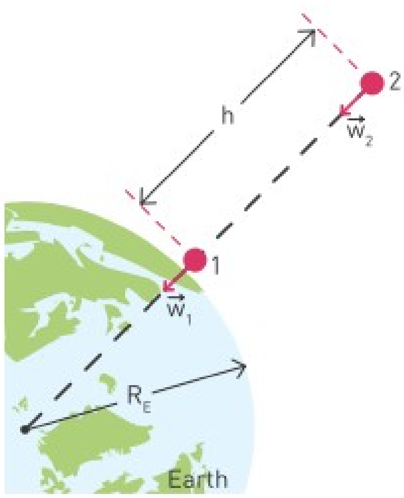
$$R^2_{Earth} = 0.64 \times (R_{Earth} + h)^2$$

$$R_{Earth} = 0.8 \times (R_{Earth} + h)$$

$$h = \frac{R_{Earth}}{4} = 1600\ km$$

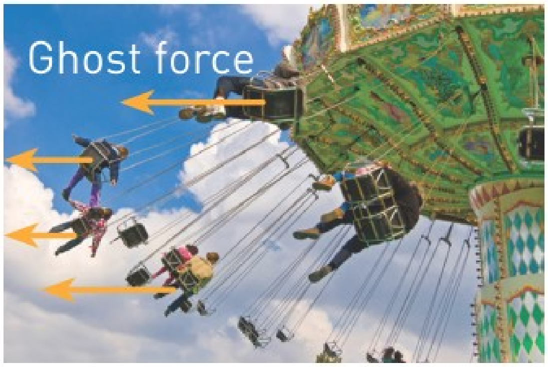
Exercise 1

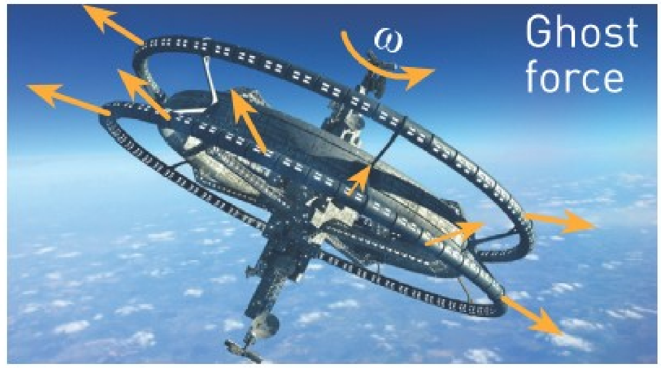
A rocket is on the surface of the Earth. Then, it rises to the point which is R_E above the Earth.How different is the weight of the rocket at that point?



Exercise 2

When swings rotate, it looks like there is some kind of force that pushes outward the seats.





Scientists used this phenomenon for the idea that if they build a rotating space station, they will get artificial gravity (**g**) in space. The magnitude of artificial gravity can be found by the formula

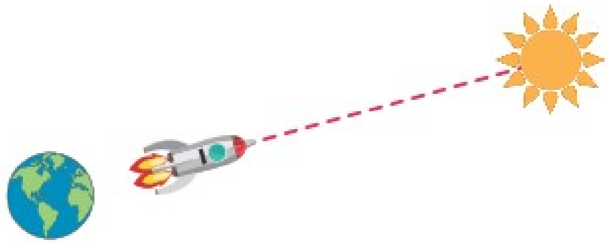
$$a_C = \frac{\upsilon^2}{R}$$

Where a_C becomes gravitational acceleration **g** .

a) The radius of the space station is 120 m. What should the angular speed of station be so people there feel normal gravity. (Hint: use $\upsilon=\omega\cdot R$)
b) How would people be able to walk inside the rotating station? Guess and draw the picture of it.
c) We know that today there is still no such rotating space station. What may be the reasons for that?
d) Imagine that you are responsible for the risk management. What precaution measures would you apply while building the station?
e) Sometimes accidents can occur. What are the possible accidents that may happen in rotating station? What are possible solutions?

Exercise 3

A spaceship is launched from the Earth. The distance between the Sun and the Earth is $15\cdot10^7$ km. $M_E=6\cdot10^{24}$ kg and $M_S=2\cdot10^{30}$ kg.



a) At what point the gravitational forces of the Earth and the Sun acting on the ship cancel each other?
b) How difficult is it for the spaceship to remain at that equilibrium point? If something pushes the spaceship from that point, how can it be returned there?

Art time

Make theatre play that shows gravity between Earth, Moon and Sun.

Terminology

racer - жарысушы / гонщик
equilibrium - тепе-теңдік / равновесие
swings - алтыбақан, әткеншек / качели
artificial - жасанды / искусственный
to guess - болжап білу / угадать
responsible - жауапты / ответственный
precaution - сақтық / предосторожность
accident - апат / авария

Literacy

1. Calculate gravitational force between you and your friend. Is it big or small?
2. Why do “neutron stars” have big gravity?
3. Imagine you become so small that your gravity is same as Earth’s gravity. What is your radius to makeit happen?

3.11 SATELLITES

You will

use formula of orbital speed of satellite for problem solving;

Question

Why do we use satellite dishes?

Consider the following example, Figure 1. Cannonballs perform horizontal projectile motion with different speeds. They fall due to gravitational attraction. However, one cannonball at a certain speed v_3 starts moving in circular path around the Earth. This cannonball is falling, but at the same time surface of the Earth is rounding up. That is why the cannonball cannot touch the Earth. From this moment we can call the cannonball as satellite.

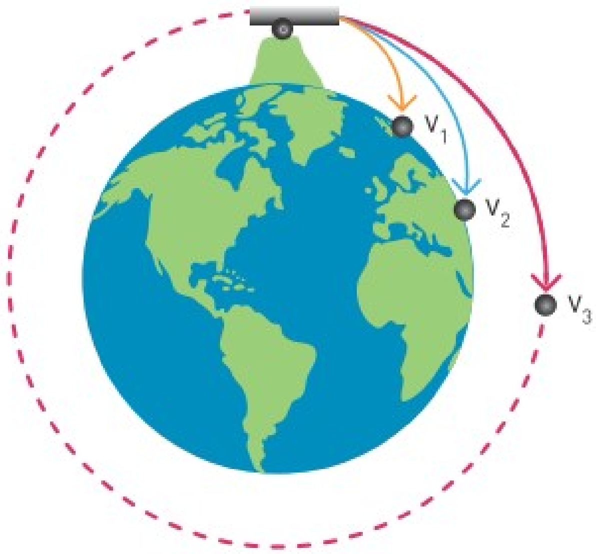


Figure 1

The certain speed from the example is called orbital speed, and can be found by the formula:

$$v_{orbital} = \sqrt{\frac{GM_{planet}}{(R_{planet} + h)}}$$

G - gravitational constant, $G=6.6\cdot10^{-11}\ Nm^2/kg^2$
M_{planet}- mass of a planet [kg]
R_{planet} - radius of a planet [meter]
h- height from the surface of a planet to the satellite (orbital height) [meter]
If the satellite is very near to a planet, we can neglect h in the formula and use

$$v = \sqrt{\frac{GM_{planet}}{R_{planet}}}$$

For example, for the Earth this speed is approximately 7.9 km/s.

Earth's satellites

There are about 3500 artificial satellites orbiting the Earth. However, only 1200 are operating. Others are no longer working. They are space junk.
Main purposes of satellites:
a) Communication b) Earth observation

c) Navigation and positioning d) Space exploration

e) Military force

Satellites are located in different heights from the ground (orbit altitude). Look at the table, there are some examples of orbits. Their examples are shown on the Figure 2.

Type of orbit	Orbital height(km)	Approximate period of rotation (hours)	Details
Low Earth Orbit(LEO)	200-1200	1.5 - 2.1	High speed of rotation. Short working life span.
Sun Synchronous Orbit (SSO)	700-800 km	1.6 - 2	Can always be in illuminated region
Medium Earth Orbit (MEO)	1200-30000	3-20	Angle of observation is greater that in LEO
Geostationary Orbit (GO)	35790	24	Above one point of the Earth. Great angle of observation

Example

How fast the ball should be hit so that it revolves around the Earth on 100 m height? $M_E=5.98\cdot10^{24}$, $G=6.67\cdot10^{-11}$ Nm^2 /kg^2 , $R_E=6.4\cdot10^6$ m.

Solution:

To find the speed we equalise centripetal force with gravitational force

$F_c=F_g$

$$\frac{mv^2}{R_E+H}=\frac{GmM_E}{(R_E+H)^2}$$

where m - mass of ball, - radius of Earth, M_E-Mass of Earth.

Mass of ball and (R_E+H) simplifies

$$\Rightarrow v^2=\frac{GM_E}{(R_E+H)}$$

$$\Rightarrow v = \sqrt{\frac{GM_E}{(R_E + H)}} = \sqrt{\frac{(6.67 \times 10^{-11}\ Nm^2/kg^2) \times (5.98 \times 10^{24}\ kg)}{6.4 \times 10^6\ m\ + 100m}} = 7894.42\ m/s$$

Activity

a) Type of orbit is very important for satellite's mission. Recall main purposes of satellites. What may the types of orbit be for each purpose?
b) The Figure 2 does not show example of SSO. Where would you draw it? Explain your answer.
c) Choose a specific problem from each field. Explain how satellite can solve it:
1. Agriculture 2. Environment
3. Meteorology 4. Travelling and logistics
5. Global health 6. Technology
d) Identify a problem (not from fields in part c). Then, explain how satellite can solve your problem.

Research time

Design and build models of your own satellites. Before that, discuss with your group and answer these questions.

1. How is your satellite powered? What is its mission?
2. What kinds of remote sensing activities will you want satellite to perform? What kind of equipment will satellite use?
3. How will satellite communicate with people on Earth?
4. What kind of orbit will you choose for satellite?

Art time

Imagine you are satellite that revolves around Earth. Write story about things you see and your feelings about them.

Fact

KazSat-1 (was launched in 2006), KazSat-2 (was launched in 2011), KazSat-3 (was launched in 2014) are telecommunications satellites. They are used for services of telecommunications, television broadcasting and high-speed Internet access.

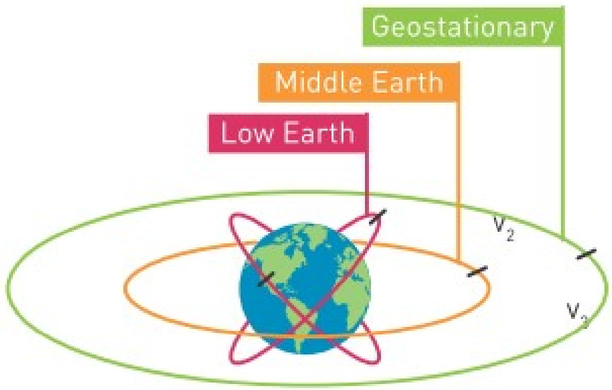


Figure 2

Terminology

satellite - серік / спутник
cannonball - зеңбірек ядросы / пушечное ядро
space junk - ғарыштағы қоқыс / космический мусор
communication - байланыс / связь
observation - бақылау / наблюдение
exploration - зерттеу / исследование
altitude - биіктік / высота
agriculture - ауыл шаруашылығы / сельское хозяйство
environment - қоршаған орта / окружающая среда
logistics - тауар тасымалдауын басқару / управление перевозкой товаров
television broadcasting
- теледидарлық хабар тарату / телевизионное вещание

Literacy

1. Why is there so much space junk? Why people do not return old satellites back to the Earth?

2. What if all satellites stop working? Can you predict possible outcomes?
3. Each country has different laws. Whose laws must work in space? On the Moon? On other planets?
4. How do satellites stay in orbit?
5. Do satellites ever fall out of orbit?
6. Do satellites ever get lost?

3.12 MOTION OF SATELLITES

You will

- compare different orbits of satellites;
- calculate parameters of motion of objects moving in gravitational field;

Question

Some satellites revolve close to Earth and some revolve far from Earth. Why?

The trajectory of most satellites is elliptic, Figure 1.

Figure 1

When cannon makes a launch with a speed greater that orbital speed $\upsilon_{orbital}$, the cannonball performs rotation in path D, Figure 2. This path has elliptical shape. However, at some point the cannonball's speed may be so high, that it flies from the Earth and never returns back: path E. This speed is called escape speed.

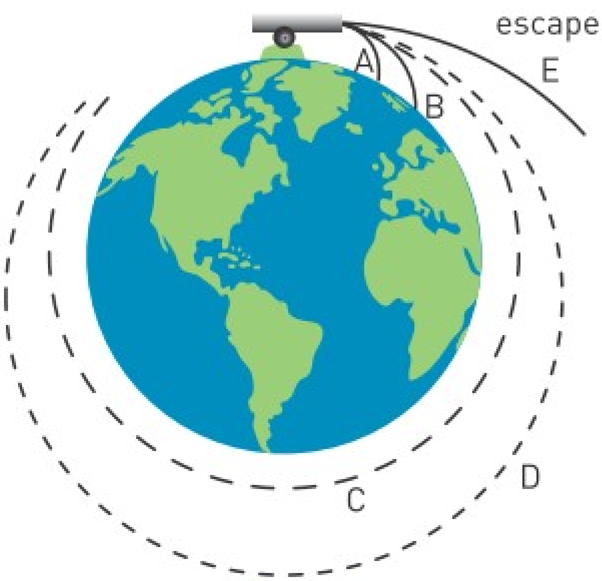


Figure 2

Each planet has different escape speed. For example, the speed to escape the Earth's attraction is about 11.2 km/s. You can find the comparison of different speeds of a satellite on the Figure 3.

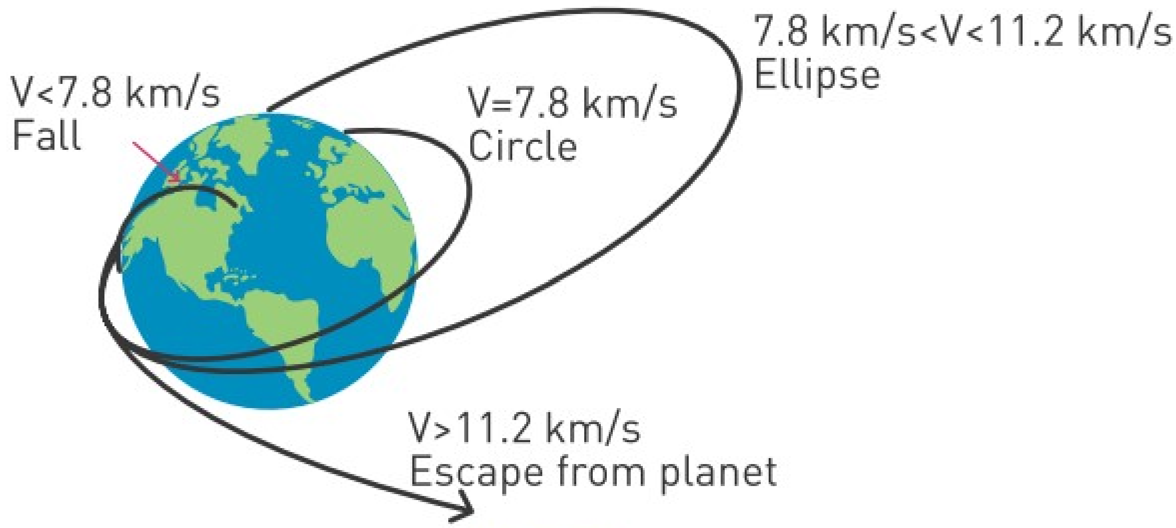


Figure 3

We can find the escape speed for any planet by formula:

$$v_{escape} = \sqrt{\frac{2GM_{planet}}{R_{planet}}}$$

Satellite and computation

Computation is very important for rocket launching. Initially, we assume that orbits are circular. The main parameters of computation are:

1. Speed of satellite: υ [m/s]
2. Orbital height: h [meter]
3. Period of rotation: T [seconds]
4. r- radius of rotation ($r=R_{planet}+h$) [meters]

Since we consider orbits to be circular, we can use formulas of circular motion.

$$v = \frac{2\pi r}{T} \quad \omega = \frac{2\pi}{T}$$

Example

A geosynchronous satellite is one that stays above the same point of the Earth. What is the satellite's orbit? $M_E=5.98\cdot10^{24}$ kg, $G=6.67\cdot10^{-11}$ Nm^2/kg^2, $R_E=6.4\cdot10^6$ m, $\pi=3.14$.

Solution:

The only force on the satellite is the gravitational force. Assuming that the satellite moves in a circle, the second law of motion can be applied

$$\vec{F}_{net}=m\vec{a} \qquad G\frac{m_s M_E}{r^2}=\frac{m_s v^2}{r}$$

Since the period of the satellite is

T=1 day = (24 h)(3600 s/h) = 86400 s,

the speed of the satellite can be found from the equation

$$v=\frac{2\pi r}{T}$$

Substitute υ:

$$G\frac{m_s M_E}{r^2}=\frac{m_s(\frac{2\pi r}{T})^2}{r}$$

Now solve for r:

$$r^3=G\frac{M_E T^2}{4\pi^2}\Rightarrow r=4.23\times10^7\ m$$

Activity

1. “Predict the outcome”

A satellite orbits the Earth at a certain orbital height. Then, the satellite turns on engines and the speed of the satellite increases. How further motion of satellite may change? How it may affect other parameters? Draw a picture of your prediction.

2. “To send, or not to send”

Do we need more satellites? Do we need space exploration at all? Discuss and make list of advantages and disadvantages. Support your answers.

Art time

Imagine you are an astronaut who searches for new planets. You have mission and you will return to Earth 30 years later. Write letter (or record video-message) to your parents (or relatives and friends) before you leave for mission.

Literacy

1. How fast do you need to throw stone so that it never returns to Earth?
2. How fast do you need throw stone on the Moon so that it never returns to Moon?
3. Why are speeds in question 1 and question 2 different?
4. What does happen to Earth (also oceans and you) if Moon disappears?

Research time

You are a group of engineers of the National Space Agency of the Republic of Kazakhstan. You have a new mission. You should take soil and rock samples from the Mars. Draw plan of mission and show plan of mission to your classmates.

Fact

Study these websites. What abilities and qualifications do you need to work for these companies? kazcosmos.gov.kz, gh-ecology.kz, rcsc.kz, spaceres.kz, infracos.kz, gharysh.kz, bayterek.kz.

Terminology

to revolve - айналу / вращаться

possible - болуы мүмкін / возможный
outcome - нәтиже / результат
computation - есептеу / вычисление

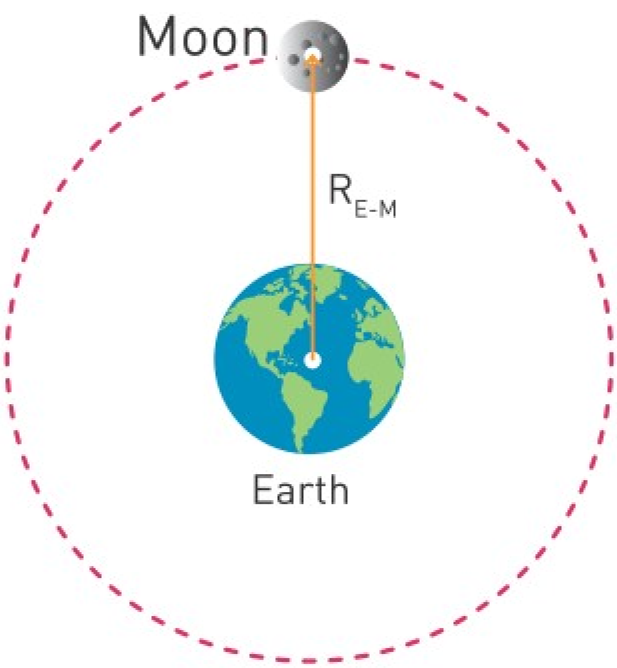
3.13 PROBLEM SOLVING

Question

What does happen if all satellites do not work for one hour? Describe your life.

Example 1

The distance between the centres of the Moon and the Earth is about 3.8×10^5 km.



a) What is the speed of rotation of the Moon around the Earth?
b) How long does it take for the Moon to revolve once around the Earth?
$M_{Earth} = 5.98 \cdot 10^{24}$ kg, $G = 6.67 \cdot 10^{-11}$ Nm^2 /kg^2 kg,

$M_{Moon} = 7.5 \cdot 10^{22}$ kg.

Solution:
a) We can find the speed of the Moon by the formula

$$v_{orbital} = \sqrt{\frac{GM_{planet}}{R_{planet} + h}}$$

$$v_{orbital} = \sqrt{\frac{6.67 \times 10^{-11} \times 6 \times 10^{24}}{3.8 \times 10^{8}}}$$

$\upsilon_{orbital}=1.03 \cdot 10^3$ m/s

b) Period could be found by the formula

$$T = \frac{2\pi R}{v}$$

$$T = \frac{2 \times 3.14 \times 3.8 \times 10^{8}}{1.03 \times 10^{3}}$$

T=2325404.64 s≡27 days

Example 2

The rocket is launched from a planet of mass $5{\times}10^{28}$ kg and radius of $3.5{\times}10^{8}$ m.The rocket can reach maximal speed of 120 km/s. What purposes can we use this rocket for? Can we use this rocket for circular orbit, elliptical orbit, to travel to other planets?

Solution:

Let's analyse the planet first. We need to calculate $\upsilon_{orbital}$ near to the planet and υ_{escape}

$$v_{orbital} = \sqrt{\frac{GM_{planet}}{R_{planet} + h}}$$

$$v_{orbital} = \sqrt{\frac{6.67 \times 10^{-11} \times 5 \times 10^{28}}{3.5 \times 10^{8} + 0}}$$

$\upsilon_{orbital}$ =97614 m/s

$$v_{escape} = \sqrt{\frac{2GM_{planet}}{R_{planet}}}$$

$$v_{escape} = \sqrt{\frac{2 \times 6.67 \times 10^{-11} \times 5 \times 10^{28}}{3.5 \times 10^{8}}}$$

υ_{escape} =138047 m/s

Now we compare the maximal speed of the rocket with found data.

We see that $\upsilon_{orbital} < \upsilon_{max} < \upsilon_{escape}$

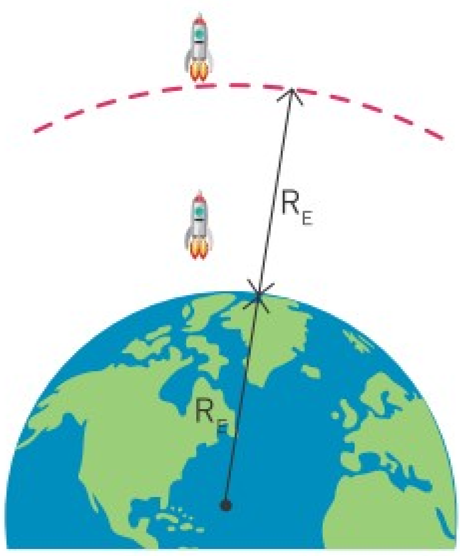
This means that we can use this rocket for

- Sending a satellite on the circular orbit
- Sending a satellite on the elliptical orbit

However, we can't use this rocket to travel to other planets.

Exercise 1

A rocket is on the surface of the Earth. Then, it rises at the point which R_E above the Earth. How different is the weight of the rocket at that point?



Exercise 2

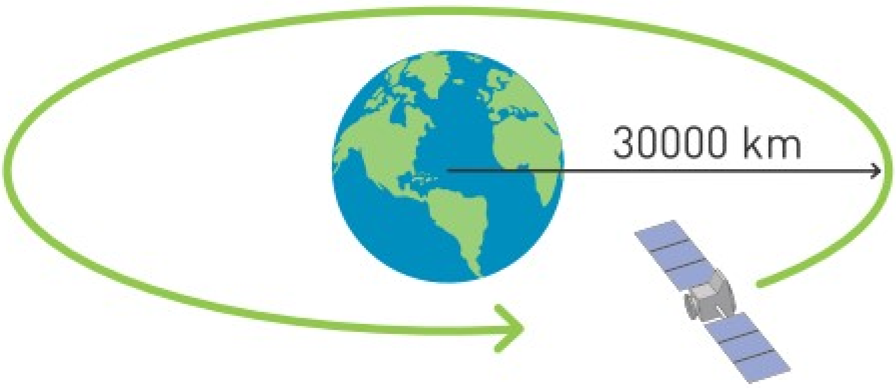
Find orbital and escape speeds for following planets:

	Mass	Radius
Planet 1	2.5×10^{22} kg	7×10^{3} km
Planet 2	12.1×10^{30} kg	12×10^{11} km
Planet 3	7×10^{18} kg	8×10^{6} km

Exercise 3

Generally, any orbiting satellite has engines with extra fuel. When satellites needs to go to higher orbit, satellite increases its orbital speed for a short time. Then on the higher orbits the speed decreases again.

$M_{Earth}=5.98\cdot10^{24}$ kg, $G=6.67\cdot10^{-11}$ Nm^2/kg^2 kg.



a) The satellite gets to the orbit of 30000 km. What is the orbital speed there?
b) What if you need to get rid of this satellite? How would you do this? Support your answer with relevant calculations.

Exercise 4

Construct a problem about satellites and motion of satellites. Let your classmates solve it. Check their answers and give feedback if needed.

Terminology

concept map
- түсінік пен идеяларды көрсететін диаграмма - диаграмма показывающая идеи и понятия.

Art time

Make “concept map” about problems and mistakes in Newton’s laws and Law of Gravity. Where and when do they NOT work?

Literacy

1. You send satellite that revolves around Earth in 3 hours. At what height from the surface of Earth does it revolve?
2. What is speed of your satellite?
3. How many kilometers does your satellite travel in one revolution?
4. How many similar satellites do you need to see ALL points on Earth?

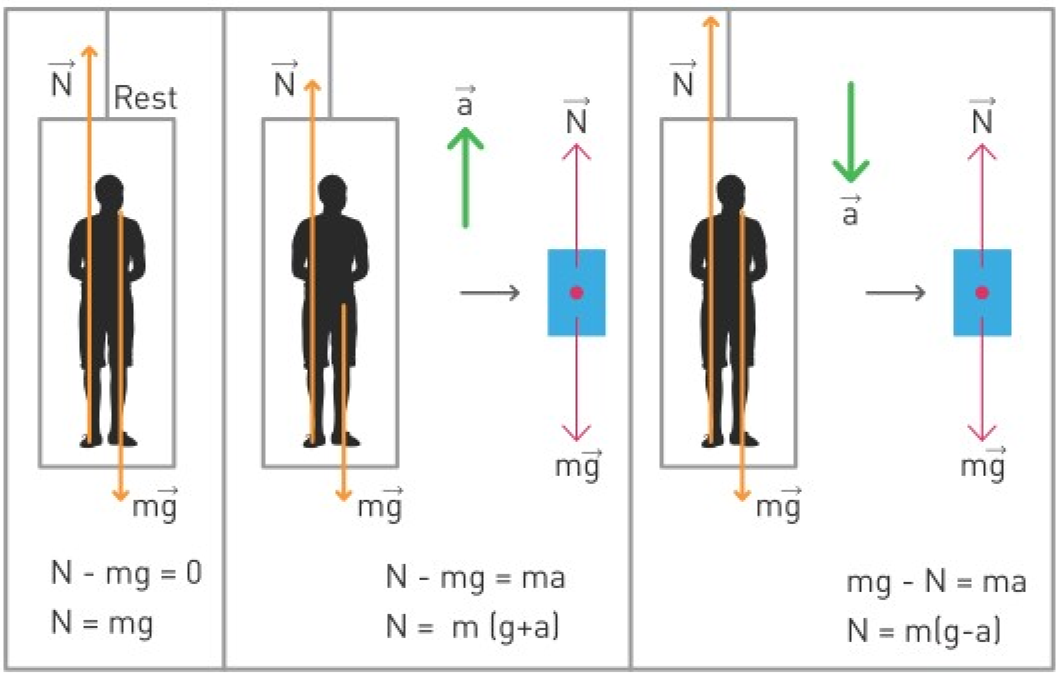
SUMMARY

3.1 Force is any push or pull.
The formula of the weight is **W=mg**,
W- gravitational force(weight) [N]
M-mass [kg]
g - gravitational field strength [m/s 2] or [N/kg]
The formula of spring's elastic force is
F=-kx
F- force of spring [F]
K- spring constant [N/m]
x- extension or compression of spring [m]
Friction force is always against the motion.
3.2 Newton's first law of motion states that we can change the speed of an object only by resultant force.If there is no resultant force,the speed of the object will not change.
Resultant force acting on a body is zero.
Fresultant= 0
State does not change: a) Constant speed b) Speed is zero
3.3 Newton's second law of motion states that the acceleration is directly proportional to force applied and indirectly proportional to mass.
The formula for the Newton's second law is $\mathbf{F_{net}=ma}$
F_{net}- resultant force acting on an object
m - mass of the object
a- acceleration of the object
Resultant force acting on a body is not zero.
$F_{resultant} \neq 0$
State changes: Speed changes
The resultant force means the sum of all forces.
3.4 Newton's third law of motion states that when one object applies a force on the second object, the second object applies the same force on the first one. However, with oppositedirection.
The formula for the Newton's third law is

$$\vec{F_1} = -\vec{F_2}$$

1 = – 2

Sign “-” means that the forces are in opposite directions.
Normal force is always perpendicular to the surface.
3.5 Laws of dynamics help us to understand why objects move or don’t move. We can apply them by drawing free body diagram. This diagram includes all forces that currently act on an object.
3.6 The weight of a person is a reaction force N from the surface. This example shows that weight can be changed by acceleration.
3.7



The weight of a person is a reaction force N from the surface. This example shows that weight can be changed by acceleration.
3.8. When elevator moves downward with g, it’s as if a man falls downward with g. During this motion a man does not feel own weight because there is no reaction force N. When an object has no weight, we call such condition as weightlessness.
When astronauts are in space, they don’t feel reaction force. They are weightless
3.9. Any object that has mass, attracts another object that has mass. If the distance between these objects increases, the attraction force decreases.

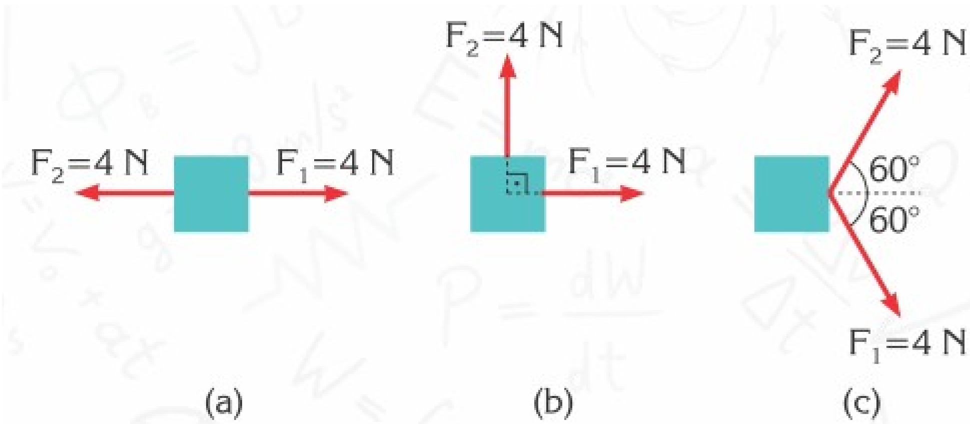
$$F = G\ \frac{m_1 \times m_2}{r^2}$$

F - attraction force [N]
G - gravitational constant
m_1- mass of first object [kg]
m_2- mass of second object [kg]
R - distance between centers of masses [meter]
3.11-12 Escape and orbital speeds of satellites:

$$v_{escape} = \sqrt{\frac{2GM_{planet}}{R_{planet}}} \quad v_{orbital} = \sqrt{\frac{GM_{planet}}{(R_{planet}+h)}}$$

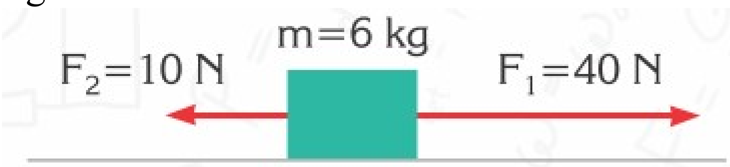
PROBLEMS

1. What is a force?
2. What is a “net force”?
3. The magnitudes and the directions of some forces acting on an object on a frictionless surface are shown in the figure. Find the net force in each case.

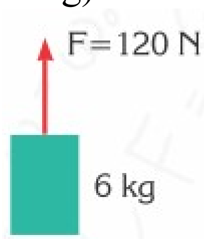


4. Explain the first law of motion and inertia
5. If a body is stationary, can we say that there is no force acting on it?
6. If no net force acts on a body, is it possible for it to move?
7. Explain the second law of motion
8. Express the unit Newton in terms of base SI units.
9. If there is only one force acting on a body, can it be at rest?
10. If the acceleration of a body is zero, can we say that no force acts on it?
11. Is the motion of bodies always in the same direction as that of the net force?
12. Can the direction of the net force acting on an object be opposite to that of its acceleration?
13. Which forces act on an apple when it
a) remains on a tree?
b) falls from a tree?
c) remains on the ground?
14. Prove that N/kg = m/s^2
15. Find the acceleration of an object experiencing a force F=120 N, as shown in the figure. (The surface is frictionless).

16. Find the acceleration of an object on a smooth surface, as shown in the figure.

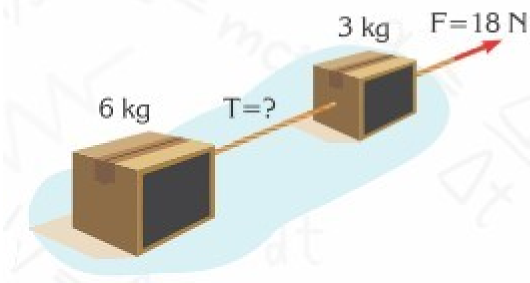


17. If the mass of the object in problem 3 is 2 kg, find the acceleration of the object for each case.
18. Find the acceleration of the object shown in the figure. (Take g=10 N/kg)

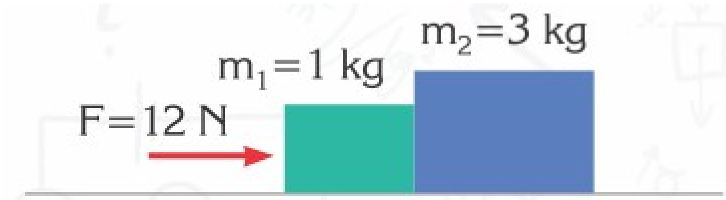


19. Two perpendicular forces act on a 400 g object. The object moves with an acceleration, $a=25\ m/s^2$. If F_1=8 N find the other force? (Assume no gravity acts)
20. What force is needed to stop a truck of mass 4 tons moving at a velocity of 36 km/h in 50 m?
21. An object of mass 1g is moving under a force of 1 N. Find its acceleration.
22. A 2-kg object accelerates from rest to 5 m/s in 0.4 s. What is the net force on the object?
23. A force of 20 N acts on a 5-kg object, initially at rest. What distance does the object travel in 3 s? (assume no gravity acts)
24. A 10 g-bullet leaves an 80 cm long barrel of a rifle at a velocity of 400 m/s. What is the average force on the bullet while it is in the rifle?
25. A man weighs 800 N on Earth. Find his weight and mass on Jupiter where g=26 N/kg. (on Earth g=10 N/kg).
26. Two boxes having masses of 3 kg and 6 kg, attached to each other by a rope, rest on a horizontal smooth surface. If the 3-kg box is pulled by a force of 18 N, as shown in the figure, find

a) the acceleration of the boxes
b) the tension in the rope between the boxes



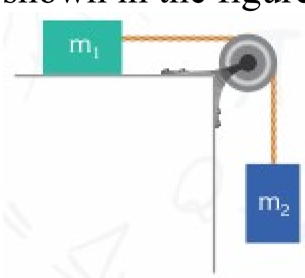
27. The system in the figure moves under the effect of a force of 12 N on a smooth surface. If m_1= 1 kg and m_2= 3 kg,



find
a) the acceleration of the system,
b) the force moving the mass m_2 .

28. On a building site, two buckets of paint of masses 10 kg each are attached to each other by a rope in the vertical as shown in the figure. Find the force F and the tension in the rope between the buckets when
a) the buckets are at rest
b) the buckets are pulled upwards with an acceleration of 1 m/s^2. (Neglect the weight of the rope.)

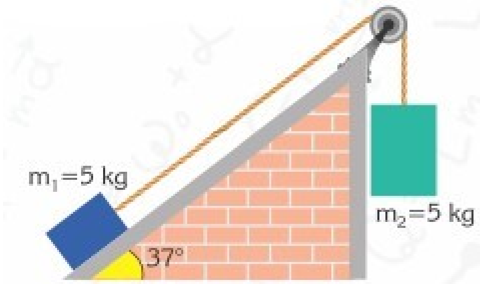
29. A frictionless system consisting of masses m_1=3 kg and m_2=1 kg is shown in the figure. If the system is released from rest,



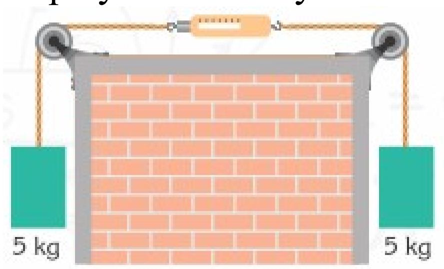
find
a) the acceleration of the system,
b) the tension in the string. (Take g=10 N/kg)

30. If the inclined plane, shown in the figure, is frictionless, find the acceleration of the object.
(g=10 m/s 2 ; sin 37°=0.6, cos 37°=0.8)

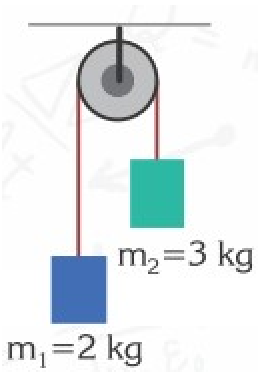
31.Two blocks, 5 kg each, are attached to each other with a string. They are placed on an inclined frictionless plane, as shown in the figure, then released. (sin37°=0.6; cos 37°=0.8)



Find
a) the acceleration gained by the system
b) the tension in the string.
32. Two blocks, of mass 5 kg each, are attached to two ends of a dynamometer by the strings shown in the figure. What is the force displayed on the dynamometer? (Take g=10 N/kg)



33. Neglecting the friction in the system shown in the figure.

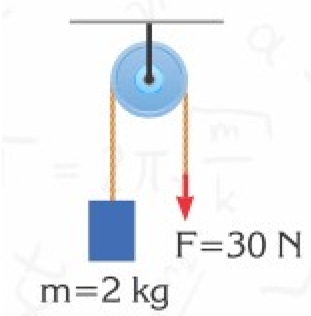


Find

a) the acceleration of the system

b) the tension in the string

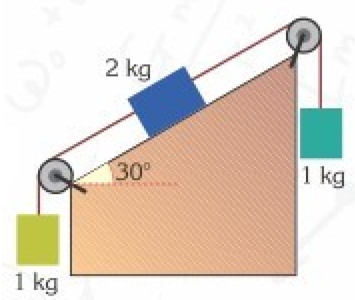
34. Neglecting the friction in the system shown in the figure find



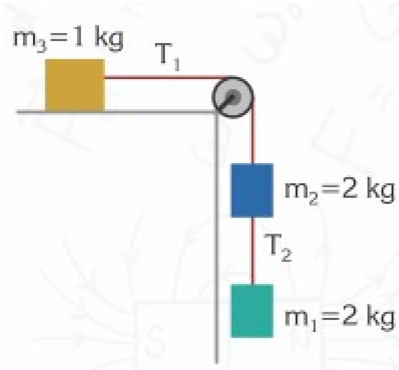
a) the acceleration of the object

b) the tension in the string

35. If the system shown in the figure is frictionless, what is the acceleration of the system? (sin30°= 0.5)

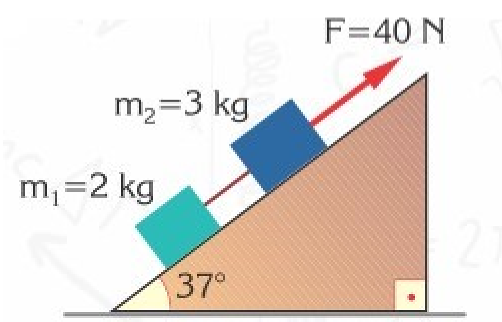


36. What is the ratio of the tensions in the T_1/T_2 strings connecting the masses moving in the smooth system shown in the figure?

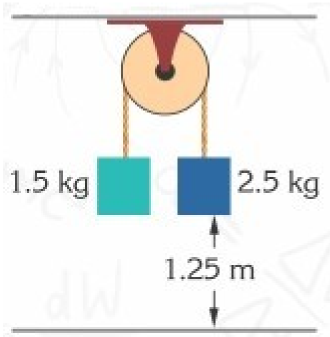


37. For the frictionless system shown in the figure,

find
a) the acceleration of the system
b) the tension T in the string. (sin 37 = 0.6; cos 37 = 0.8)
38. 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,

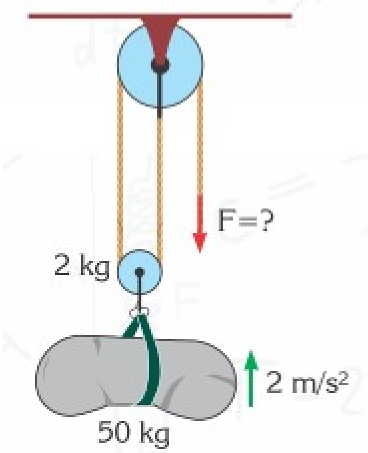


a) what is the acceleration of the system
b) find the tension in the string connecting the masses. (sin 37=0.6, cos 37=0.8)
39. The masses in an Atwood machine are 1.5 kg and 2.5 kg (See the figure). If the masses are at a height of 1.25 m when the system is released.

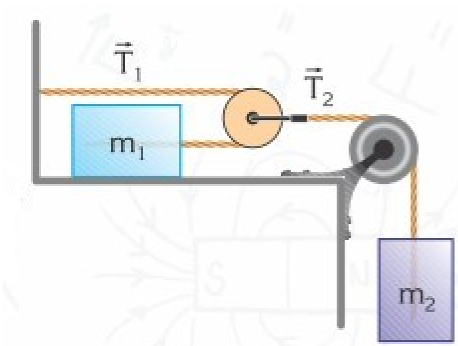


a) how many seconds does it take for the greater mass to reach the ground?
b) What is the velocity of the smaller mass when the greater one strikes the ground?
c) If this experiment were carried out on the Moon, how many seconds would it take for the 2.5 kg mass to fall? (g_E=10 N/kg, g_M=g_E/6)

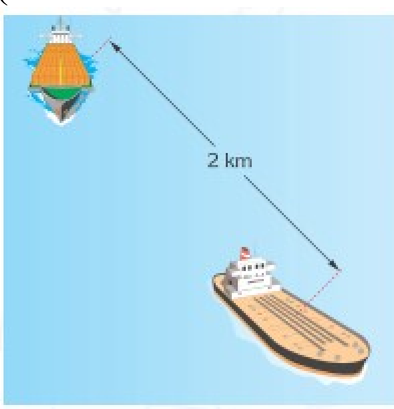
40. The cement bag shown in the figure has a mass of 50 kg and the small pulley has a mass of 2 kg. If the cement bag is pulled upwards with an acceleration of 2 m/s 2 , find the force F pulling the rope.



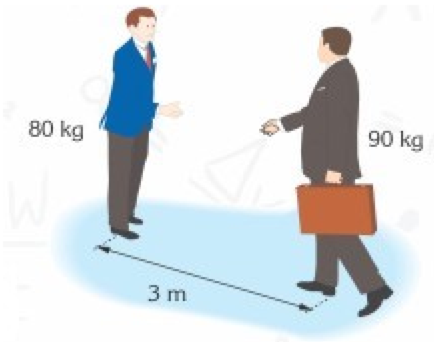
41. The masses m_1=1 kg and m_2=6 kg, in the system shown in the figure, are attached to each other with weightless pulleys and strings. If the pulleys and the surface are smooth



a) what are the accelerations of m_1 and m_2?
b) what are the tensions in the strings?
42. Why does an object thrown upwards slow down, stop and fall back downwards?
43. What force will a human body experience at the center of the Earth?
44. What does the attraction between masses depend upon?
45. Which amount of force is greater, apple attracting the Earth or Earth attracting an apple?
46. Why is the weight of a body different at the poles and at the equator of the Earth?
47. Is it true that the Earth and the Moon apply "equal and opposite" forces upon each other? Since it has a smaller mass, why does the Moon not crash into the Earth?
48. If the mass of the Earth is 6×10^{24} kg, and the mass of the Moon is 7×10^{22} kg and the distance between them is 384 000 km, calculate the gravitational force acting between them.
(Take $G = 6.67\times10^{-11}$ $N\cdot m^2/kg^2$)
49. If the distance between two ships, one weighing 8×10^5 tons and the other 3×10^5 tons is 2 km, find the gravitational force between these ships.
(Take $G = 6.67\times10^{-11}$ $N\cdot m^2/kg^2$)



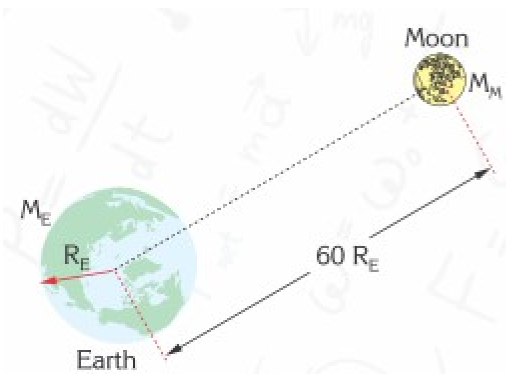
50. What is the gravitational force acting on two men, one weighing 80 kg and the other weighing 90 kg, who are standing 3 metres away from each other?
(Take $G = 6.67\times10^{-11}$ $N\cdot m^2/kg^2$)



51. What is the ratio of the weight of a rocket of mass 1800 kg on the Earth to the gravitational force acting on it when it is at a distance equal to the Earth's radius, above the Earth?

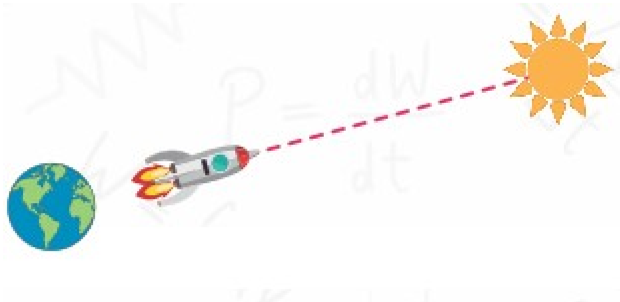
52. The mass of Jupiter is 1.9×10^{27} kg and its radius is 7×10^{4} km, whereas, the mass of Mars is 6.4×10^{23} kg and its radius is 3.4×10^{3} km. Find the gravitational acceleration on the surfaces of Jupiter and Mars. (Take $G = 6.67\times10^{-11}\ N\cdot m^2/kg^2$)

53. Where is the gravitational force acting on an object between the Earth and the Moon zero?

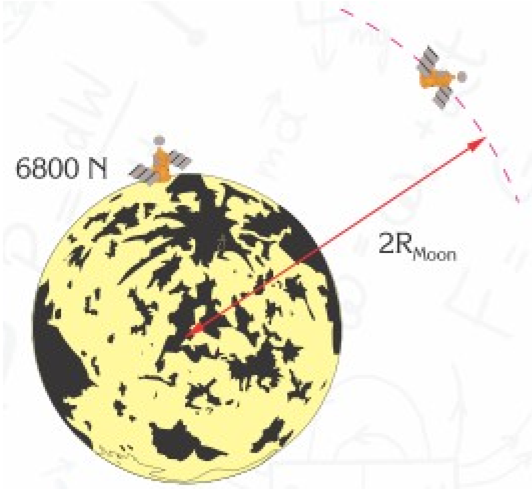


Find the result in terms of R_E . (The mass of the Earth is 81 times greater than that of the Moon and the distance between their centres is approximately 60 times greater than Earth's radius.)

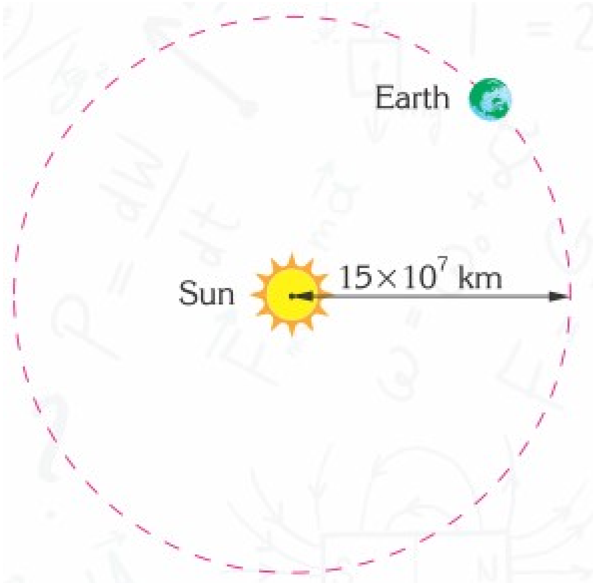
54. At what distance from the Earth do the gravitational forces of the Earth and the Sun, affecting a spaceship which is travelling from Earth towards the Sun, cancel each other out? (The distance between the Earth and the Sun is 15×10^{7} km; $M_E = 6\times10^{24}$ kg; $M_S= 2\times10^{30}$ kg.



55. The weight of a space probe on the Moon is 6800 N.



a) If the gravitational acceleration of the Moon is approximately 1.7 N/kg, what is the mass of the probe?
b) What is the gravitational force on the probe while it is orbiting the Moon at twice the radius of the Moon from its centre?
56. A communication satellite is orbiting the Earth 36 000 km above sea level. Knowing that the radius of the Earth is 6 400 km, its mass is 6×10 24 kg, and the universal gravitational constant is $G = 6.67\times10^{-11}$ $N\cdot m^2/kg^2$ find
a) the period of the satellite?
b) the tangential speed of the satellite?(Take π=3.14)
57. Considering the Earth is orbiting in a circular path around the Sun, as shown in the figure.

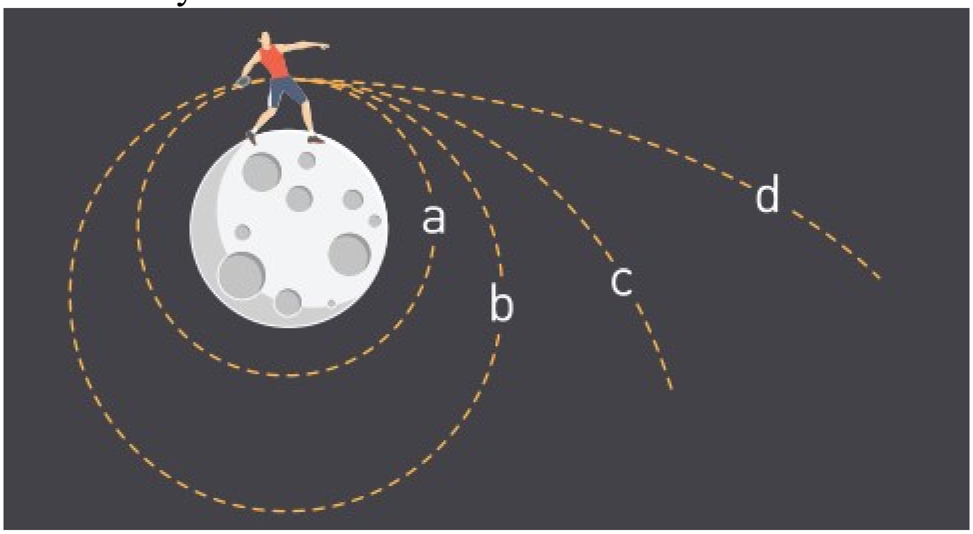


a) Calculate the speed of rotation of the Earth around the Sun.

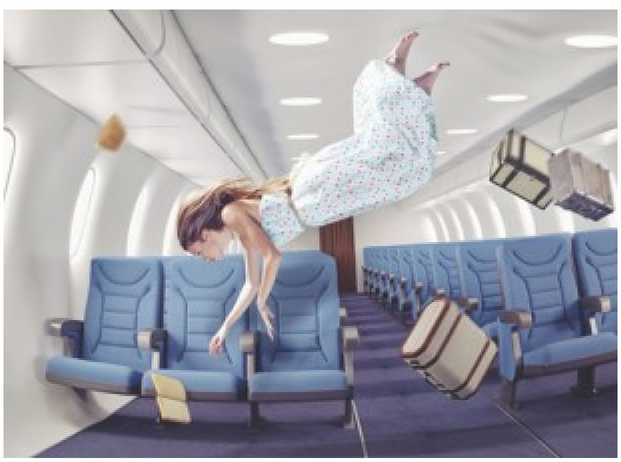
b) Calculate the mass of the Sun.(Take π=3.14; 1 year=365 days)

PHYSICS IN LIFE

1. Imagine that you are at moon. At what speed you should throw disc horizontally to make it satellite of the moon?

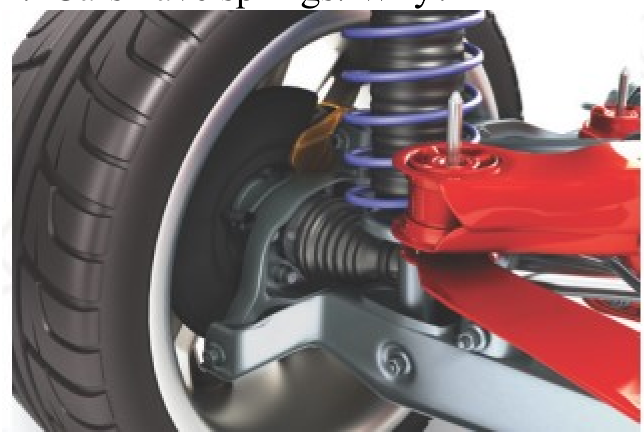


2. Why sometimes people feel weightlessness inside plane or even inside cars?

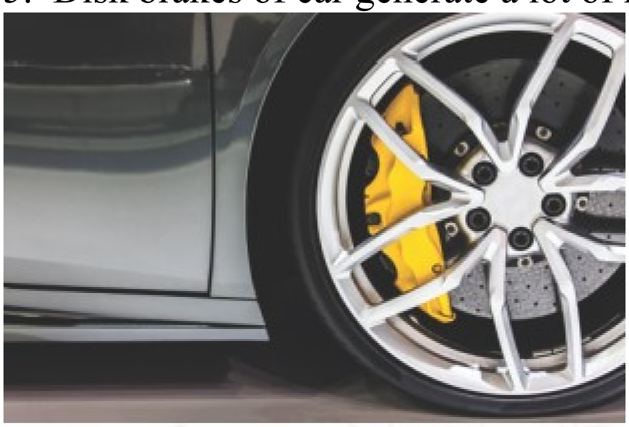


3. When you hit the wall, you feel the pain. Why?

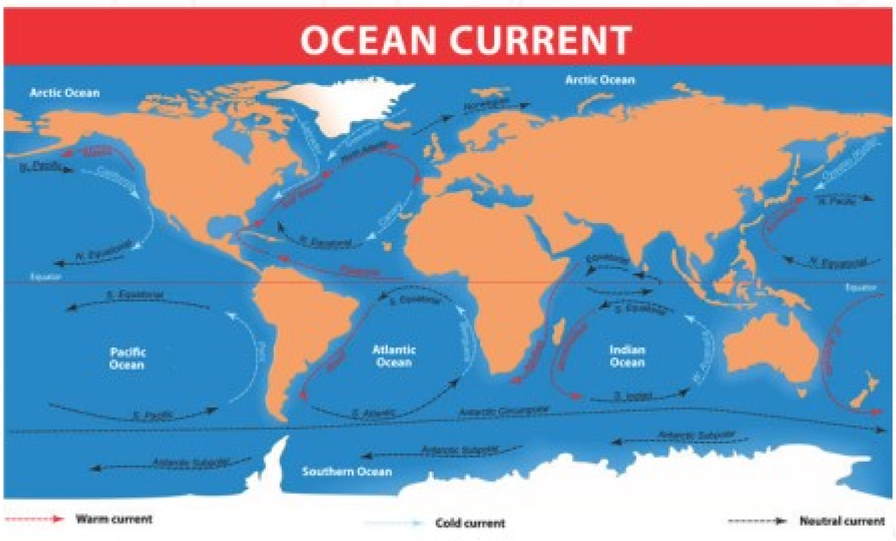
4. Cars have springs. Why?



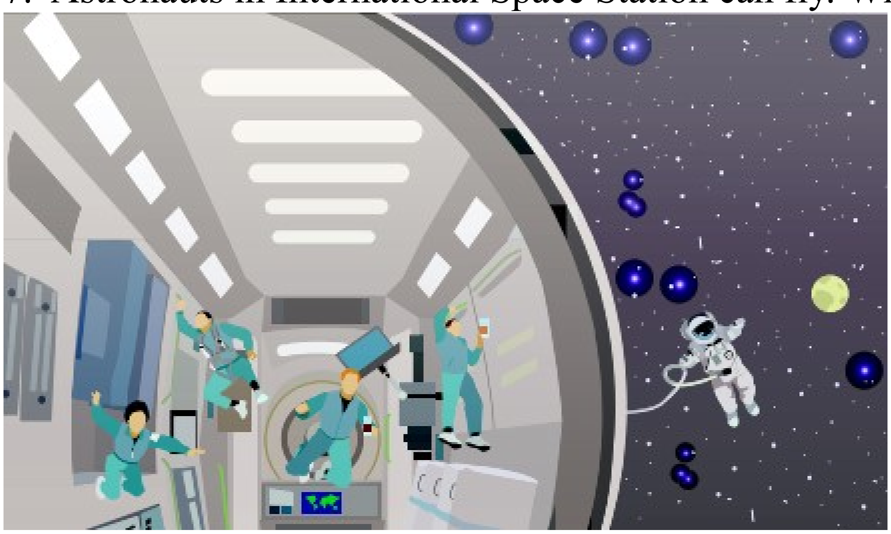
5. Disk brakes of car generate a lot of heat. Why?



6. Ocean currents rotate clockwise in Northern hemisphere and anticlockwise in Southern hemisphere. Why?



7. Astronauts in International Space Station can fly. Why?



8. Tankers cut off engines 25 km before the port. Why?

9. When rocket is launched, astronauts are in such position. Why?

CHAPTER 4. CONSERVATION LAWS

4.1 MECHANICAL WORK
4.2 WORK-ENERGY THEOREM
4.3 CONSERVATION OF ENERGY
4.4 IMPULSE AND MOMENTUM
4.5 CONSERVATION OF MOMENTUM
4.6 JET PROPULSION
4.7 PROBLEM SOLVING

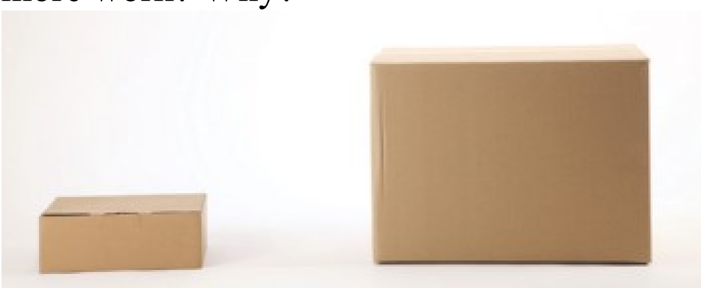
4.1 MECHANICAL WORK

You will

determine mechanical work analytically and graphically;

Question

You push small and big crates to same distance. In which case do you do more work? Why?



Children are playing together, Figure 1. One of them pulls the cart from the rest. Let us say they travel 40 meters. We will neglect friction between ground and the box. Initial velocity of the box is $\upsilon_o=0$.

Figure 1

Let us use Newton's second law

$$a = \frac{F}{m}$$

and insert to formula

$$v^2 = v_0^2 + 2ax$$

We get

$$v^2 = 2\left(\frac{F}{m}\right)x$$

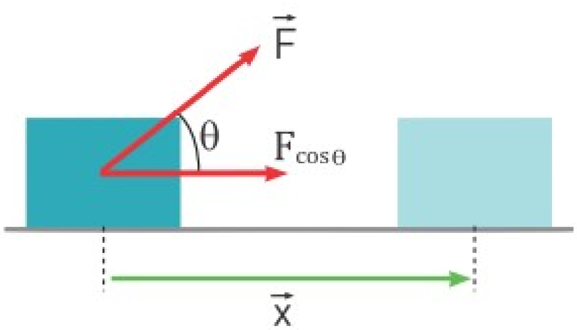
Let us change this expression to

$$\frac{mv^2}{2} = Fx$$

The left part

$$\frac{mv^2}{2}$$

is kinetic energy of the box. Then, the right side Fx must have the unit of energy. It actually means that the child have spent own energy to push the box. We can say "the force F has done work". In physics Fx is called mechanical work, and the energy is ability to do work. If the child does not have enough energy, he will not be able to do mechanical work.



A=Fx*cos*θ

A - mechanical work [N . m] or [J]

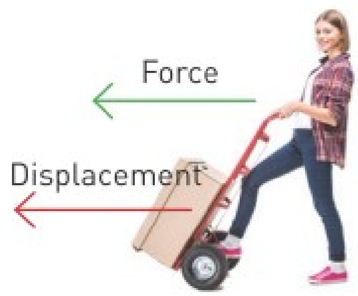
F - applied [N]

x - distance travelled [m]

θ - angle between F and x

Work is a scalar quantity. It does not have a direction associated with it.

a) No work



b) Mechanical work

Figure 2

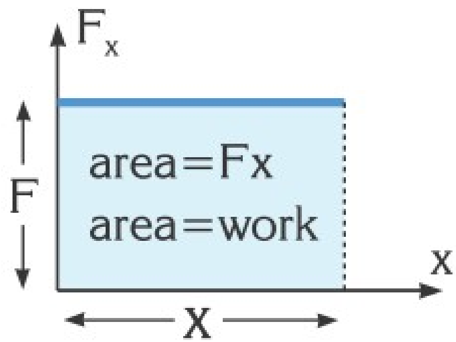
The formula means that when force acts on an object in a certain displacement, it can change its speed. Mechanical work is done under 2 conditions.

1. There must be force.
2. There must be distance travelled in direction of force.

If angle between force and displacement	Work is
Less than 90^0	positive
Equal to 90^0	zero
Bigger than 90^0	negative

Force - Position (F - x) Graphs

If force and displacement are parallel, the area under the force-displacement graph equals work done by that force.



Example 1

The object in the figure moves under the action of four forces on a smooth surface, as shown in the figure. What is the net work done on the object when it moves a distance of 5m, if F_1 =20 N, F_2=13 N and θ=37⁰? (Take cos37° = 0.8)

Solution:

A_{mg}= 0 and A_N= 0 (because both forces are perpendicular to the displacement)

$A_1 = F_1 x \cos \Theta$

$A_2 = F_2 x \cos 180°$ (angle between the force F_2 and the displacement vector is 180°, cos 180° = –1)

$A_2 = - F_2 x$

The net work done on the object along distance s is,

$A_{net} = A_1 + A_2 + A_{mg} + A_N$

$A_{net} = F_1 x \cos 37° - F_2 x + 0 + 0$

A_{net} = (20 N)(5 m)(cos 37°) – (13 N)(5 m)

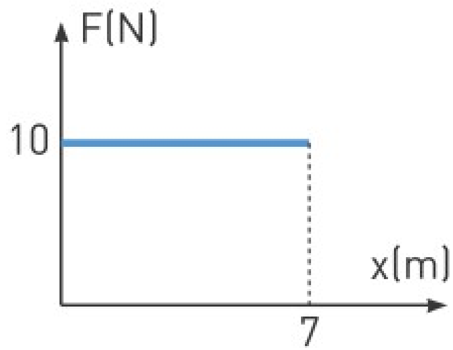
A_{net} = 80 J - 65 J

A_{net} = 15 J

Note that the net work done on the object equals the work done by the net force on the object.

Example 2

Figure shows the graph F-x. What work is done by the force?



Solution:

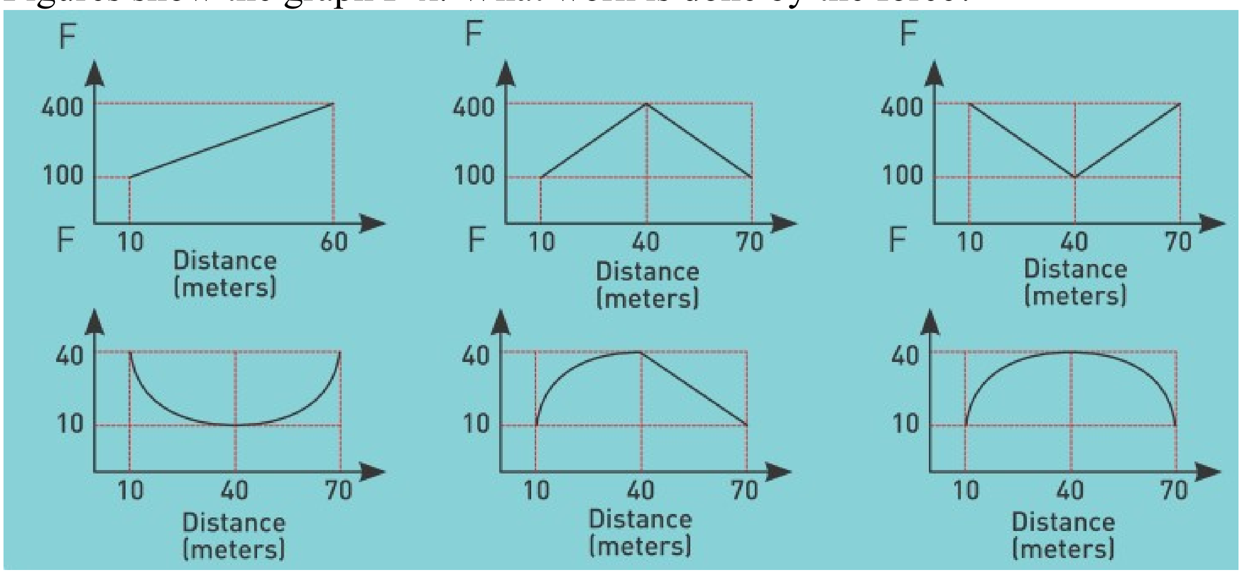
Area under the line gives us the work done by the force.

Area=Fx=10 N·7m=70 Nm

Area=W=70 J

Literacy

Figures show the graph F-x. What work is done by the force?



Art time

Make “rollback can”. Why does it roll back?

Fact

Ants are very strong and hard-working. They can carry between 10 to 50 times their own body weight! The Asian weaver ant, for example, can lift 100 times its own mass.

Research time

You and your classmates are a group of engineers. There are many bricks. The mass of each brick is 4 kg. You should build whatever you want. But it must be something new and beautiful. You have only
0.5 MJ of energy to build. Draw project of your building and calculate number of bricks that you need.

Activity

Make a list of 5 sports and specify the work done in each sport. Draw it and show your examples to classmates.

Terminology

crate - ағаш қорап / деревянный ящик
case - жағдай / случай
insert - кірістіру / вставить

condition - шарт / условие
brick - кірпіш / кирпич

4.2 WORK-ENERGY THEOREM

You will

explain relationship between work and energy;

Question

What does happen to speed of shot if work of shot putter increases?

Work and components of force

A girl on the Figure 1 pulls a cart. She applies force F at angle. In such cases to use the component of force which is parallel to the displacement: F_x . Vertical component F_y does not do work because the cart doesn't move vertically.

Figure 1

Then, the mechanical work is

$$A = (F\cos\alpha)x \text{ or } A = Fx\cos\alpha$$

Work and friction force

In daily life we always have friction force. It is opposite to the speed of the object. For example, Figure 2. In this case mechanical work is A=(F-Ff)x . This is because force F does positive work, and friction force does negative work.

Work and energy theorem

When force acts on an object, sometimes the initial velocity is not zero. For example, Figure 3.

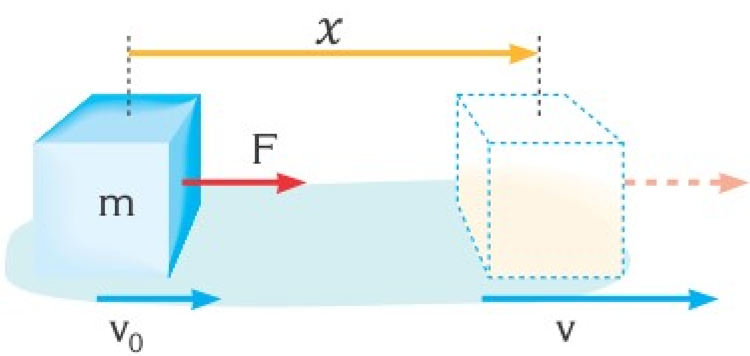


Figure 3

Due to work done kinetic energy changes. We write it in the formula

$$\frac{mv_{final}^2}{2} - \frac{mv_{initial}^2}{2} = Fx$$

This formula is called work and energy theorem. It is obtained from

$$a = \frac{F}{m}$$

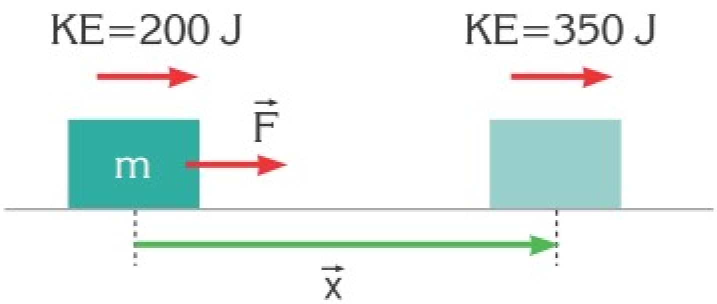
and

$$v^2 = v_0^2 + 2ax$$

The meaning of this theorem is “if you want to change the kinetic energy of an object, you need to do mechanical work (spend energy).”

Example

The kinetic energy of an object increases from 200 J to 350 J, under constant force, as shown in the figure. What is the work done on the object?



Solution:
Net work done on an object equals the change in kinetic energy of the object. Therefore,

$A_{net}=KE_f-KE_i$

$A_{net} = 350\ J - 200\ J$

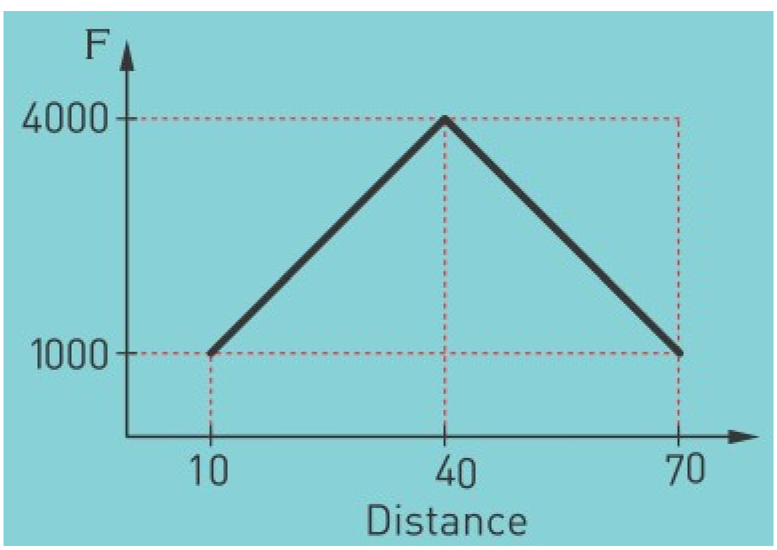
$A_{net} = 150\ J$

Activity

Why do you have to push pedals to keep your bicycle at constant speed? Discuss in pairs.

Literacy

1. 1700 kg sports car goes from 0 to 100 km/h in 35 meters. Determine force that engine produces. Is it bigger or smaller than your weight?
2. On the graph you see force that car engine produces. Mass of the car is 2000 kg, initial speed is 50 km/h. Determine final speed. Is it more or less than 100 km/h?



Terminology

engine - қозғалтқыш / двигатель
impossible - мүмкін емес / невозможный

Art time

Make “rubber band helicopter”. Why does it fly?

Fact

Friction, in fact, always opposes movement, but without it walking and keeping a car on the road would be impossible.

Research time

Find "Forces and motion basics Phet" simulation. Learn how force, work, energy and speed are related.

4.3 CONSERVATION OF ENERGY

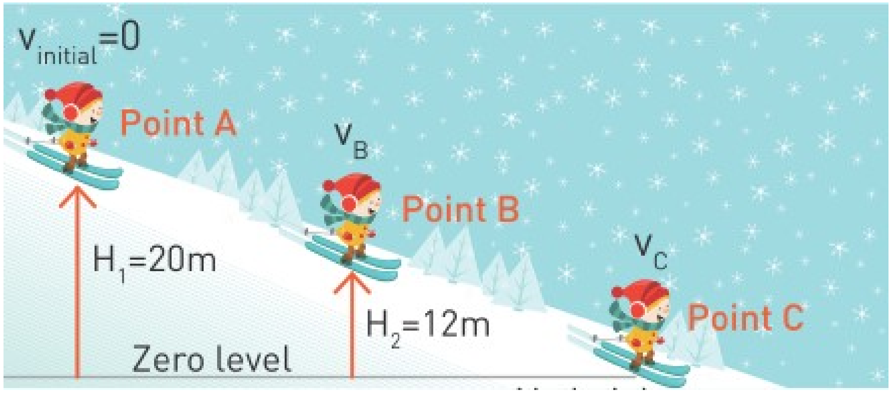
You will

apply law of conservation of energy for problem solving;

Question

Why speed of “bungee jumper” is zero at some points? At which point speed of “bungee jumper” is maximum?

A child slides down from point A, Figure 1. As the child goes down, his speed increases. We can use law of conservation of energy to describe motion of the child. This law has 2 main rules:
Rule 1: Energy can transform from one form to another. It can not be destroyed or created.
Rule 2: Total energy of an isolated system at any point is always the same.



Let us apply these rules.
Rule 1: Potential energy (E_p) of the child is decreasing. However, kinetic energy (E_k) is increasing. We say E_p transforms into E_k . In this example we neglect friction and air resistance forces.
Rule 2: When we find total energy at a point, we need to have one common zero level, Figure 1. Each E_p is calculated according to the common zero level. Then, let's use the table for points A, B, and C.

	Point A	Point B	Point C
Potential	$E_p = mgH_1$	$E_p = mgH_2$	0
Kinetic	0	$E_k = \frac{1}{2}mv_B^2$	$E_k = \frac{1}{2}mv_C^2$
Total (E_p+E_k)	$mgH_1 + 0$	$\frac{1}{2}mv_B^2 + mgH_2$	$0 + \frac{1}{2}mv_C^2$

Now we can equalise total energy (E_p+E_k) of a point with any other point. For example, points A and B.

$$mgH_1 + 0 = \frac{1}{2}mv_B^2 + mgH_2$$

We can express this rule in the form

$$(E_1 + E_2 + E_3 + \cdots + E_n)_{initial} = (E_1 + E_2 + E_3 + \cdots + E_n)_{final}$$

Elastic potential energy

We can store energy in springs, Figure 2.

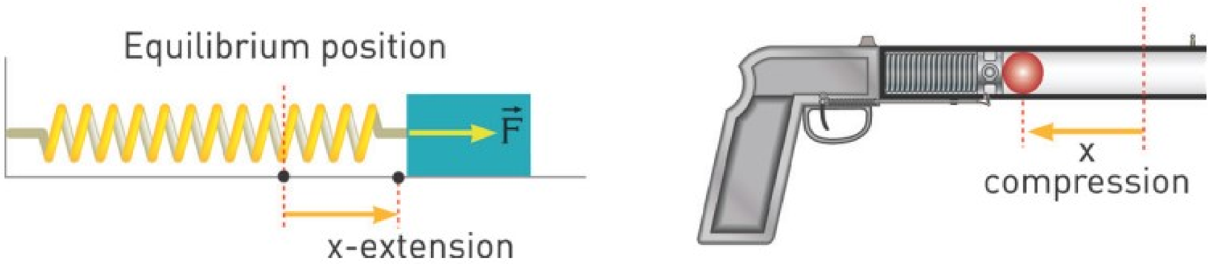


Figure 2

Let's call it E_p . The formula of E_p is

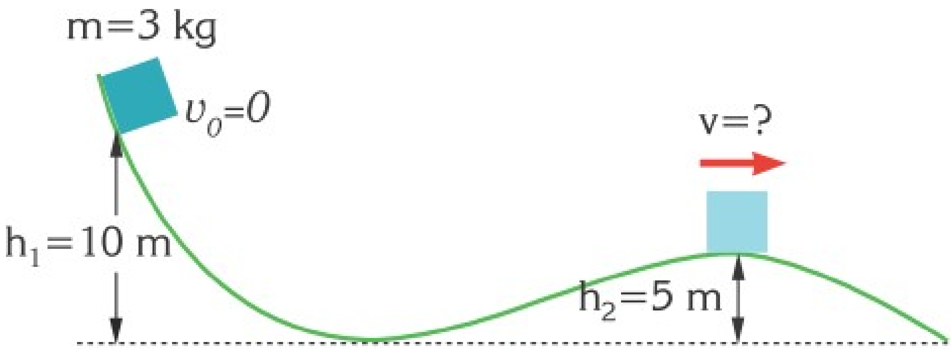
$$E_p = \frac{1}{2}kx^2$$

k - spring constant [N/m]
x - extension or compression [m]
More examples of E_p are on the Figure 3.

Figure 3

EXAMPLE

What is the velocity of an object at h=5 m?



Solution:

At the beginning, the object has potential energy. At the second position the object has both potential and kinetic energy. Using the law of conservation of mechanical energy:

$$mgh_1 = mgh_2 + \frac{1}{2}mv^2; \quad \frac{1}{2}mv^2 = mg(h_1 - h_2);$$

$$v = \sqrt{2g(h_1 - h_2)}; \quad v = \sqrt{2 \times 10 \times (10 - 5)}; \quad v = 10\, m/s;$$

Activity

a) Which energy transformation can you see in each sport?
b) Draw a real life example where you can see law of conservation of energy.

Literacy

1. Bungee jumper (60 kg) jumps from 100 m height. Bungee cord has length of 30 m and spring constant of 100 N/m. Determine maximum speed of jumper and minimum distance between jumper and water.
2. You kick soccer ball with speed of 30 m/s upwards. What is maximum height of ball? How many storey building is it?

Art time

Make “rubber band plane”. Why does it fly?

Terminology

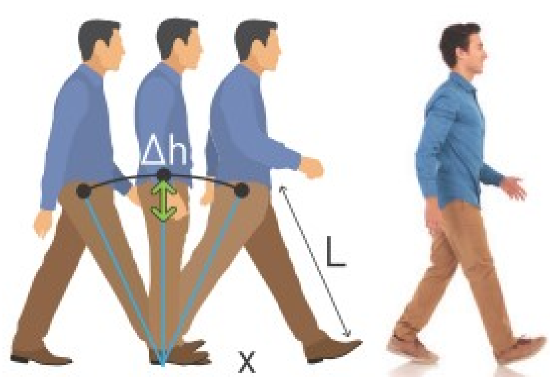
conservation - сақталу / сохранение
destroy - жоғалып кету жойылу/ разрушение
extension - кеңейу / удлинение
compression - қысу / сжатие
estimate - шамалап есептеу / подсчитывать приблизительно
pace - қарқын / темп

IT-link

Play this Go phet.com. Search “Energy Skate Park”

Research time

When we walk, we spend energy. This is because we lift our body a little.



1 pace takes energy $E_p = mg\Delta h$. Δh is found by

$$\Delta h = L - \sqrt{L^2 - (X/2)^2}$$

a) Estimate the energy you spend to walk 5 km.
b) Choose 5 food products. Estimate number of paces and distance you need to walk in order to burn the energy you ate.

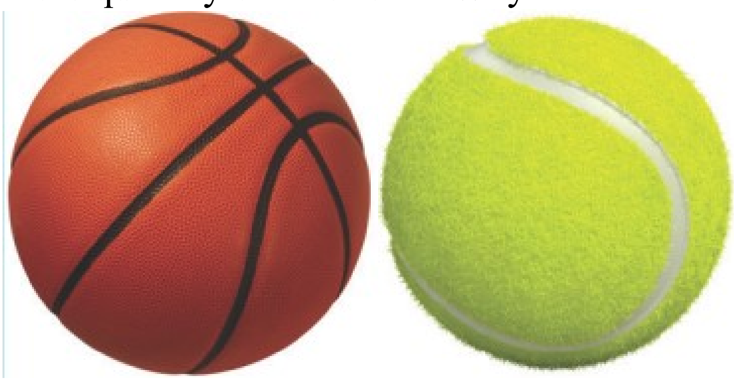
4.4 IMPULSE AND MOMENTUM

You will

tell the difference between concepts of "momentum" and "impulse";

Question

Basketball and tennis ball move at the same speed. Which one does have more quantity of “motion”? Why?



Consider the examples on Figure 1. They need to increase speeds of object from 0 to 10 m/s.

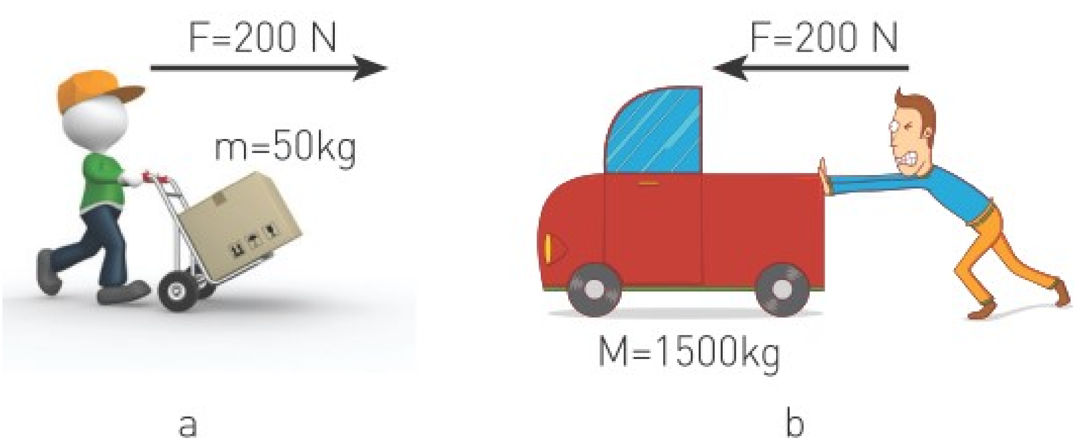


Figure 1

It is clear that case b takes more time. We can show it by combining 2 formulas:

$$\vec{F} = m\vec{a} \text{ and } \vec{a} = \frac{\overrightarrow{\Delta v}}{\Delta t}$$

We get Newton's second law in different form.

$$\vec{F}\Delta t = m\overrightarrow{\Delta v}$$

Let us use this formula.

The Box	The Car
$200\Delta t = 50 \times 10$ $\Delta t = 2.5\ s$	$200\Delta t = 1500 \times 10$ $\Delta t = 75\ s$

The left side

$$\vec{F}\Delta t$$

is called impulse. It means "how long the force F has acted".
The right side

$$m\overrightarrow{\Delta v}$$

is called change in momentum.

Momentum

It means "quantity of motion" that we have, Figure 2. Both mass and velocity are included in "quantity of motion". When body has a great momentum, it takes more time to change its speed.

Figure 2

The formula of momentum

$$\vec{p} = m\vec{v}$$

m - mass [kg]
v - velocity [m/s]
p - momentum [kg×m/s]

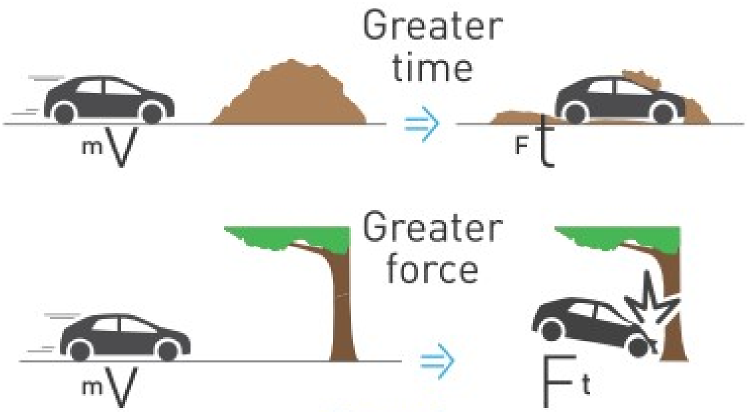
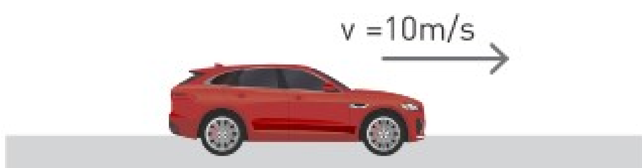


Figure 3

Impulse can change momentum. We can produce great impulse either by greater force or greater time, Figure 3. Both impulse and momentum are vector quantities. That's why we need to choose "+" and "-" directions for velocity and force. This is because the speed of an object can increase under effect of force, and sometimes the speed can decrease.

Example

A car having a mass of 900 kg is moving to the east at a velocity of 10 m/s.



Calculate
a) the momentum of the car
b) the impulse when velocity increases to 30 m/s in 5 seconds
Solution:
a) From the equation of momentum

$$\vec{p} = m\vec{v}$$

$p = m\upsilon = 900 \times 10 = 9000$ kg·m/s
The momentum has the same direction as the velocity, to the east.
b) The initial and final momenta of the car are

$$\vec{p_i} = m\vec{v_i}; \qquad p_i = mv_i; \qquad p_i = 900 \times 10 = 9000\ kg \cdot m/s$$

$$\overrightarrow{p_f} = m\overrightarrow{v_f}; \quad p_f = mv_f; \quad p_i = 900 \times 30 = 27000\, kg \cdot m/s$$

$$\vec{F}\Delta t = \overrightarrow{\Delta p}; \quad \Delta p = p_f - p_i$$

$$\Delta p = 27000 - 9000 = 18000\, kg \cdot m/s$$

$$F\Delta t = 18000\, kg \cdot m/s;$$

Research time

Make "EGG DROP" device. You should drop the egg from 2 m. Egg should not be broken.

Literacy

1. Car of 1.5 tons moves with 90 km/h speed.
a) In how many seconds does car stop if friction force is 7.5 kN?
b) How many meters is stopping distance?
c) Is it safe or dangerous to drive with 90 km/h in city? Why?
2. You throw an egg into a wall with all force you have. However, the egg does not break. What kind of wall may it be? Draw it.

Activity

a) How can we use

$$\vec{F}\Delta t = m\overrightarrow{\Delta v}$$
?

b) Draw 2 other examples from daily life.
c) Draw 2 examples from a movie, a book, a song, a poem, etc.






Terminology

momentum - дене импульсы / импульс тела
impulse - күш серпіні, күш импульсы / импульс силы

Research time

Make “EGG DROP” device. You should drop the egg from 2 m. Egg should not be broken.

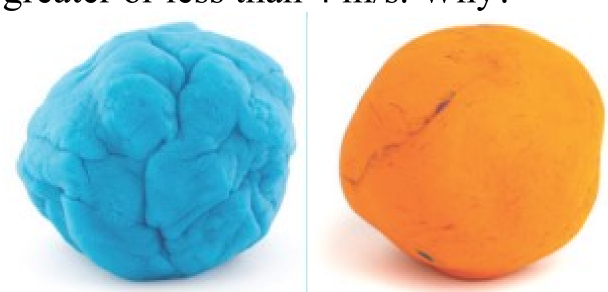
4.5 CONSERVATION OF MOMENTUM

You will

define law of conservation of momentum and use it for problem solving;

Question

Blue plasticine ball moves with 4 m/s. It strikes orange plasticine ball that does not move. They have same mass. What is their common speed? Is it greater or less than 4 m/s. Why?



During collisions total momentum of system is conserved. It means that sum of momentums before collision is equal to sum of momentums after collision. It is called law of conservation of momentum.

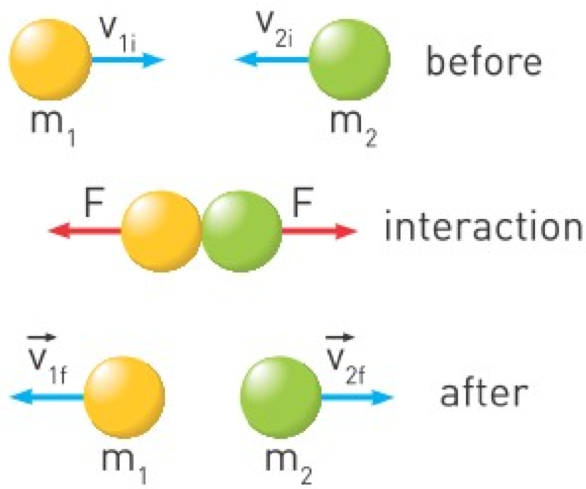


Figure 1

$$(\vec{p}_1 + \vec{p}_2 + \vec{p}_3 + \cdots + \vec{p}_n)_{initial} = (\vec{p}_1 + \vec{p}_2 + \vec{p}_3 + \cdots + \vec{p}_n)_{final}$$

There are two types of collisions: inelastic and elastic.

Inelastic collision

The case when objects stick together after collision, Figure 2.

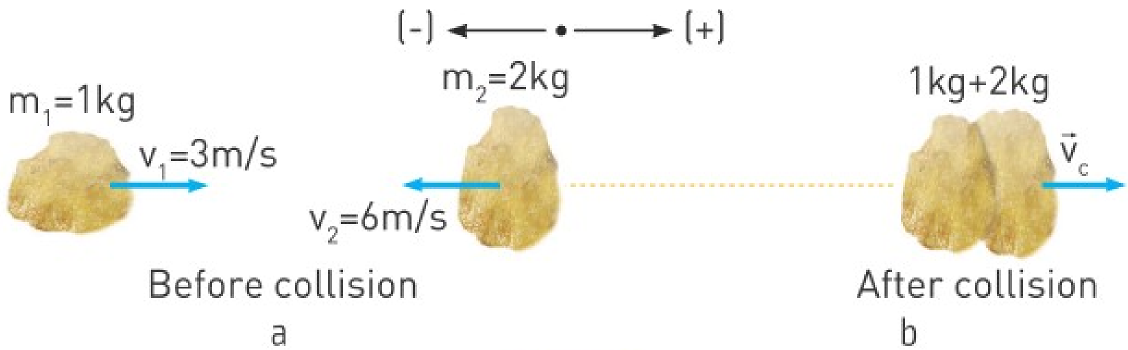


Figure 2

Let us write conservation of momentum for this case.

$$m_1\vec{v}_1 + m_2\vec{v}_2 = (m_1 + m_2)\vec{v}_c$$

Before solving this problem, we have to convert vector addition into scalar form by paying attention to directions of motion of bodies. According to the figure 2 before collision second object moves in negative direction so it is taken with "-"sign.

$$m_1 v_1 + m_2(-v_2) = (m_1 + m_2)v_c$$

$$m_1 v_1 - m_2 v_2 = (m_1 + m_2)v_c$$

$$\upsilon_c = \frac{m_1 \upsilon_1 - m_2 \upsilon_2}{(m_1 + m_2)} = \frac{1 \cdot 3 - 2 \cdot 6}{1 + 2} = -3\, m/s$$

We get "- 3 m/s" that means both objects after collision will move in negative direction.

Note: in inelastic collision energy is not conserved because some energy is lost due to deformation.

$$E_{initial} \neq E_{final}$$

$$Q = E_{initial} - E_{final}$$

Elastic collision

In an elastic collision both momentum and energy are conserved.

$$(\vec{p}_1 + \vec{p}_2 + \vec{p}_3 + \cdots + \vec{p}_n)_{initial} = (\vec{p}_1 + \vec{p}_2 + \vec{p}_3 + \cdots + \vec{p}_n)_{final}$$

$$m_1 \vec{\upsilon}_{1i} + m_2 \vec{\upsilon}_{2i} = m_1 \vec{\upsilon}_{1f} + m_2 \vec{\upsilon}_{2f} \quad (1)$$

$$(E_1 + E_2 + E_3 + \cdots + E_n)_{initial} = (E_1 + E_2 + E_3 + \cdots + E_n)_{final}$$

$$\frac{1}{2} m_1 \upsilon_{1i}^2 + \frac{1}{2} m_2 \upsilon_{2i}^2 = \frac{1}{2} m_1 \upsilon_{1f}^2 + \frac{1}{2} m_2 \upsilon_{2f}^2 \quad (2)$$

In order to simplify the application of these equations they can be rearranged into:

$$\vec{\upsilon}_{1i} + \vec{\upsilon}_{1f} = \vec{\upsilon}_{2i} + \vec{\upsilon}_{2f} \quad (3)$$

Note: all problems related to elastic collision can be solved by using equations (1) and (3).

When we use conservation of momentum and additional formula, we get υ_{1f}=-13 m/s and υ_{2f}=2 m/s. This means, that after collision the yellow ball goes to the left, and the green goes to the right.

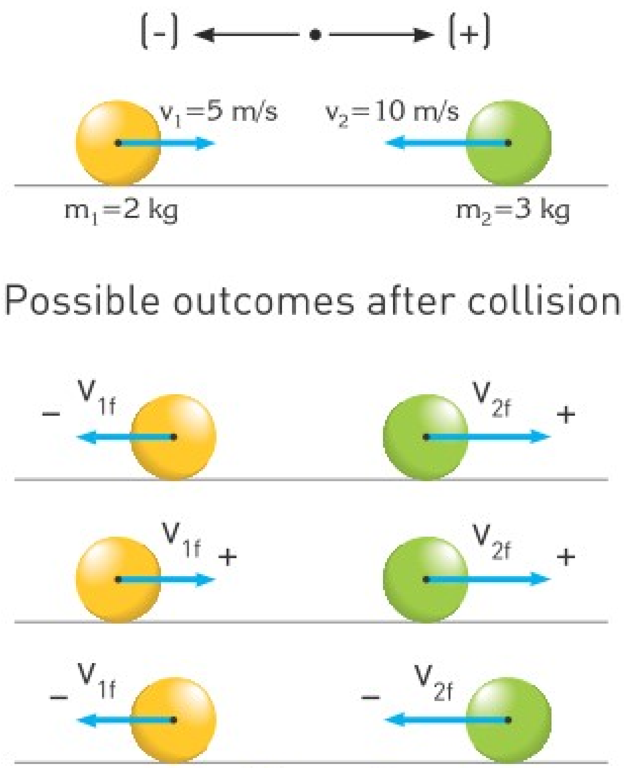
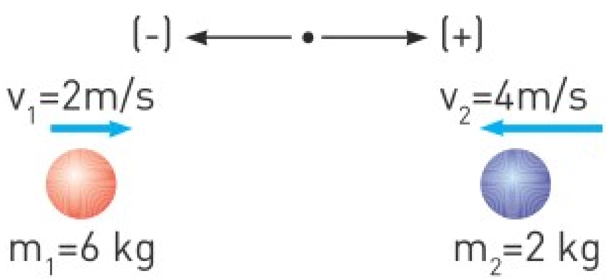


Figure 3

Example

Two objects of masses $m_1 = 6$ kg and $m_2 = 2$ kg approach each other with speeds $v_1 = 2$ m/s and $v_2 = 4$ m/s and undergo a head-on elastic collision.



Find the velocities of the objects after the collision.

Solution:
Since the collision is elastic, both energy and momentum are conserved.

$$(\vec{p}_1 + \vec{p}_2 + \vec{p}_3 + \cdots + \vec{p}_n)_{initial} = (\vec{p}_1 + \vec{p}_2 + \vec{p}_3 + \cdots + \vec{p}_n)_{final}$$

$$m_1\vec{v}_{1i} + m_2\vec{v}_{2i} = m_1\vec{v}_{1f} + m_2\vec{v}_{2f}$$

$$(6\,kg) \times (2\,m/s) - (2\,kg) \times (4\,m/s) = (6\,kg) \times v_{1f} + (2\,kg) \times v_{2f}$$

$$(6\,kg) \times v_{1f} + (2\,kg) \times v_{2f} = 4\,kgm/s$$

$$6\,v_{1f} + 2\,v_{2f} = 4m/s \quad (1)$$

The equation for the conservation of velocities is:

$$\vec{v}_{1i} + \vec{v}_{1f} = \vec{v}_{2i} + \vec{v}_{2f}$$

$$2\,m/s + v_{1f} = -4\,m/s + v_{2f}$$

$$6\,m/s + v_{1f} = v_{2f} \quad (2)$$

putting equation (2) into equation (1),

$$6\,v_{1f} + 2\,(6\,m/s + v_{1f}) = 4m/s \Rightarrow v_{1f} = -1m/s$$

$$v_{2f} = 6\,m/s + v_{1f} = 5m/s$$

Mass m_1 will move with a speed of 1 m/s in the negative direction, and mass m_2 will move with a speed of 5 m/s in the positive direction.

Research time

Show the momentum from surrounding processes. Represent it by video, photo or etc.

Literacy

1. Archer shoot 20 gram arrow with 40 m/s into 500 gram target. What is their common speed?
2. 100 gram ball moves at 10 m/s and collides with stationary 1.5 kg ball. After collision, 1.5 kg ball moves with 1.25 m/s. Where does 100 gram ball move? What is its speed?

Art time

Make video of “Stacked Ball Drop”. If you can, make it slow motion. Why do uppermost ball fly so high?

Activity

You will observe the conservation of momentum in balls collisions.

1. Place one ball in the grooved section of the ruler.
2. Put the second ball on the zero end of the ruler. Flick the ball on the zero end with your finger so it rolls down and strikes the ball at the centre of the ruler.
3. Repeat these steps, but this time place two balls.
4. Continue to vary the number and arrangement of balls and observe what happens.

Questions:

1. What happened to the single centre ball when it was struck by one ball? What happened to the ball that struck the one ball at rest?
2. What happened in the other collisions? How does this activity confirm the law of conservation of momentum?

Terminology

interact - әсерлесу / взаимодействовать
collision - соқтығыс / соударение
outcome - нәтиже / исход
temporarily - уақытша/ временно
approach - жақындау / приближение
grooved - кедір-бұдыр / рифленая
flick - жеңіл соққы / легкий удар
to vary - өзгерту / менять
arrangement - орналасуы, орын / расположение

4.6 JET PROPULSION

You will

- tell examples of jet propulsion in nature and industry;
- tell regional and international significance of Baikonur Cosmodrome;

Question

Why does not man fall into water? How does "water jet pack" work?

The balloon, Figure 1, pushes air. Air, in turn, pushes the balloon (Newton's third law). As a result, balloon moves. Initially the balloon does not move. That's why initial momentum is zero. Final momentum is also zero.

Figure 1

This kind of motion is called jet propulsion. People use jet propulsion to build rockets and send satellites into the space. Jet propulsion uses this formula:

$$M \times \Delta v = \Delta m \times v$$

M× Δυ=Δm×υ
M- mass of rocket [kg]
Δυ- change of velocity of rocket [m/s]
Δm - mass of ejected gas (propellant) [kg]
υ - velocity of ejected gas (propellant) [m/s]
More than a half of a rocket is propulsion system, Figure 2.

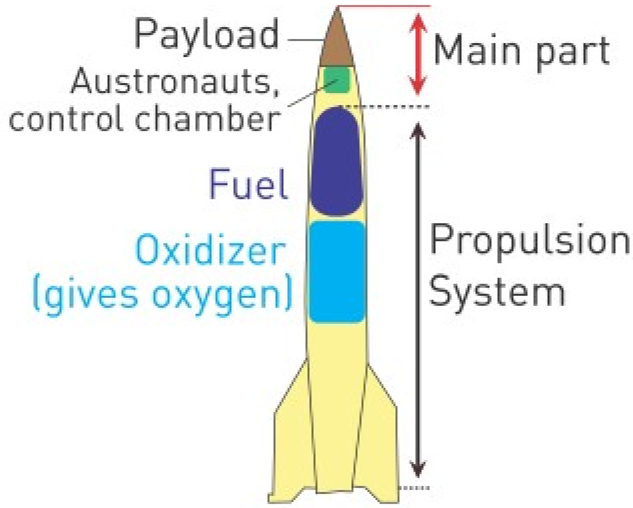


Figure 2

Rocket has 3 main masses:

1. M_O- mass of useful load
2. M_S - mass of structure (metal parts of propulsion system)
3. M_P- mass of propellant (fuel+oxidizer)

A rocket is evaluated by main 3 properties.

1. Payload - Useful load - satellite, equipment, supplies, space probe.
2. Propellant mass fraction - Ratio of fuel+oxidizer to the initial mass of the whole rocket.
3. Mass ratio - Ratio of initial mass of the whole rocket to the mass that does not reach the mission point.

Actvity

There are names of some devices launched into the atmosphere. What can you say about them? Calculate three properties mentioned on previous page.

Name	Total mass (kg)	Mass at mission point (kg)	Properties
Soyuz-2	312 000	8 200	
Saturn-5	3 038 500	131 300	
Space shuttle	2 040 000	132 800	
Boeing 787	227 930	172 000	
Apollo lunar module (Descent stage)	15 200	6 845	
Ariane 5	746 000	18 700	

Example

Which one(s) below use jet propulsion? How do they achieve jet propulsion?
1. Octopus
2. Rabbit
3. Space shuttle/ rocket
4. Plane
5. Bear
6. Cheetah
7. Jellyfish

Answer:
Octopus, space shuttle/ rocket, plane, jellyfish have jet propulsion, because jet propulsion is force produced by passing a fluid in the opposite direction to the direction of motion. By Newton's third law, the motion is in the opposite direction to the flow of fluid.

Research time

Use your imagination and investigation skills to model jet propulsion. You can use whatever you want.

Literacy

1. 80 kg person wears 20 kg “water jet pack”. “Water jet pack” uses 20 kg of water per second. What is speed of jet stream so that man can fly?
2. 5 kg rocket emits 0.5 kg of gas at 100 m/s. What is speed of rocket?
3. “Newton’s third law gave us internet, and planes”. This expression is not wrong. Why?
4. When rocket rises, it drops parts of itself. Why?

Terminology

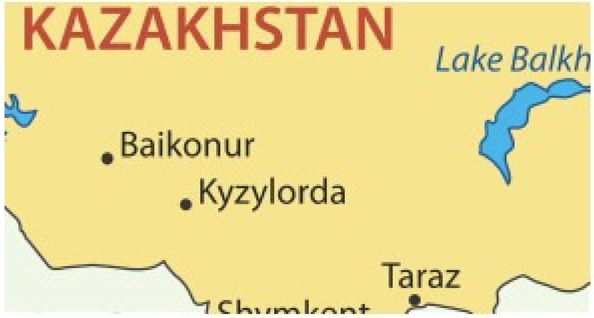
jet propulsion - реактивті қозғалтқыш / реактивный двигатель
satellite - жасанды серік / спутник
ejected - бөлініп шыққан / выброшенный
payload - пайдалы жүктеме / полезная нагрузка
propellant - зымыран отыны / ракетное топливо
cheetah - гепард / гепард
jellyfish - медуза / медуза
imagination - қиял / воображение
investigation - зерттеу / исследование

Art time

Make “water rocket”. Why does it fly?

Fact

Baikonur Cosmodrome is the world's first and largest operational space launch facility.



Activity

a. Which of these transports use jet propulsion?
b. Do you know other examples of jet propulsion? Also try to invent new applications of jet propulsion.

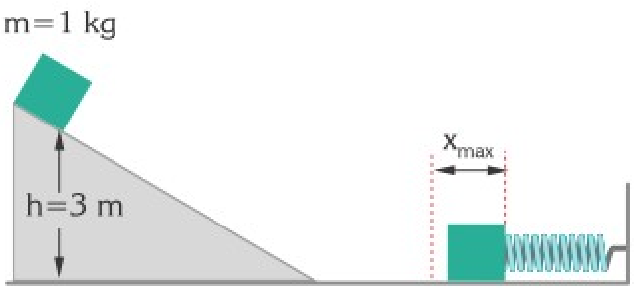
4.7 PROBLEM SOLVING

Question

Why do we use smartphone rubber (or silicone) covers?

Example

A box is released from the top of the inclined plane. The spring constant k=240N/m. Neglect the friction. Take g=10 m/s^2.



a) Find the speed of the box when it reaches the ground.
b) Find the compression of the spring.
Solution
a) We can use law of conservation of energy

$$(E_1 + E_2 + E_3 + \cdots + E_n)_{initial} = (E_1 + E_2 + E_3 + \cdots + E_n)_{final}$$

$$mgh = \frac{mv^2}{2} \Rightarrow v^2 = 2gh$$

$$v \approx 2.78\, m/s$$

b. $E_{before}=E_{after}$

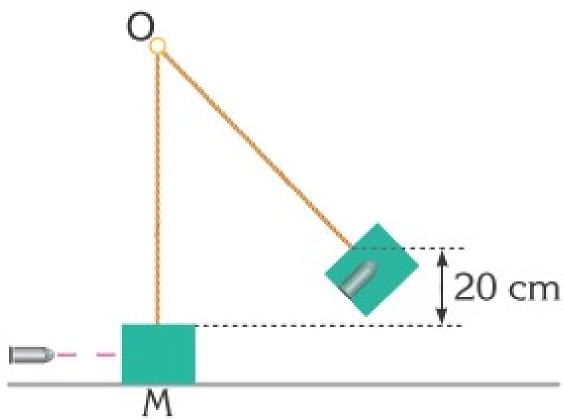
$$\frac{mv^2}{2} = \frac{kx^2}{2} => x^2 = \frac{mv^2}{k}$$

x=0.5 m
We could also equalise the initial potential energy to final elastic energy. The result would be the same.

Example 2

A bullet is fired into a wooden block. Then, they together rise at a certain height.

Take g=10 m/s^2.



a) What is the common speed of the bullet and the box?
b) What is the value of h?
Solution
a) We can use conservation of momentum. This is inelastic collision. Then,

$$(\vec{p}_1 + \vec{p}_2 + \vec{p}_3 + \cdots + \vec{p}_n)_{initial} = (\vec{p}_1 + \vec{p}_2 + \vec{p}_3 + \cdots + \vec{p}_n)_{final}$$

$$mv = (m + M)u_{common}; \qquad u_{common} = \frac{mv}{m + M};$$

$$u_{common} = \frac{0.02 \times 200}{0.02 + 1.98}; \qquad u_{common} = 2\ m/s;$$

$$E_{before} = E_{after}$$

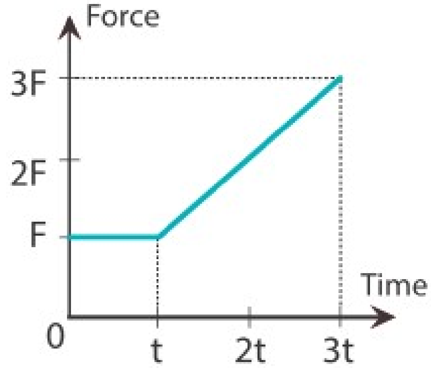
$$\frac{(m+M)u_{common}^2}{2} = (m+M)gh$$

$$h = \frac{u_{common}^2}{2g}$$

$$h = 0.2\ m$$

Example 3

An object of mass 400 kg is initially at rest. Then, the changing force starts acting on it. The initial value of the force is 100 N. The force acts on the object for 30 seconds. Use the F(t) graph to find the speed of the object after 30 seconds.



Solution:

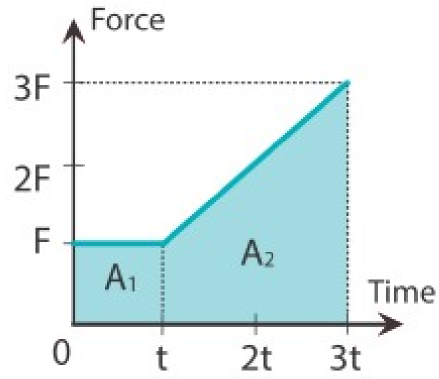
We can use the formula of impulse and momentum

$$\vec{F}\Delta t = m\overrightarrow{\Delta v}$$

We can find

$$\vec{F}\Delta t$$

if we calculate the area under the F(t) graph



$$A_1 = 100 \times 10 = 1000\text{Ns}$$

$$A_2 = (100 \times 20) + (\frac{200 \times (30-10)}{2}) = 2000 + 2000 = 4000\ Ns$$

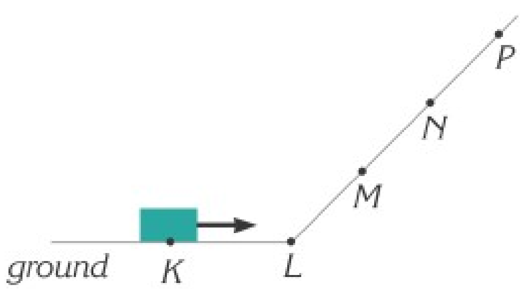
$$\Delta v = \frac{F\Delta t}{m}; \quad v - v_0 = \frac{F\Delta t}{m}; \quad v = v_0 + \frac{F\Delta t}{m}; \quad v = 0 + \frac{5000}{400};$$

υ=12.5 m/s.

Since the initial velocity is zero, then the final velocity is 12.5 m/s.

Exercise 1

A box has initial kinetic energy of 400 J at point K. When the box reaches point P, it stops. Distances between points are the same. Neglect the friction.

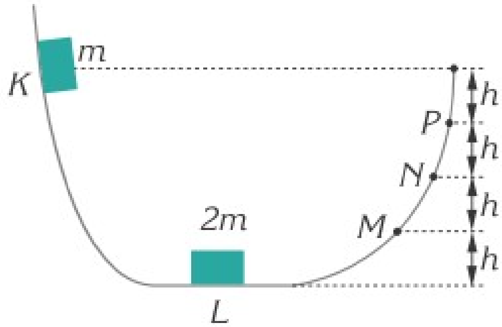


a) What is the value of kinetic energy at point M?

b) What is the value of potential energy at point N?

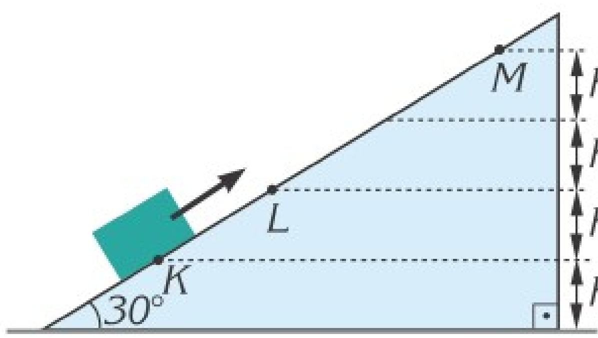
Exercise 2

The object of mass m is released from the height of 4 h. Then, it inelastically collides with the object of mass 2m. What maximal height these objects can reach? Neglect the friction.



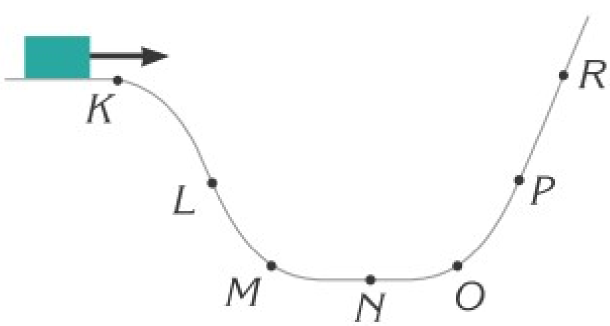
Exercise 3

When an object launched from point K has initial speed 10 m/s, it can reach point L. What speed must the object have to reach the point M? Neglect the friction.



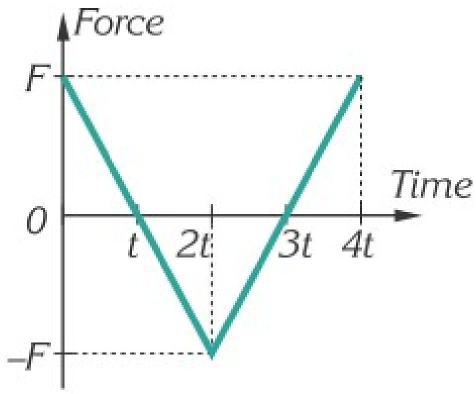
Exercise 4

In real life there is friction force that is always against the speed of a moving object. When the box passes point K in has kinetic energy. The box reaches point R. Then, it slides back and stops at point N. In which section(s) must the friction exist?



Exercise 5

An object of mass 5 kg moves with velocity of 10 m/s. Then, a changing starts acting on the object. If the F=20 N and t=4 s, at what time(s) during the motion the velocity of the object equals to 10 m/s?



Literacy

1. 200 gram smartphone falls on the floor from height of 1.5 meters. Duration of impact is 0.001 seconds.
a) How many Newtons is force of impact?
b) Is it more or less than your weight?
c) What is potential energy of smartphone?
d) What is speed of smartphone before impact?

SUMMARY

4.1 The work is the force multiplied by the distance:
A = Fx
F - force. [N]
x - distance. [m]
A - mechanical work. [J]
Mechanical work is done under 2 conditions:
1. There must be force.
2. The force must be parallel to displacement; not perpendicular.
4.2 In some cases we need to use the component of force which is parallel to the displacement: F_x . Vertical component F_y doesn’t do work because the cart doesn’t move vertically.
Then, the mechanical work is
A = (F × cos α) x or A = Fx cos α
α- angle between force and horizontal.
work and energy theorem:

$$\frac{mv_{final}^2}{2} - \frac{mv_{initial}^2}{2} = Fx$$

4.3 Law of conservation of energy has 2 main rules:
Rule 1: Energy can transform from one form to another. It can’t be destroyed.
Rule 2: Total energy of the isolated system at any point is always the same.

$$(E_1 + E_2 + E_3 + \cdots + E_n)_{initial} = (E_1 + E_2 + E_3 + \cdots + E_n)_{final}$$

Elastic potential energy:

$$E_p = \frac{1}{2}kx^2$$

k - spring constant [N/m]
x - extension or compression [m]
Newton’s second law in different form:

$$\vec{F}\Delta t = m\overrightarrow{\Delta v}$$

The left side

$$\vec{F}\Delta t$$

is called impulse. It means "how long the force F has acted".
The right side

$$m\overrightarrow{\Delta v}$$

is called change in momentum.
The formula of momentum:

$$\vec{p} = m\vec{v}$$

m - mass [kg]
v - velocity [m/s]
p - momentum [kg × m/s]
4.5 Law of conservation of momentum for isolated system:

$$(\vec{p}_1 + \vec{p}_2 + \vec{p}_3 + \cdots + \vec{p}_n)_{initial} = (\vec{p}_1 + \vec{p}_2 + \vec{p}_3 + \cdots + \vec{p}_n)_{final}$$

The case when objects stick together after collision is called inelastic collision.
The case when objects don't stick together is called elastic collision.
4.6 The balloon, Figure 1, pushes air. Air, in turn, pushes the balloon (Newton's third law). As a result, balloon moves.This kind of motion is called jet propulsion.

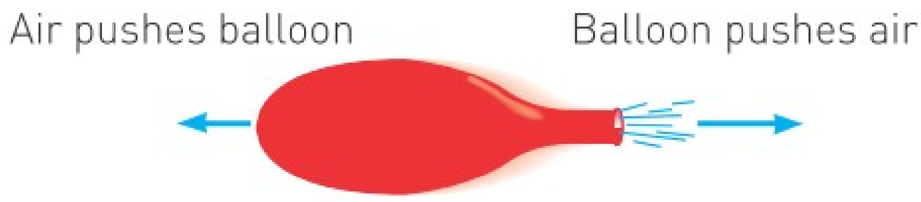


Figure 1

PROBLEMS

1. Explain the difference between the meaning of the word “work” in physics and in daily life.

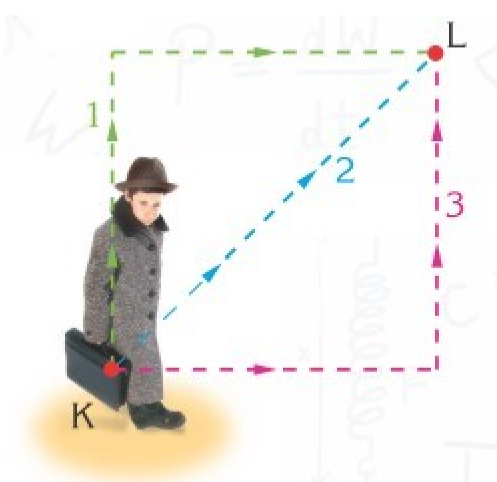
2. Does every force do work? Answer this question by considering the forces acting on yourself at the moment.

3. Give two examples of forces which act on an object but do not do any work.

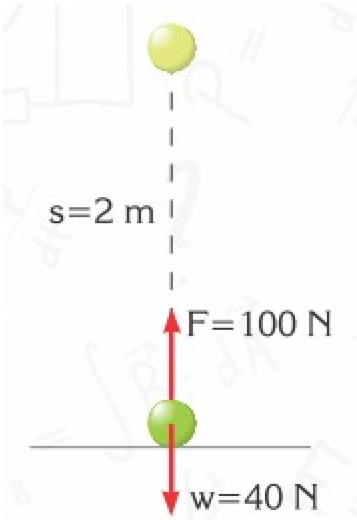
4. How much work is done if a force of 10 N moves an object a distance of 10 m?

5. A 2-kg object which rests on a frictionless horizontal plane, is acted on by a force of 10 N at an angle of 37° with the horizontal, as shown in the Figure. If the object moves a distance of 2 m on the horizontal plane, what is the work done by force F?

6. A boy takes his 5 kg bag to point L which is 3 m vertically upwards along 3 different paths, as shown in the figure. What is the relationship between the work done while lifting the bag along the 3 different paths? (Take g = 10 N/kg).



7. If a force of 100 N acts on an object weighing 40 N and lifts it to a height of 2 m, as shown in the figure.

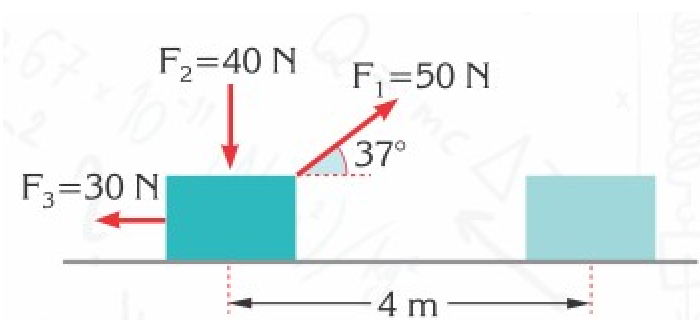


a) What is the work done by the force of 100 N?

b) What is the work done by the weight of the object?

c) What is the net work done?

8. An object moves horizontally 4 m under the effect of forces F_1= 50 N, F_2= 40, and F_3= 30 N, as shown in the figure.



Find

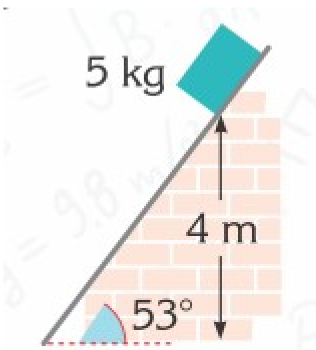
a) the work done by each force

b) the net work done by the net force.

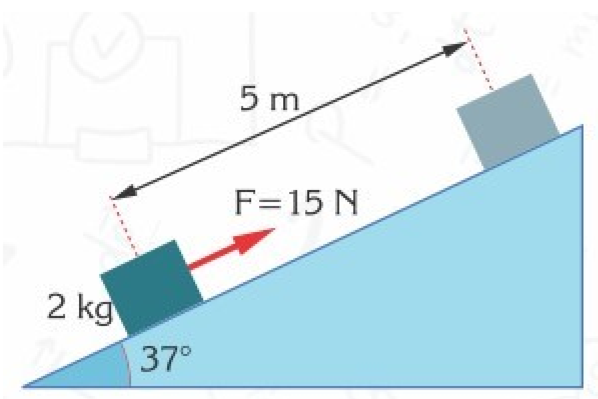
9. A 5 kg object is released from a height of 4 m on a smooth inclined plane, as shown in the figure. When it reaches the bottom of the inclined plane, find

a) the work done by the normal force

b) the work done by the gravitational force (Take g = 10 N/kg; sin 53°=0.8; cos 53°=0.6)



10. A force F = 15 N is applied to a 2 kg block resting on an inclined frictionless plane. If the block moves 5 m under the effect of this force,



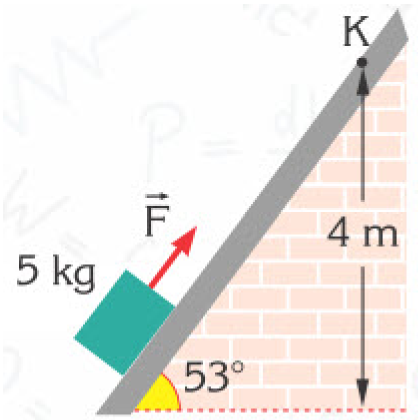
find

a) the work done by force F

b) the work done by the gravitational force.

c) Does the reaction force from the surface do any work? (Take sin 37°=0.6; cos 37°=0.8)

11. By applying a force **F**, as shown in the figure, a 5 kg object is moved at a constant speed from the bottom of an inclined plane to point K on the smooth inclined plane.



Find

a) the work done by force

b) the work done by the normal force

c) the work done by gravity (Take sin 53°=0.8; cos 53°=0.6)

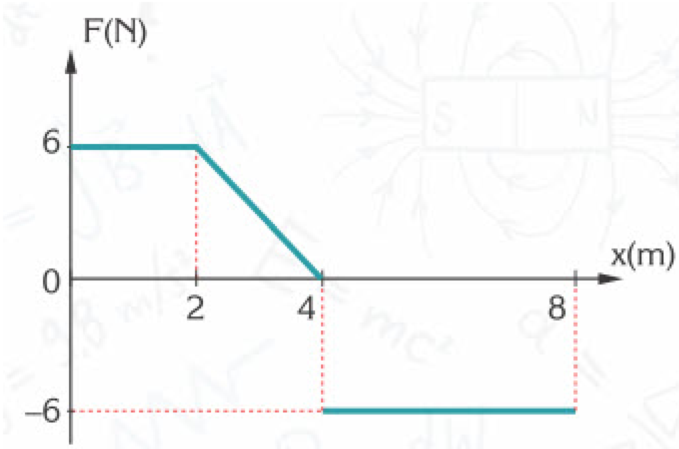
12. The force versus position graph of an object on a horizontal frictionless plane is shown in the figure. If the force is applied to the object parallel to the direction of its motion, find the work done by the force

a) between x = 0 and x = 2 m,

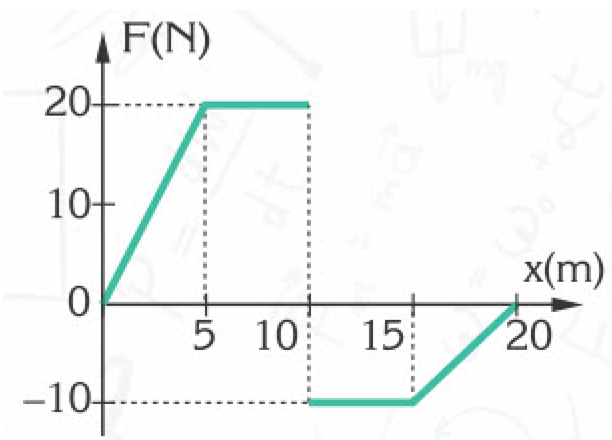
b) between x = 2 m and x = 4 m,

c) between x = 4 m and x = 8 m,

d) between x = 0 and x = 8 m



13. The force versus position graph of an object on a horizontal frictionless plane is as shown in the figure. If the force is applied to the object parallel to the direction of its motion, find the net work done between x=0 and x=20 m



14. What are the following amounts of energy in joules?

a) 1 kJ = ... J

b) 10 MJ = ... J

15. What does kinetic energy depend on? What is the SI unit of energy?

16. Which one has more kinetic energy; a train carriage or a car, if both are moving at the same speed?

17. How many joules is the kinetic energy of a 1 kg toy aeroplane;

a) when its speed is 4 m/s?

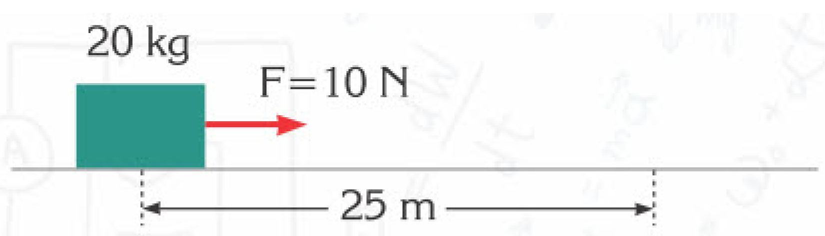
b) when its speed is 10 m/s?

18. One of two lorries is half the weight of the other, but is moving at twice the speed of the other. Which of the lorries has more kinetic energy?

19. If the speed of a 20 g bullet which is shot out of a gun is 200 m/s, what is the kinetic energy of the bullet?

20. The kinetic energy of a 0.5 g rain drop which is falling at its terminal speed is 10^{-3} J. What is the terminal speed of the rain drop?

21. While initially resting on a frictionless horizontal plane, a 20 kg case is pulled 25 m by a 10 N force.



a) What is the work done?

b) What is the speed of the case at the end of 25 m?

c) How many seconds does it take for the case to reach this speed?

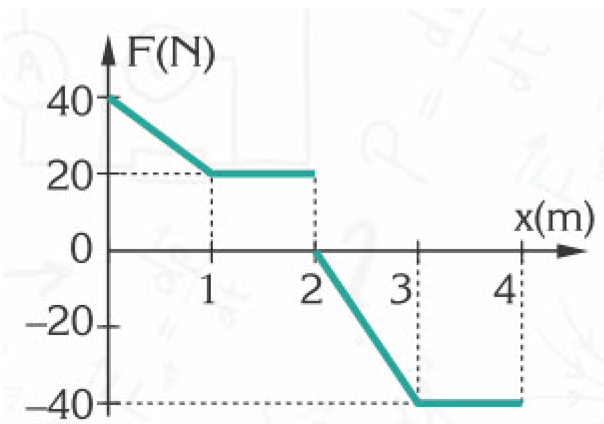
22. At the instant a 6 kg object starts to move from x = –1 m towards the +x direction at a velocity of 4 m/s, a force of 24 N is applied to the object until x = 5 m. If there is no friction between the object and the floor

a) what is the change in the kinetic energy of the object?

b) what is the velocity of the object at x = 5 m?

c) If the initial velocity of the object was zero, what would its velocity be at x = 5 m?

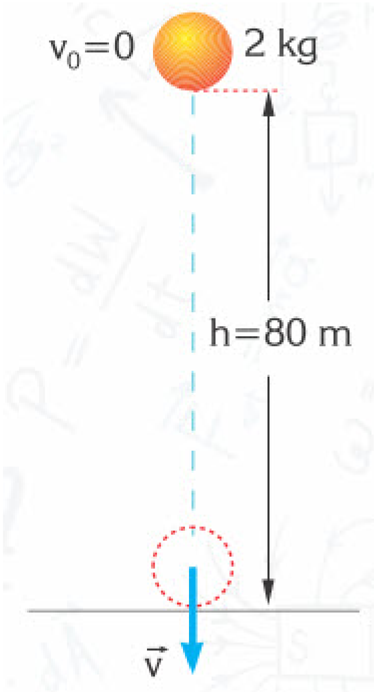
23. The force–position graph of a 1 kg object, experiencing a horizontal force **F** on a smooth horizontal plane, is shown in the figure. If the object reaches a velocity of 4 m/s after it covers 4 m, find



a) the net work done between 0 – 4 m

b) the initial velocity of the object.

24. A 2 kg object is released from a height of 80 m.



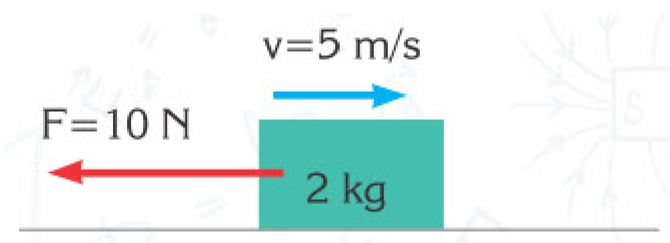
a) What are the forces acting on the object?

b) Find the work done by each force.

c) What is the change in the kinetic energy of the object during its flight?

d) What is the velocity of the object at the moment it strikes the ground? (Take g=10 N/kg and neglect any friction effects.)

25. A 2 kg block is moving on a horizontal frictionless surface at a velocity of υ=5 m/s. A force of F=10 N is applied to it in the opposite direction to its motion, as shown in the figure. How many joules of work has been done by the force when the block stops?

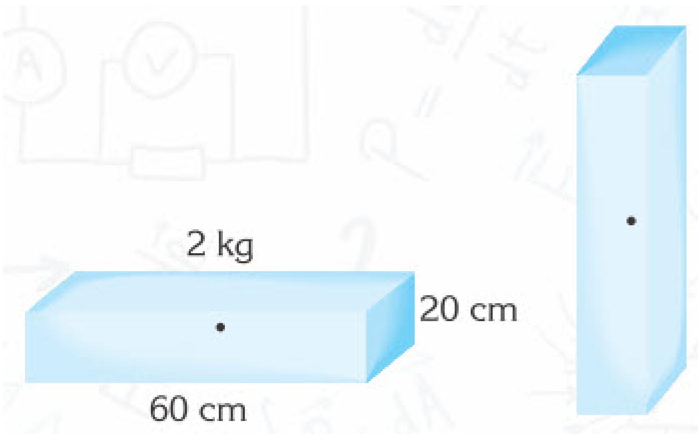


26. A 2 kg object is moving on a smooth horizontal surface at a velocity of 10 m/s. A horizontal force F is applied to it in the same direction as its motion in 4 s. If the object gains an acceleration of 0.5 m/s^2, find

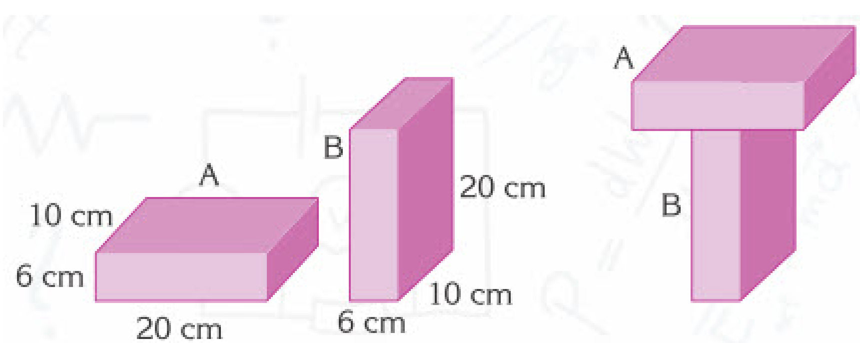
a) the work done by the force F

b) the change in the kinetic energy of the object.

27. What work is done in bringing the uniform object from the horizontal position to the vertical position, as shown in the figure?



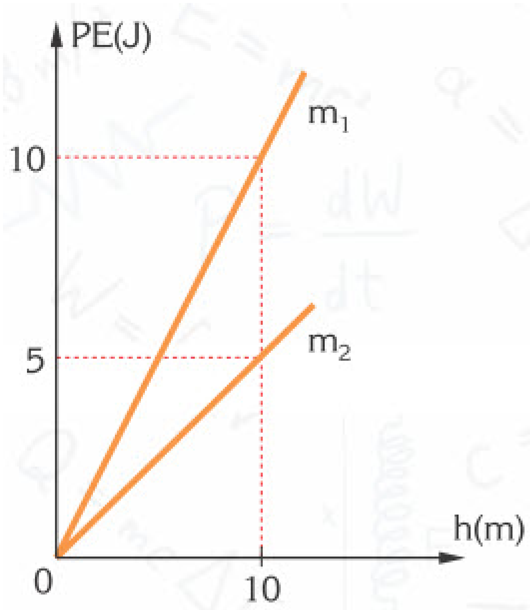
28. Two homogeneous objects A and B of dimensions 20 cm, 10 cm and 6 cm rest in two different configurations, as shown in Figure-I. Later, object A is placed on top of object B, as shown in Figure-II. If the mass of each object is 10 kg



a) what are the gravitational potential energies of the objects in Figure-I relative to the floor?

b) what work is done to obtain the configuration in Figure-II?

29. The graphs of potential energy versus height from a chosen reference level, of masses m_1 and m_2 are shown in the figure.



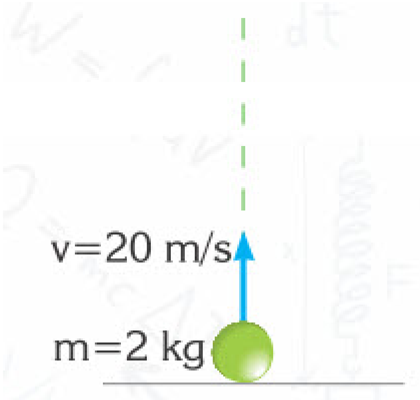
a) How many kg are the masses m_1 and m_2?

b) What are the potential energies of these masses when they are lifted to a height h = 20 m?

30. An object is released 5 m above the ground. What is its velocity at the moment it strikes the ground? (Take $g=10\ m/s^2$)

31. A ball with a mass of 2 kg is dropped from the top of a building and strikes the ground at a velocity of 10 m/s. What is the height of the building from which the ball is dropped?

32. A 2-kg ball is thrown upwards at a velocity of 20 m/s.

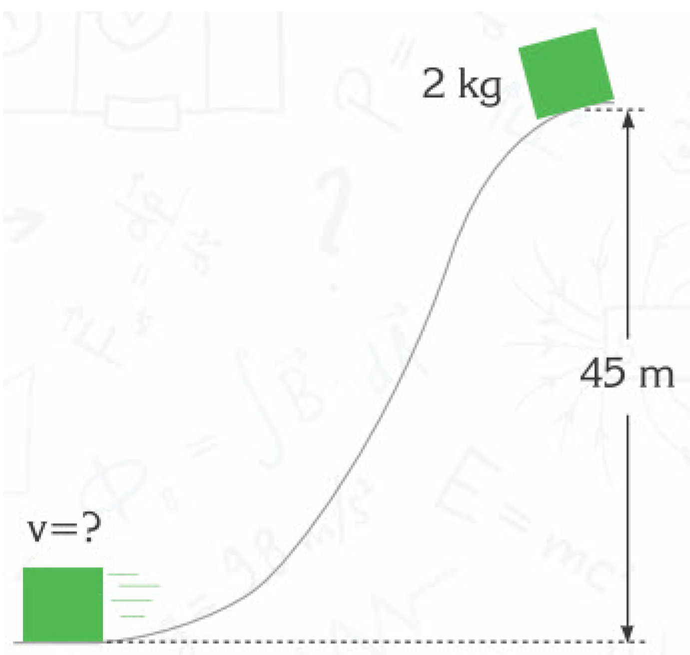


a) What is the potential energy when it is at its maximum height?

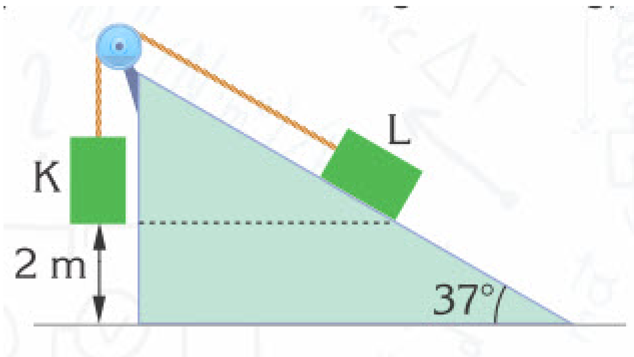
b) What is the velocity of the ball when it is 15 m above the ground? (Take $g=10\ m/s^2$)

33. When a 4-kg ball is thrown upwards at 40 m/s, at what height is the potential energy equal to the kinetic energy.

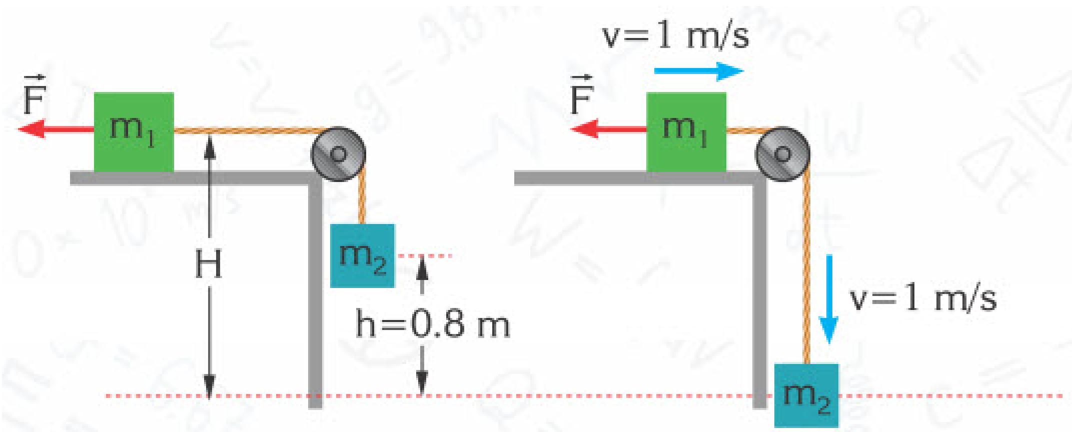
34. A 2-kg object slides down a smooth hill, as shown in the figure. What is the velocity of the object at the bottom? (Take $g=10 m/s^2$)



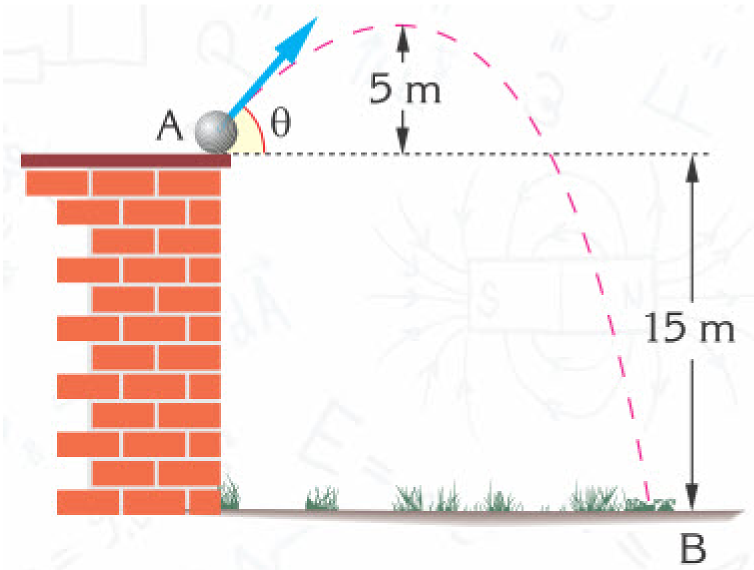
35. The frictionless system shown in the figure, composed of two identical objects K and L, is released from rest. What is the velocity of object K, in m/s, when it strikes the ground? (Take sin 37°=0.6; g=10 N/kg)



36. The system in the figure, consisting of two objects of masses 5 kg and 3 kg, are attached to each other with the aid of a pulley. The system arrives at the position in figure II from the position in figure I, under the effect of force F. If the speed of each object in figure II is 1 m/s, how many newtons is force **F**?



37. An object of mass 400 g is launched, as shown in the figure, making a certain angle with the horizontal. If the maximum height the object can reach is 5 m and its kinetic energy at its maximum height is 20 J, what is



a) the vertical component of the initial velocity

b) the kinetic energy of the object at the moment of launch

c) the work done by gravity from the point where the object is launched to the point where it lands.

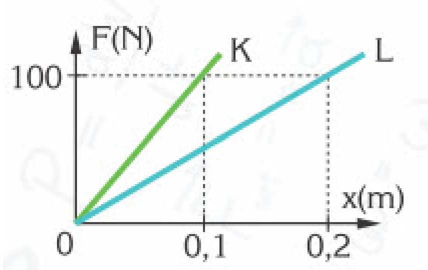
d) the kinetic energy of the object at the moment it strikes the ground?

38. If a spring has a spring constant of 800 N/m, find its potential energy when it is compressed by

a) 10 cm.

b) 20 cm.

39. In the figure the force position graphs for two different springs are shown. Calculate the potential energy stored in each spring when they are stretched x = 0.4 m.

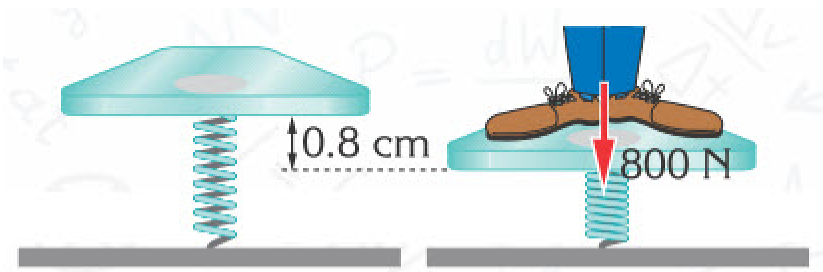


40. An 80 kg man steps on a spring, as shown in the figure. If he compresses the spring by 0.8 cm, calculate

a) the spring constant of the spring

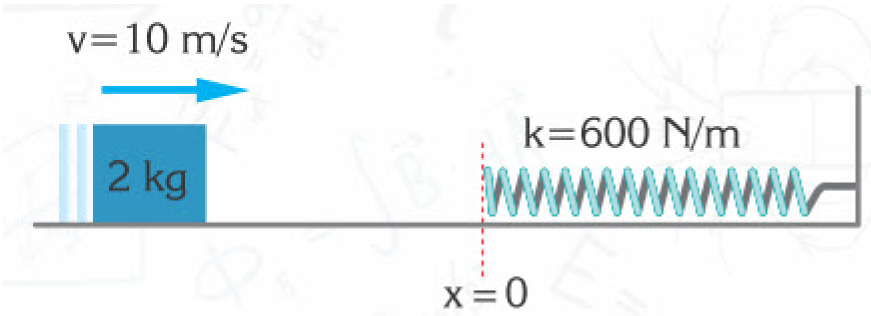
b) the work done by the weight of the man

c) the energy stored in the spring.



41. An object of mass 2 kg moving with a velocity of 2 m/s compresses a spring with a spring constant of 200 N/m, as shown in the figure. Calculate the maximum amount of compression of the spring.

42. A 2 kg object is launched at a velocity of v=10 m/s towards a spring with a spring constant of k=600 N/m, as shown in the figure.

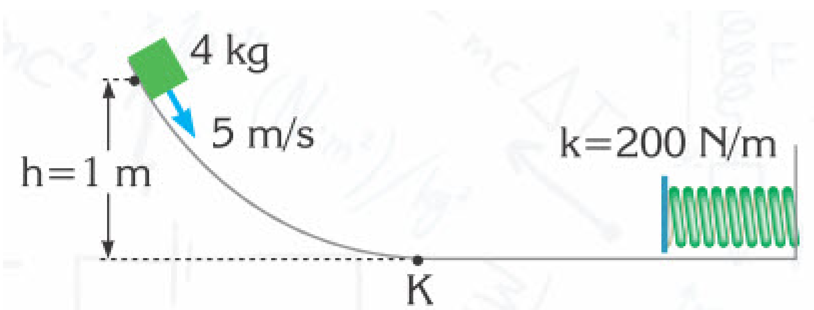


Calculate

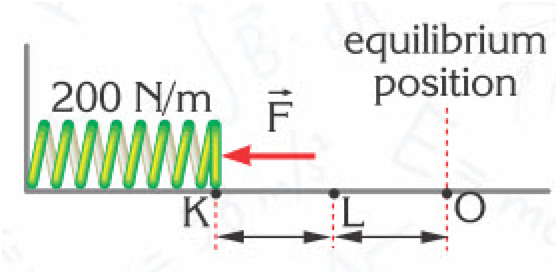
a) the compression of the spring at the moment the velocity of the object is 5 m/s,

b) the maximum amount of compression of the spring. (Neglect any friction effects.)

43. A 4 kg object at a height of 1 m is pushed with a velocity of 5 m/s towards a spring, as shown in the figure. If the surface is frictionless and the spring constant is 200N/m, what is the maximum compression of the spring?



44. When a spring is compressed by a force F from point L to point K, as shown in the figure, its potential energy increases increases by 12 J . If the spring constant is 200 N/m find the distance, x.



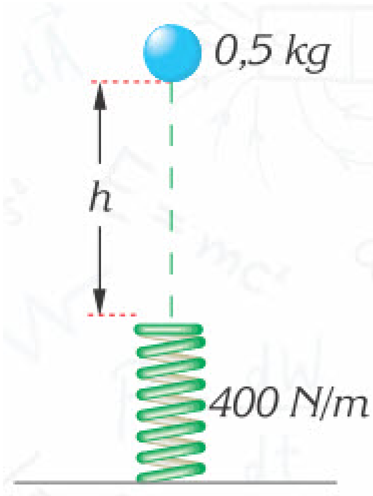
45. An archer places an arrow in a bow and pulls the bowstring 60 cm back from its equilibrium position, by applying a force of 300 N.

By considering the bowstring to be a spring, find

a) the spring constant,

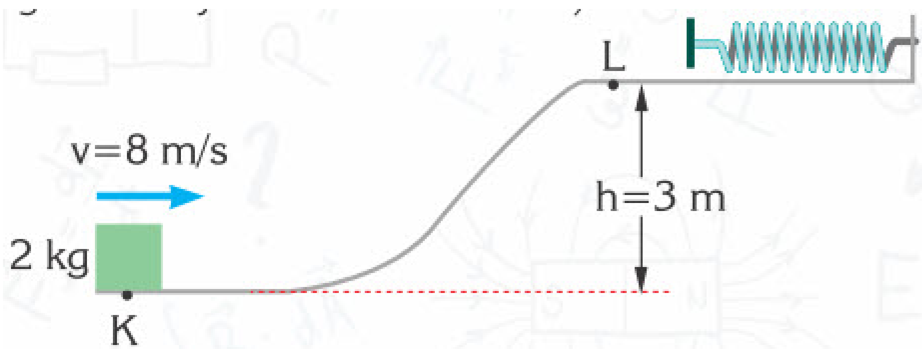
b) the potential energy stored in the bowstring when stretched.

46. A 0.5 kg mass released from a height h compresses a spring by 0.1 m, as shown in the figure.



If the spring constant is 400 N/m, find the height, h. (Take $g=10\ m/s^2$)

47. A 2 kg object which is launched at a velocity of 8 m/s from point K, passes point L, which is at a height of 3 m, at velocity v_L and compresses the spring.

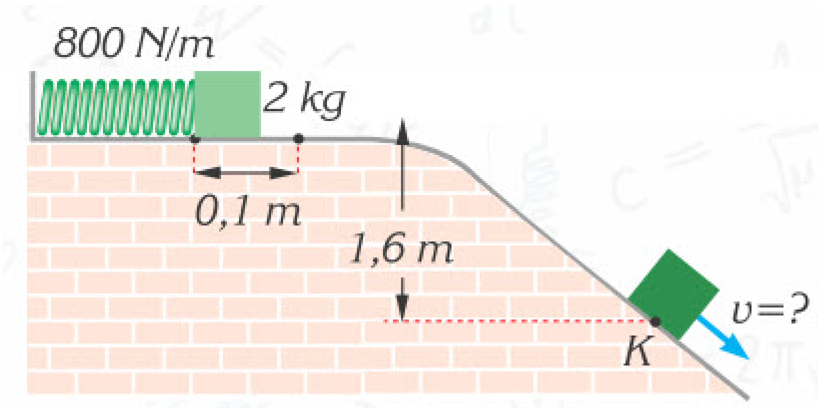


a) What is the velocity of the object at point L?

b) If the spring constant is 200 N/m, what is the maximum amount of compression of the spring? (Neglect any friction effects.)

48. A spring which has a spring constant of 800 N/m is compressed 0.1 m by a 2 kg object, as shown in the figure. If the whole path is smooth, find the velocity, v of the object at point K?

(Take $g = 10\ m/s^2$)



49. What does the momentum of an object depend upon?

50. What is the momentum of an 18 g bullet which moves at a velocity of 250 m/s?

51. What is the momentum of an electron, having a mass of $9.1 \cdot 10^{-31}$ kg, which moves at a velocity of 200 km/s?

52. The velocity of a 1800-kg lorry which has the same momentum as a 900-kg car, is 36 km/h. What is the velocity of the car?

53. A 0.2 kg ball is thrown vertically upwards with an initial velocity of 20 m/s

a) What is its momentum when it is at its maximum height?

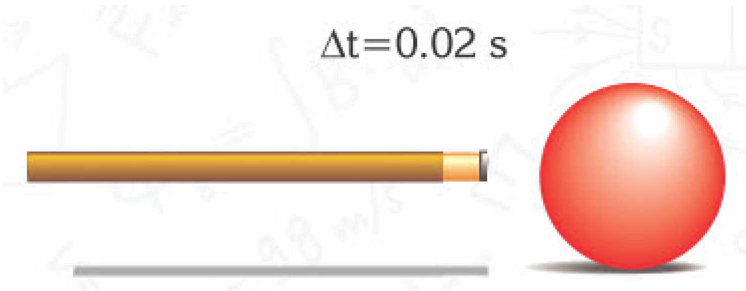
b) What is its momentum when it is halfway to its maximum height?

54. What is the change in the momentum of a 1200 kg car when its velocity decreases from 180 km/h to 36 km/h?

55. Which equation is used to calculate impulse?

56. What is the impulse applied by a boxer to his rival when he strikes him with a force of 100 N in 0.05 s?

57. An average force of 40 N which is parallel to the ground is applied to a billiard ball in 0.02 s.



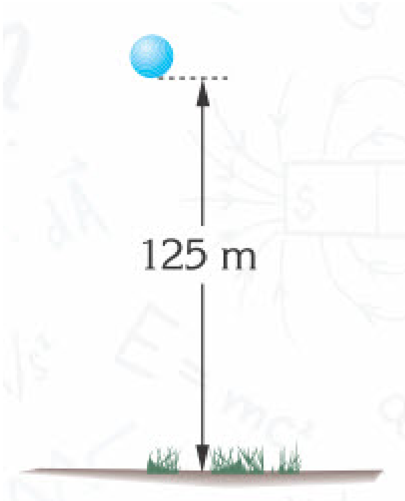
a) What is the impulse applied to the ball?

b) What is the velocity given to the ball if its mass is 200 g?

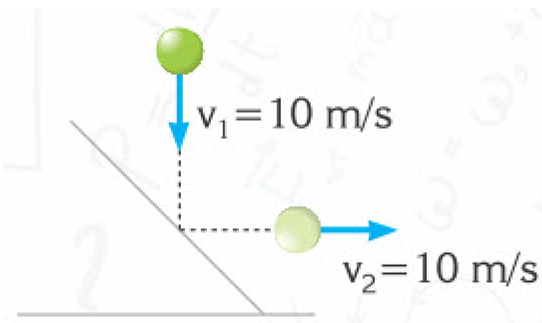
58. A basketball player is bouncing on a flat surface. The time of interaction of the ball with the surface is 1/600 s and the impulse that the surface applies to the ball is 3 Ns.

What is the average force applied by the surface to the ball?

59. A 2 kg object is released from a height of 125 m, strikes the ground and then stops without bouncing. Calculate the impulse applied by the ground upon the object.



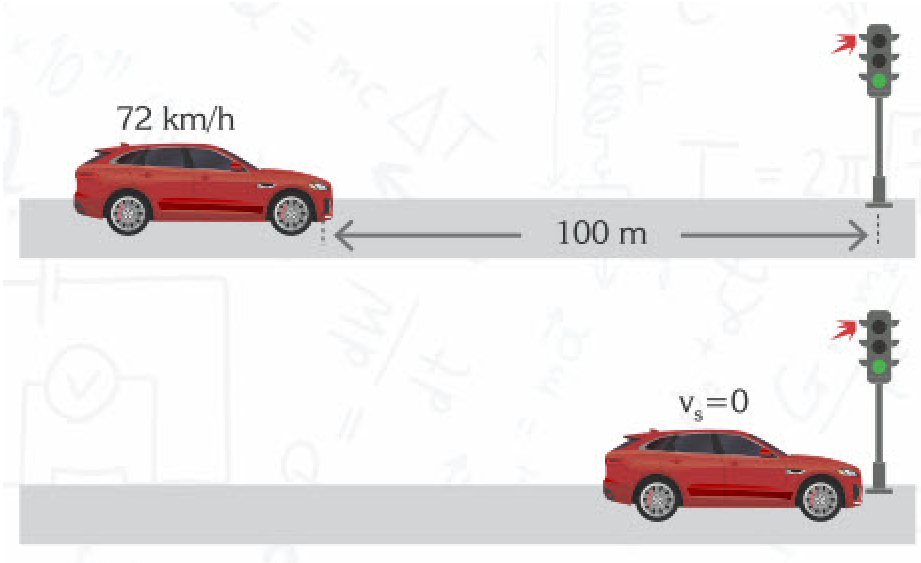
60. If the velocity of 10 m/s of a ball, with a mass 0.5 kg, is the same just before and justafter a collision with a wall, as shown in the figure



a) what is the change in the momentum of the ball?

b) if the interaction time between the wall and the ball is 0.2 s, find the average force exerted by the wall on the ball.

61. A driver travelling at a velocity of 72 km/h sees a red light at a distance of 100 m. He breaks and stops near the traffic lights, as shown in the figure. If the mass of the car including the driver is 800 kg



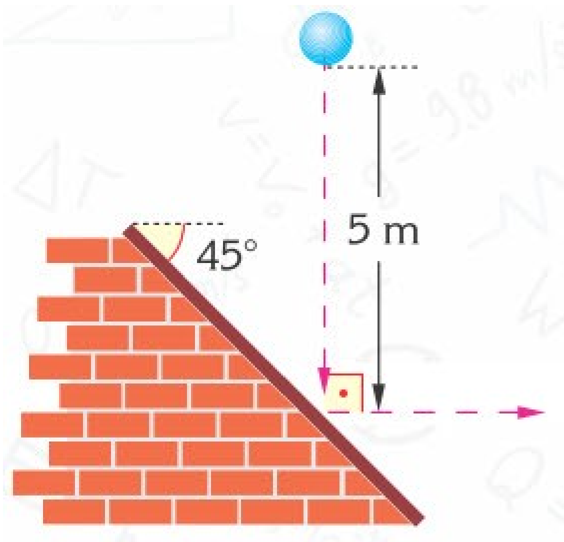
a) what impulse is applied to the car?

b) If the driver has a mass of 60 kg, what impulse is applied to him?

c) What is the average stopping force applied to the car by the brakes?

62. A 1 kg object released from a height of 5 m strikes a hard plane making an angle of 45°with the horizontal, as shown in the figure. After the object strikes the plane it changes direction so that its new direction makes an angle of 90° with its initial direction. What is the impulse given by the plane to the object? (Assume that the magnitude of the velocity of the ball just before and just after the collision

is the same.)

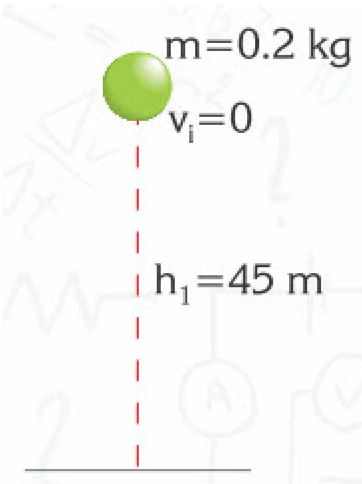


63. A tennis ball of mass m=2 kg strikes the ground with a velocity of 10 m/s, making an angle of 30° with the horizontal, and bounces off, as shown in the figure. Find the impulse delivered by the ground to the ball.

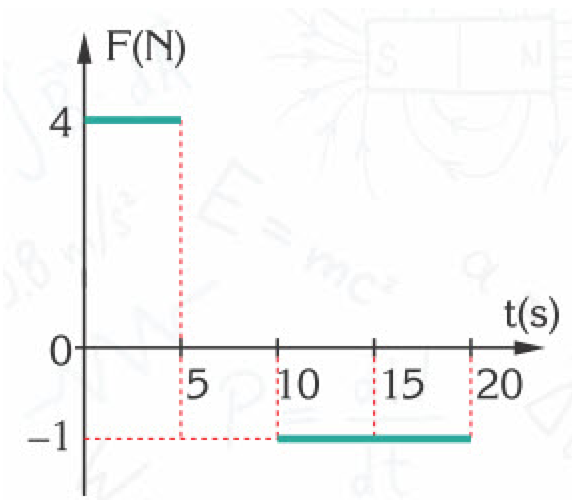
64. When a ball is released from a height of 45 m, it rises to a maximum height of 20 m after it makes a collision with the ground. If the interaction time is 0.1 s, find

a) the impulse given by the ground to the ball.

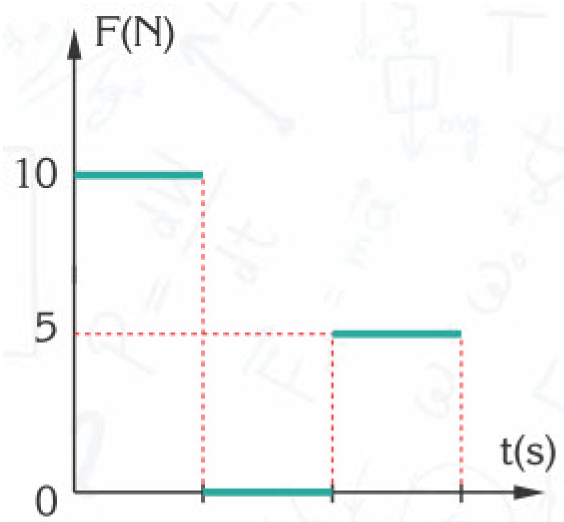
b) the average force exerted by the ground on the ball.



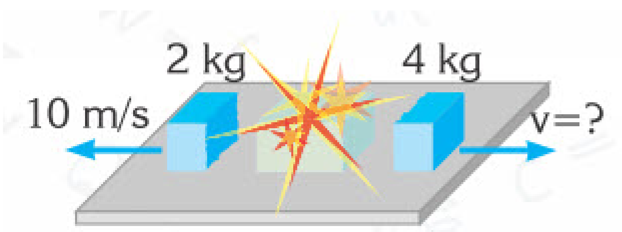
65. The force-time graph of an object is shown in the figure. What is the change in the momentum of the object between t = 0 and t = 20 s?



66. The graph of force versus time for a 2 kg object with an initial velocity of v_o=10 m/s is as shown in the figure. What is the momentum of the object at the end of 6 seconds?



67. A 6 kg chemistry tube, which is at rest on a smooth plane, fragments into two pieces of masses 2 kg and 4 kg after an internal explosion, as shown in the figure. If the 2 kg piece moves due west at a velocity of 10 m/s after the explosion, what is the velocity of the other piece?

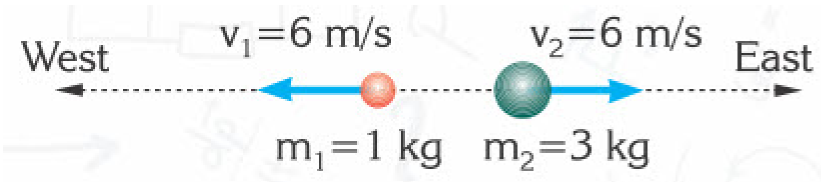


68. A 30 kg child at rest with roller skater throws a 1 kg ball at a velocity of 6 m/s to his friend horizontally.

a) What is the impulse acting on the child?

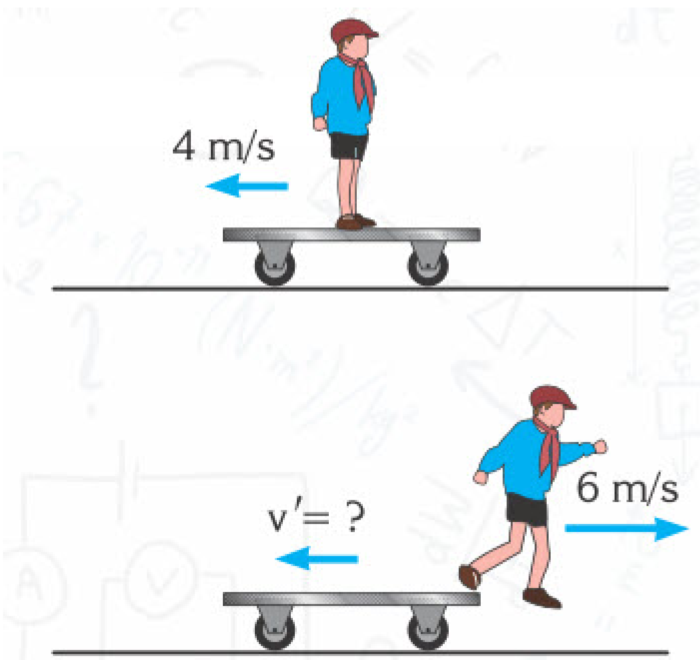
b) Neglecting the friction on the ground, at what velocity and in which direction does the child move?

69. A 4 kg mass fragments into two pieces as a result of an internal explosion.



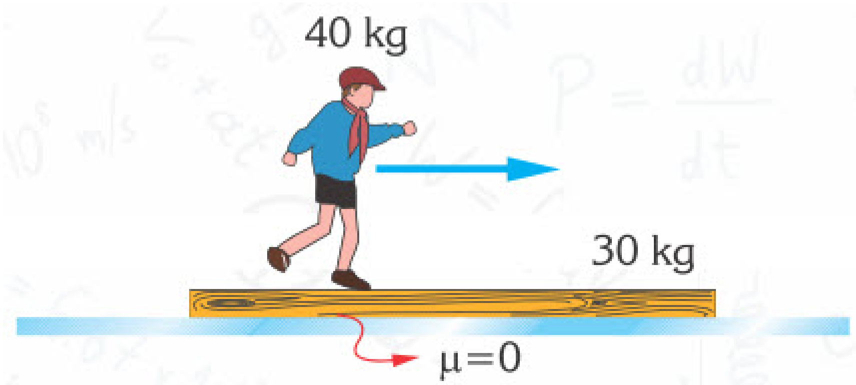
If the pieces move as shown in the figure, what is the velocity of the object before the explosion?

70. A 30 kg child is standing on a 25-kg car which is moving at a velocity of 4 m/s relative to the ground, as shown in the figure. If the child jumps off the car with a velocity of 6 m/s relative to the ground, in the opposite direction to that of the car, what will the final velocity of the car relative to the ground be?



71. A long wooden beam with a mass of 30 kg is at rest on a smooth surface. A 40 kg child who is initially stationary starts walking on the beam and reaches a velocity of 1.2 m/s relative to the ground in

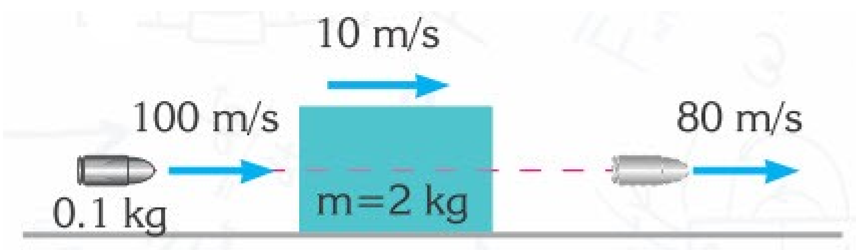
2 s.



a) What is the velocity of the beam?

b) What is the magnitude of the force applied by the child on the beam?

72. While a 2 kg object is moving at a velocity of 10 m/s, a 0.1 kg bullet is fired into the object at a velocity of 100 m/s and leaves it at a velocity of 80 m/s, as shown in the figure. What is the final velocity of the object? (Neglect any friction and energy transferred into heat.)



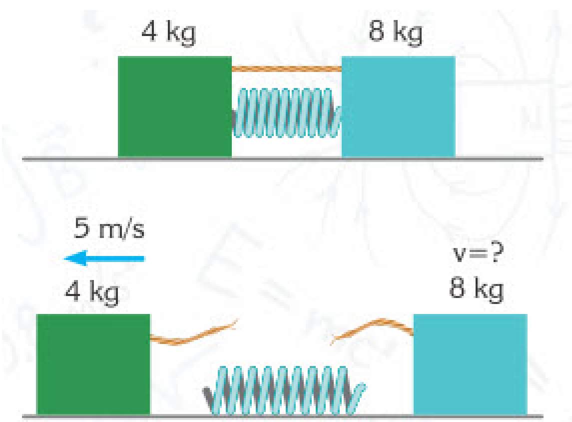
73. A hunter whose mass is 75 kg fires a 5 kg rifle. A bullet with a mass of 40 g leaves the rifle with a velocity of 500 m/s.

Find the recoil velocity of the rifle for the conditions below

a) if the hunter holds the rifle loosely.

b) if the hunter holds the rifle firmly and presses it against his shoulder.

74. A spring is placed between two objects of masses 4 kg and 8 kg on a frictionless plane. It is totally compressed by the objects, which are then tied together with a piece of cord, as shown in the figure.



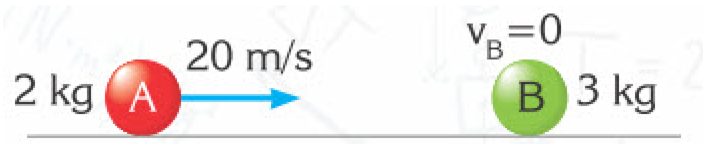
After the cord is cut, if the 4 kg object moves towards the left with a velocity of 5 m/s

a) what is the velocity of the 8 kg object?

b) what are the kinetic energies of the objects?

c) how much energy is initially stored in the spring?

75. A 2 kg ball moving with a velocity of 20 m/s on a frictionless horizontal surface undergoes a head–on inelastic collision with another object, as shown in the figure.

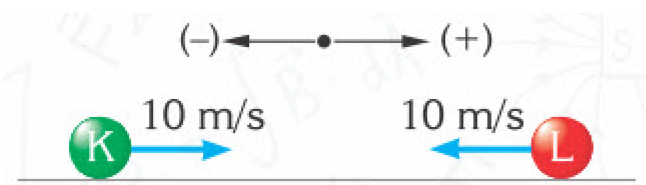


If they move off together after the collision, what is the common velocity of the balls?

76. Two 2 kg balls moving with velocities of 4 m/s and 2 m/s on a smooth horizontal surface undergo a head – on inelastic collision, as shown in the figure.

What is the common velocity of the balls after the collision?

77. The balls K and L, moving towards each other with velocities of 10 m/s, collide head-on inelastically on a frictionless horizontal surface, as shown in the figure.

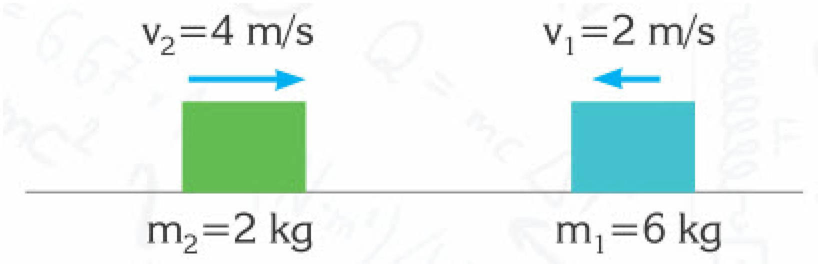


What is the common velocity of the balls, if;

a) $m_K = m_L = 2$ kg?

b) $m_K = 3$ kg and $m_L = 2$ kg?

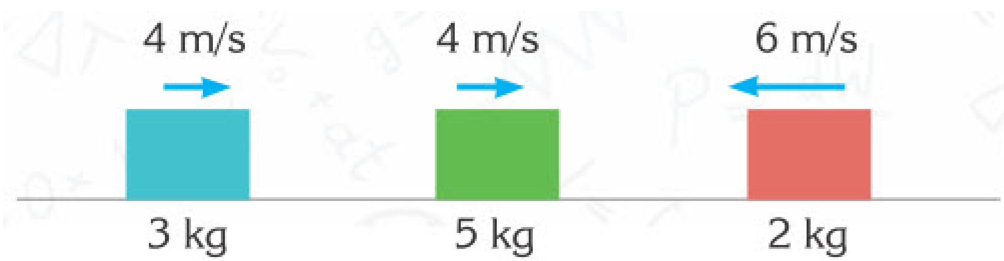
78. Two objects which are moving in opposite directions on a smooth horizontal plane undergo an inelastic collision.



What is the common velocity of the objects after the collision?

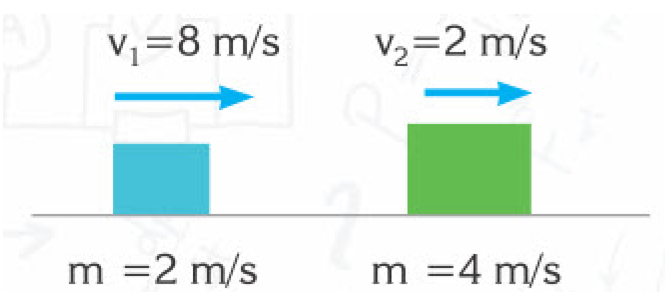
79. A 50 g bullet moving at a velocity of 240 m/s strikes and enters a stationary concrete block with a mass of 4950 g. What is the common velocity of the block and the bullet after the collision?

80. Three objects moving on a smooth horizontal plane, as shown in the figure, collide and stick together at the same time.

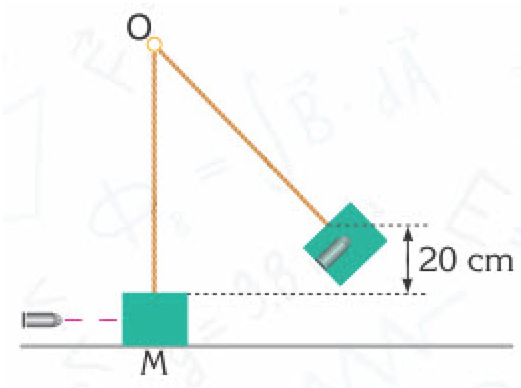


What is the common velocity of the objects after the collision?

81. Two masses moving in the same direction on a smooth horizontal plane undergo an inelastic collision and move off together. What is the ratio of the total energy after the collision to the total energy before the collision E_f/E_i?

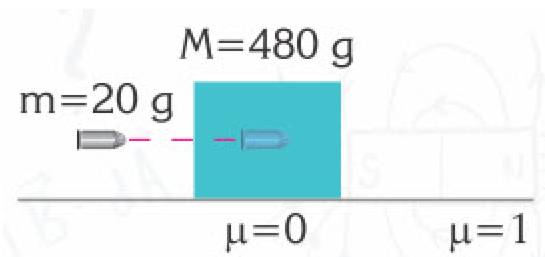


82. A 20g bullet is fired into a ballistic pendulum of mass 1980 g, as shown in the figure.



If the pendulum's block rises 20 cm as a result, what is the initial velocity of the bullet?

83. A 20 g bullet at a velocity of 250 m/s strikes and enters a wooden block of mass m=480 g, which is at rest on a smooth horizontal plane, as shown in the figure. After moving a certain period of time on the smooth plane, the wooden block slides onto a rough surface. If the coefficient of kinetic friction between the surface and the block is 1



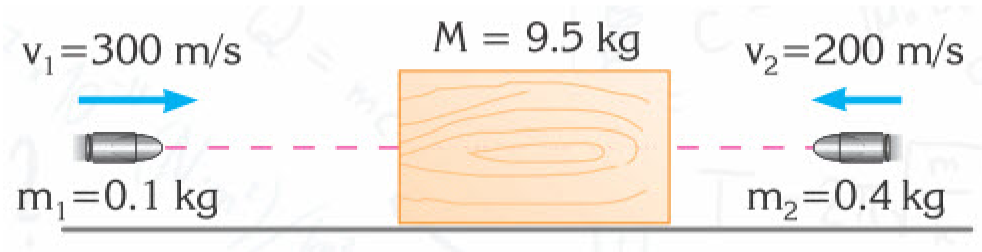
a) at what velocity do the bullet and the block move off together with after the collision?

b) what distance does the block travel along the rough surface?

c) what is the impulse applied by the friction force to the wooden block?

84. A stationary wooden block on a smooth surface is struck by two bullets of masses m_1=0.1 kg and m_2=0.4 kg travelling at velocities of v_1=300 m/s

and v_2=200 m/s in opposite directions, as shown in the figure.



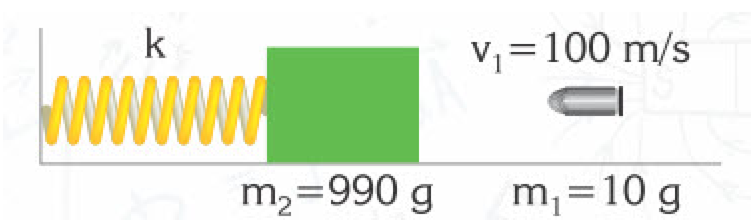
If the bullets enter the block, what is the common velocity of the system after the collisions?

85. A bullet of mass m_1=10 g enters a wooden block of mass m_2=990 g, which is fixed to a wall by a spring, as shown in the figure. If the initial velocity of the bullet is 100 m/s and the spring constant is

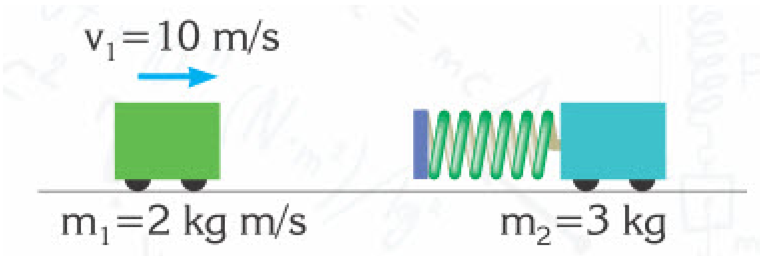
$k = 100$ N/m,

a) what is the common velocity of bullet+block just after the bullet enters the block?

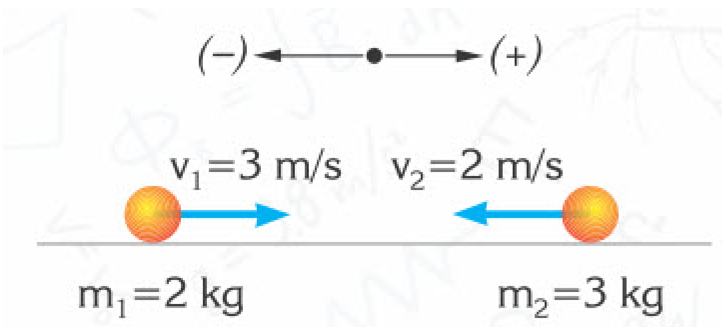
b) How many cm is the maximum compression of the spring? (Neglect the friction between the block and the surface.)



86. A spring with spring constant k=3000 N/m is attached to a car which rests on a smooth horizontal plane. The total mass of the car with the spring is m_2=3 kg. How many cm is the spring compressed when another car of mass m_1=2 kg strikes it with a velocity of 10 m/s, as shown in the figure?

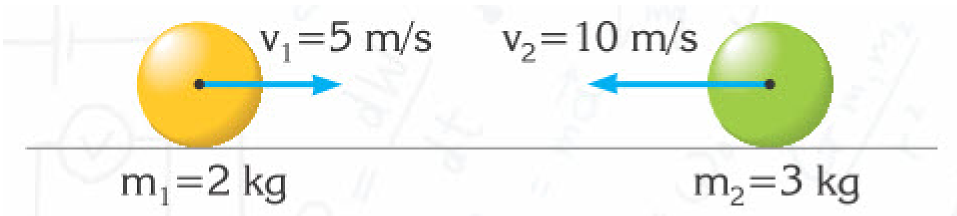


87. Two objects of mass m_1 and m_2 moving at velocities v_1 and v_2, undergo a head-on elastic collision, as shown in the figure. After the collision, if the object of mass m_1 moves at a velocity of u_1 and the object of mass m_2 moves at a velocity of u_2, what are the velocities u_1 and u_2?

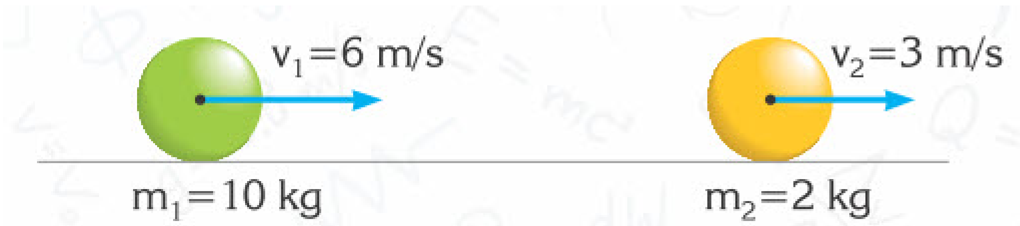


88. Two identical balls moving at velocities of 4 m/s and –2 m/s, as shown in the figure, undergo a head-on elastic collision. Calculate the final velocities of these balls after the collision.

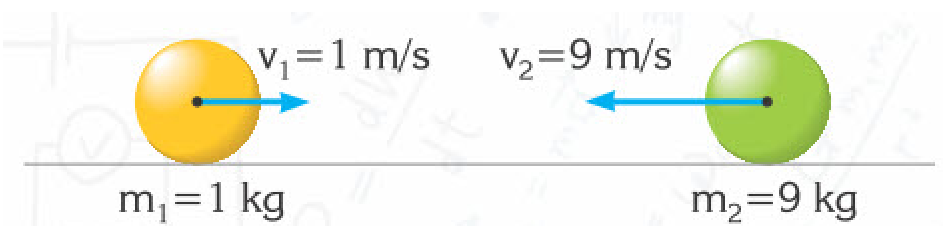
89. Two balls of masses m_1=2 kg, m_2=3 kg move towards each other. They have velocities of υ_1=5 m/s and υ_2=10 m/s, as shown in the figure. If they undergo a head on perfectly elastic collision, find the velocities of the objects after the collision.



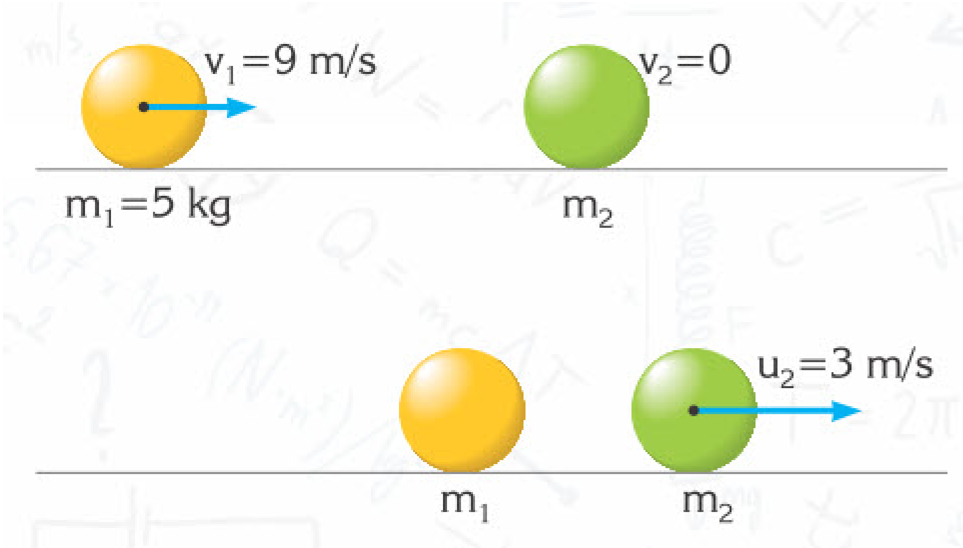
90. Two balls of m_1=10 kg and m_2=2 kg moving on a smooth horizontal plane with velocities of 6 m/s and 3 m/s in the same direction collide perfectly elastically. What are the velocities of the objects after the collision?



91. Two balls of masses m_1=1 kg and m_2=9 kg which are moving towards each other at velocities of v_1 = 1 m/s and v_2= 9 m/s collide with each other. If the collision is a perfectly elastic head-on collision, what are the velocities of masses m_1 and m_2 after the collision?



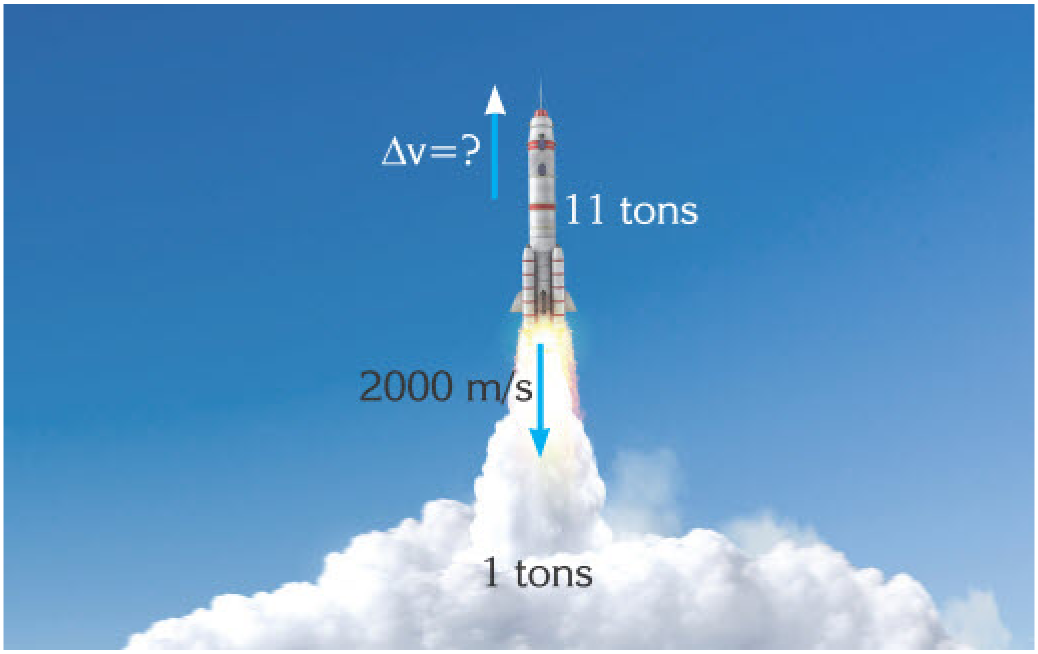
92. An object of mass m_1=5 kg moving at a constant velocity of v_1=9 m/s undergoes a head-on, perfectly elastic collision with a stationary object of mass m_2, as shown in the figure. If the mass m_2 starts moving at a velocity of u_2=3 m/s after the collision, what is the mass m_2?



93. Two balls of masses m_1=10 kg and m_2=5 kg which are moving at constant velocities of v_1=5 m/s and v_2=6 m/s collide with each other. If the collision is a perfectly elastic head-on collision, what is the velocity u_2 of mass m_2?

94. What is the change in the velocity of a rocket, which ejects 1000 kg of gas at a velocity of 800 m/s, if its mass is 20000 kg after the ejection?

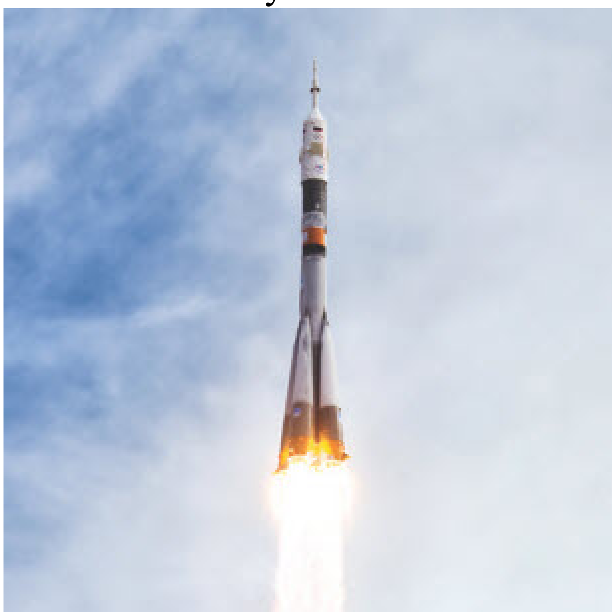
95. If there is a 10 m/s change in the velocity of a 30500 kg rocket, at what velocity is the 500 kg gas ejected?



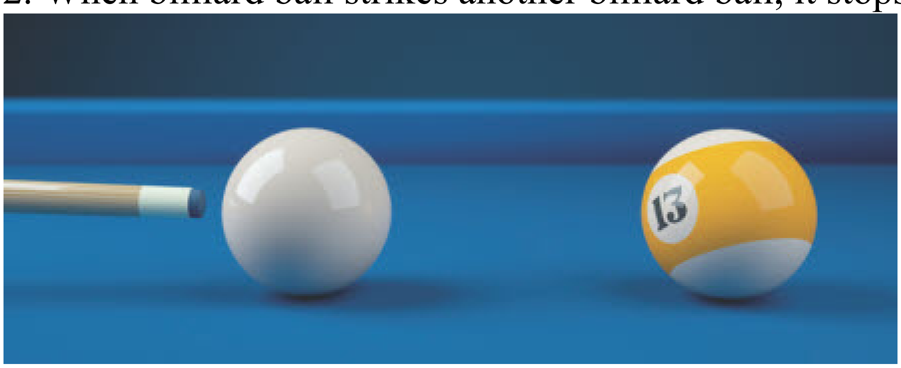
96. What is the change in the velocity of a rocket of mass 11 tons, including the fuel, from which 1 ton of fuel is ejected at a velocity of 2000 m/s?

PHYSICS IN LIFE

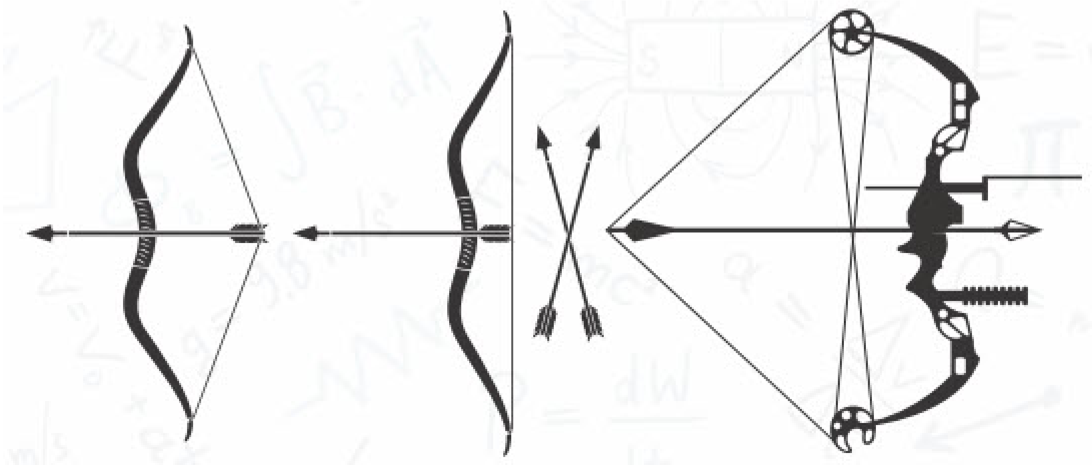
1. Spaceships start in Baikonur spaceport. They expel burning gases downwards. Why?



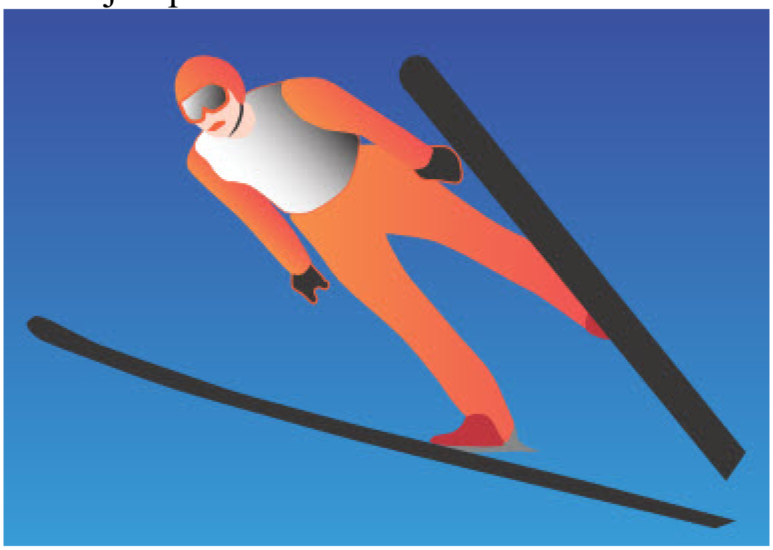
2. When billiard ball strikes another billiard ball, it stops sometimes. Why?



3. People now use compound bows instead of traditional bows. Which bow does shoot arrow faster, traditional bow or compound bow? Why?



4. Ski jumpers slide down hill that is 50-70 meter high. Why?

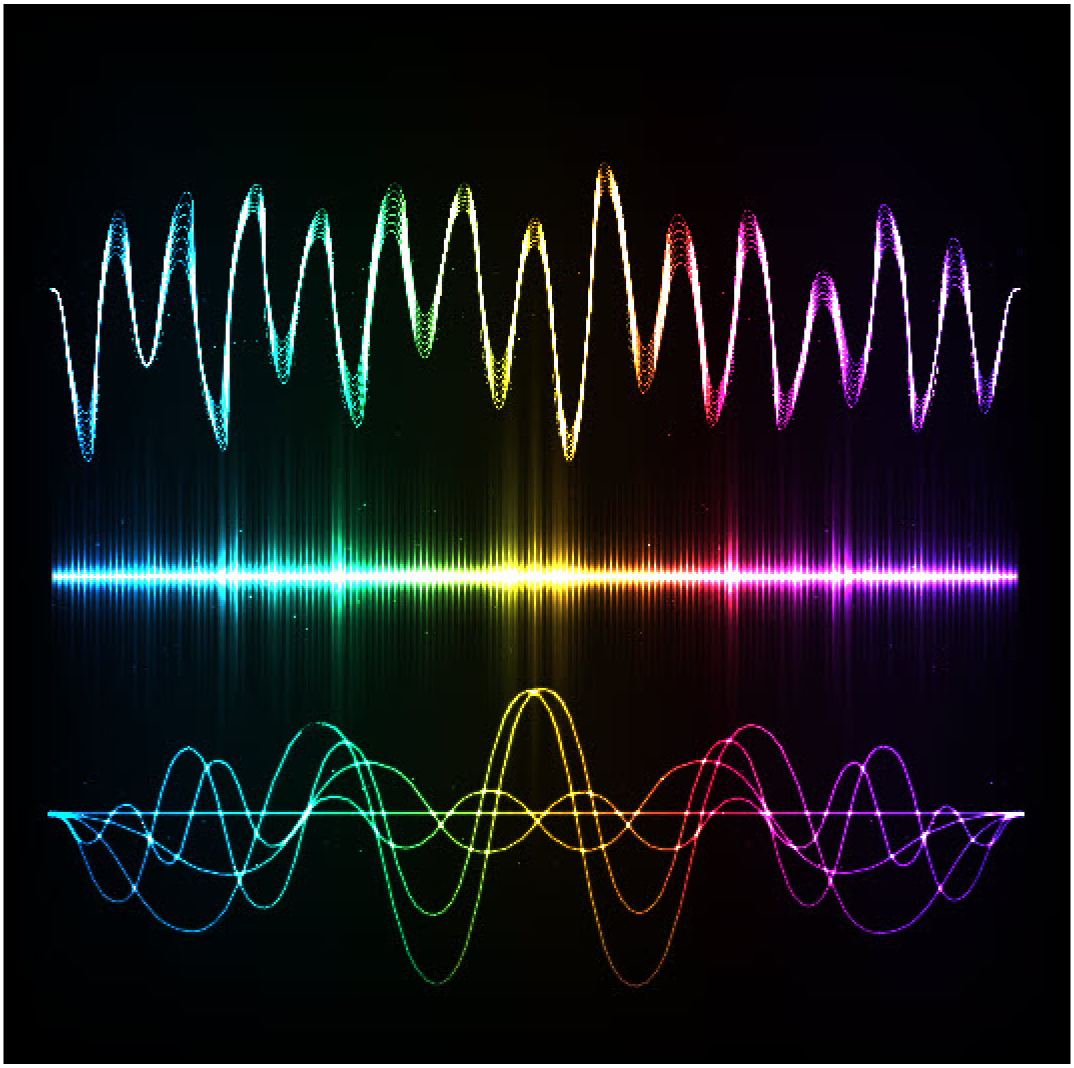


5. Airbags protect people in car crashes. How?

6. At some points child on a swing has zero velocity. Why?

7. Truck and car move at same speed. Which one is difficult to stop, truck or car? Why?

8. A man and a child moved their cars for same distance. Who does more work, man or child? Why?



CHAPTER 5

OSCILLATIONS AND WAVES

5.1 OSCILLATIONS

You will

- tell examples of free oscillation and forced oscillation;
- experimentally determine amplitude, period and frequency of oscillation;
- calculate period, angular frequency and phase by using formulas;

Question

What kind of cycles you observe in your daily life?

When spring is stretched, it produces restoring force F that pulls the box, Figure 1. If we neglect friction, the box will move back and forth continuously. Such motion is called oscillatory motion.

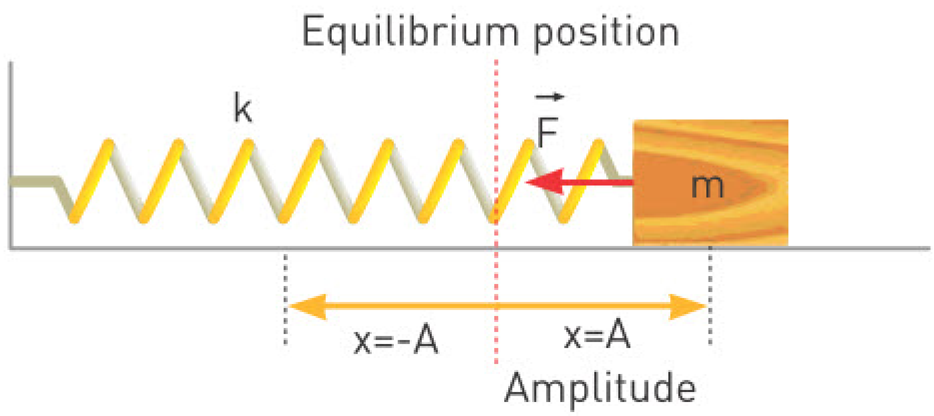


Figure 1

Equilibrium position and amplitude

When the box is at point with zero restoring force, that point is equilibrium position. The maximum displacement from equilibrium position is called amplitude, Figure 1. The motion of box is between A and -A.

Cycle of oscillation

Box starts at x = A, then goes to negative amplitude, then returns back at where it started. This is called one complete cycle.

Period of oscillations (T)

Oscillatory motion is similar to circular motion because they both have cycles. Time needed to complete one cycle is called period of oscillation and denoted as T. Unit of period is second.

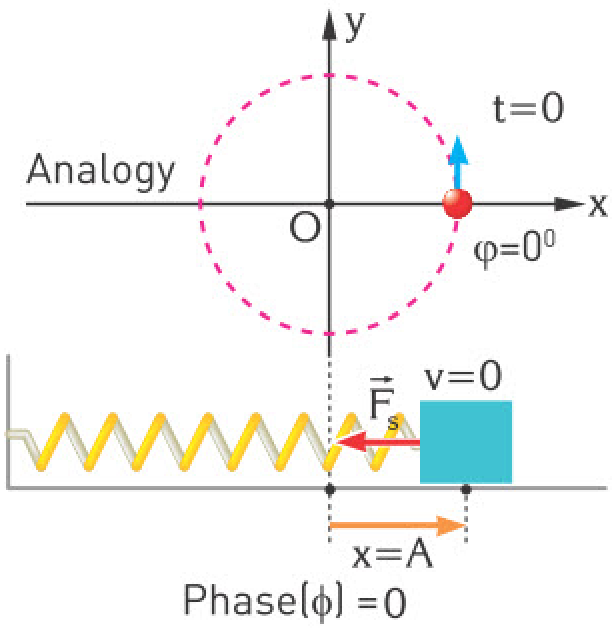
Angular frequency (ω)

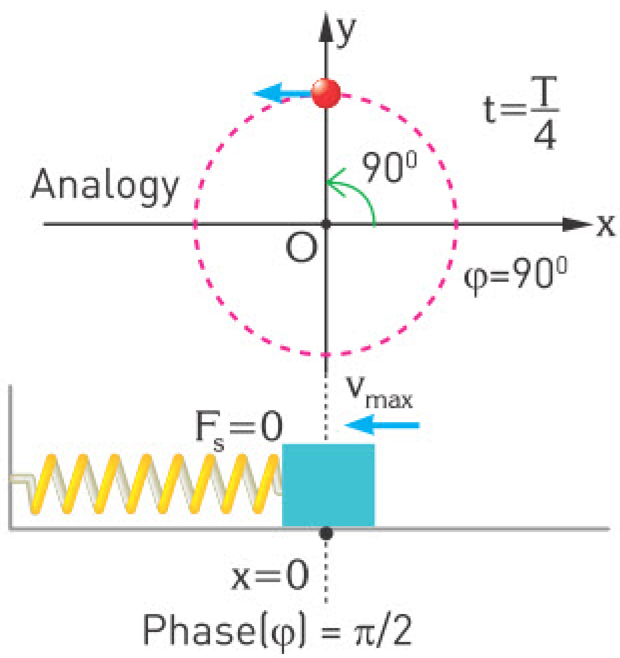
Angular speed (ω) in circular motion describes how fast the rotation swipes 2π degrees. Due to the analogy, we will use angular frequency (ω) to describe how fast the object completes one cycle. ω and T are related as

$$\omega = \frac{2\pi}{T}$$

Phase of oscillation

Let's build a circular analogy that has same ω. The current angle in circular analogy is called phase of oscillation, Figure 2.


y
t=0
Analogy
x
O
φ=0⁰
v=0
$\vec{F}_s$
x=A
Phase(ϕ) =0


y
t=T/4
Analogy
90⁰
x
O
φ=90⁰
v_{max}
F_s=0
x=0
Phase(φ) = π/2

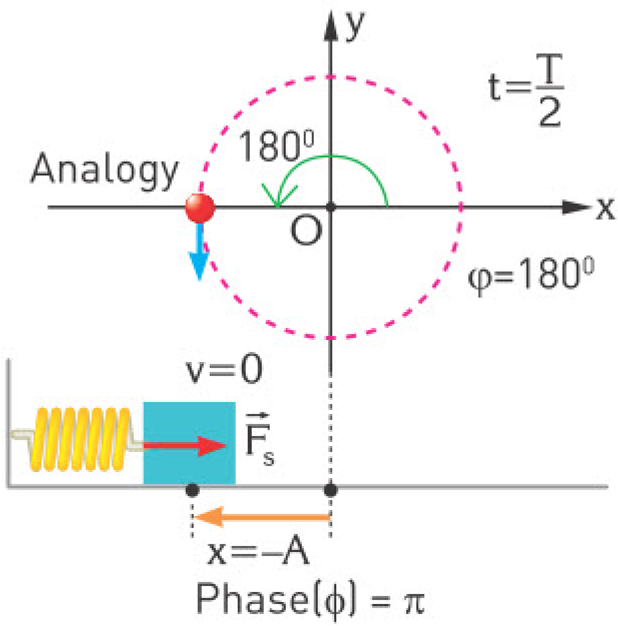


Figure 2

We use φ to show the phase of oscillation. Unit of phase is radians. We can use formula $\varphi=\omega t$ to find current phase. When $\varphi=\pi/2$ it means the quarter period (T/4) has passed. When $\varphi=\pi$, it means half period has passed.

Frequency

As you understand from analogy, oscillations are very similar to circular motion. Let's add another type of frequency, that is present in circular motion. It is measured in Hertz and formula

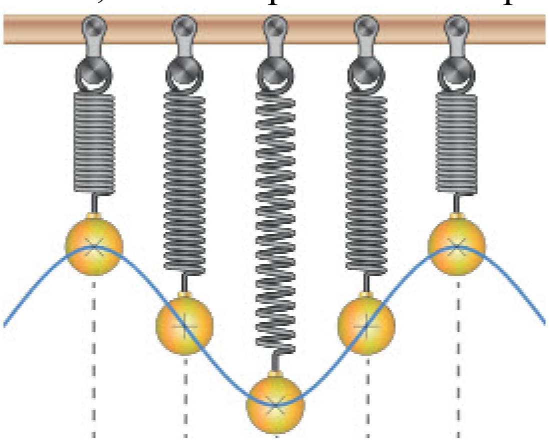
$$f = \frac{1}{T}$$

Figure 3

Figure 4. Oscillations in daily life

Example

A vertically suspended spring oscillates as shown in the figure. Look at the picture, calculate period and frequency of oscillation.



Solution:
From the picture we can see that the period is 2 s, so frequency can be found by
f=1/T=1/2 s=0.5 Hz

Literacy

1. Why do you push child on a swing? What does happen if you don't push child?
2. Mobile phones use GSM standard of 900 MHz. What is period of oscillations?
3. Child plays on swing so that she performs 30 oscillations in one minute. What is the period and fequency of oscillations?

4. Use circular analogy to draw position of the box and speed vector when phase φ is 3π/4, 2π, π/4, π/6.

Terminology

equilibrium position - тепе-теңдік нүктесі / точка равновесия
to restore - қалпына келтіру / восстановить
continuously - үздіксіз / непрерывно
oscillation - тербеліс / колебание
cycle - айналым / цикл
angular frequency - циклдік жиілік / циклическая частота
analogy - үйлестік / аналогия
swing - әткеншек / качели
shock absorbers - амортизатор/ амортизатор

Art time

Use "virtual piano" and make music piece about "oscillatory motion". For example, "Wispow Freepiano".

Research time

Make a video "oscillations are everywhere".

Fact

Shock absorbers are used in cars.

,

5.2 EQUATIONS OF OSCILLATION

You will

write equations of displacement, speed and acceleration from graphs of harmonic oscillation;

Question

What is represented on the monitor?

If we use formulas $F=m\cdot a$ and $F=-k\cdot x$ on Figure 1. We get

$$a=-\frac{k}{m}\times x$$

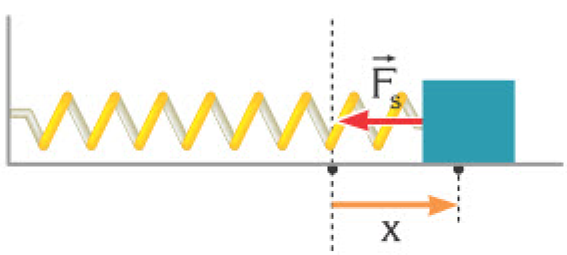


Figure 1

Acceleration is directly proportional to displacement, and it is not constant. When acceleration is directly proportional to displacement (a~x), the system performs simple harmonic motion (SHM). In this case we can use sine and cosine functions to describe it.

Equation of displacement

When a mass on spring is displaced from equilibrium point, the pencil leaves wave like pattern, Figure 2. The system performs oscillations between A and -A. After applying cosine function, we get

$x(\varphi)=A\times\cos(\omega t)$

This expression shows how position x of object depends on phase φ. Instead of φ we can write φ=ωt. Where ω is angular frequency. Then we get function of time

$\mathbf{x(t)=A\times\cos(\omega t)}$

This equation of displacement is SHM. If A is in meter, then x(t) is in meter as well.

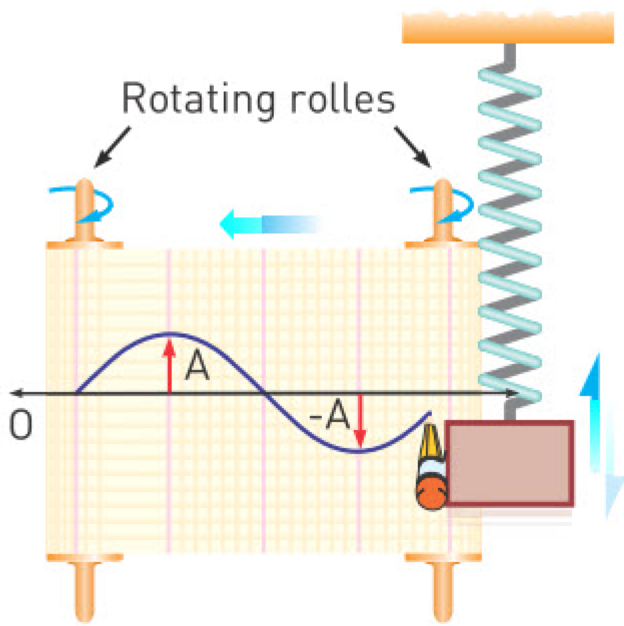


Figure 2

Equation of velocity

The velocity in SHM changes between [$-\upsilon_{max}$, υ_{max}].

$\boldsymbol{\upsilon(t)=-\upsilon_{max}\times\sin(\omega t)}$

υ_{max} is maximum velocity. This value is taken in equilibrium position. There is a negative sign because initially x and v are in opposite directions.

The formula of υ_{max} is

υ_{max} =Aω

Equation of acceleration

The acceleration in SHM is in range [$-a_{max}$, a_{max}].

$a(t)=-a_{max} \times \cos(\omega t)$

a_{max} is maximum acceleration. This value is taken at the maximum displacement. The negative sign shows that initially x and a are in opposite directions. The formula of a_{max} is

$a_{max}=A\omega^2$

Example

An object is exhibiting simple harmonic motion obeying the equation x=2 sin (100 πt) m. What is the amplitude, angular frequency, period and frequency of the simple harmonic motion?

Solution:

The displacement equation for simple harmonic motion is

$x(t)=A\times\cos(\omega t+\varphi)$

Since it is given as x=2 sin (100t)

Thus the amplitude is A=2 m, the angular speed is

ω=100 π rad/s and phase φ=0

From

$$\omega = \frac{2\pi}{T}$$

we can find period:

$$T = \frac{2\pi}{\omega} \Rightarrow T = \frac{2\pi\, rad}{100\pi\, rad/s} = \frac{1}{50} s = 0.02\ s$$

From

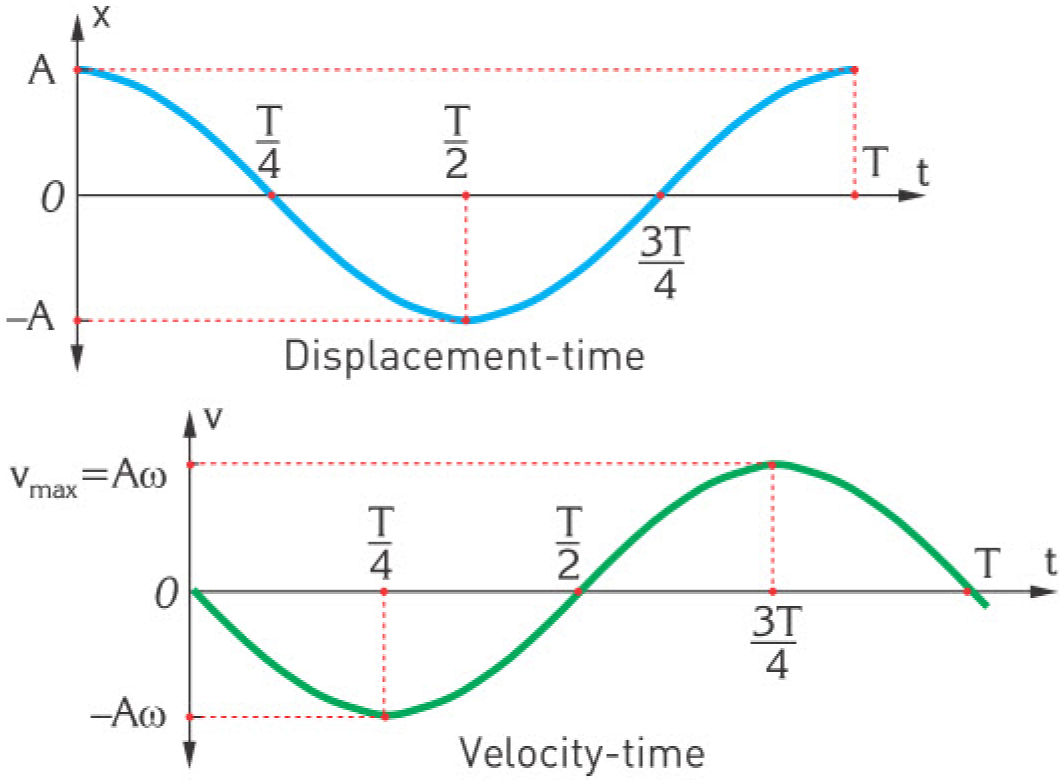
$$\nu = \frac{1}{T}$$

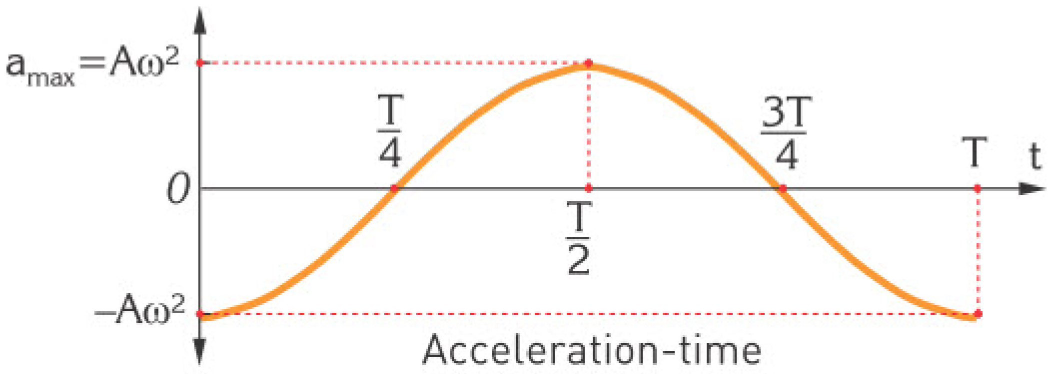
the frequency is

$$\nu = \frac{1}{\frac{1}{50}s} = 50\ s^{-1} = 50\ Hz$$

Activity

"Equations and Graphs"
a) Draw the graphs of sine and cosine functions. Use any source you want for help.
b) The graphs that describe, Figure 1, are given. What is the relationship between them and the graphs you drew?
c) What shapes are similar but not identical?





Art time

Use virtual guitar" and make music piece about graph of oscillations. For example, "tabnplay" or "riff guitar buttonbass".

Fact

Generally frequency is represented in two ways. One is and another is f.

Research time

Attach a load to rubber band and hang it. Stretch the band to certain distance and release it. Find the equations for x, v and a.

Terminology

pattern - ою/ узор
similar - ұқсас / аналогичный
identical - бірдей / идентичный

Literacy

1. Object oscillates on a spring with 10 cm amplitude and 0.67 Hertz frequency. Write equation of oscillations.
2. Measure your pulse and calculate frequency of your heart. Write equation of oscillations of your heart.

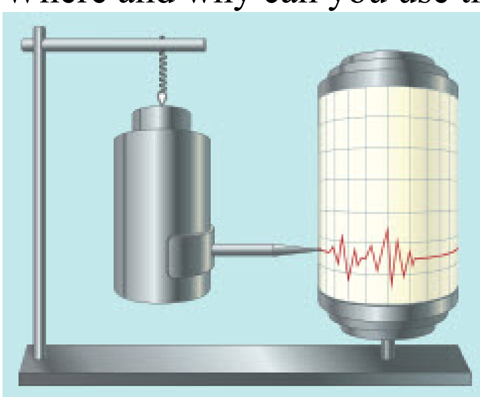
5.3 MASS-SPRING SYSTEM

You will

- explain reasons for appearance of oscillation in different oscillatory systems;
- investigate parameters affecting the period;

Question

Where and why can you use this device?



Mass-spring system has a variety of applications. For example, suspension, Figure 1.

Figure 1

We can find period of oscillation of this system by formula

$$T = 2\pi\sqrt{\frac{m}{k}}$$

The period depends on the mass [kg] of an object and spring constant [N/m]. If we combine it with formula ,

$$\omega = \frac{2\pi}{T}$$

we will get

$$\omega = \sqrt{\frac{k}{m}}$$

This expression shows that hard springs oduce faster oscillations, great masses produce slower oscillation.

Combination of springs

We can combine several springs together, so we can control the period. There are 2 common types of combinations:

a) Series combination

When springs are connected one after another, Figure 2.

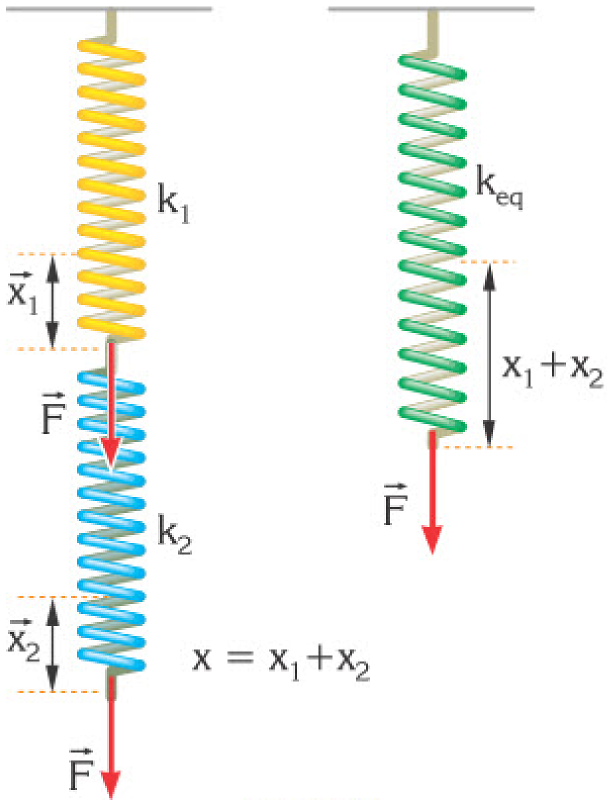


Figure 2

When force F acts on springs, extension of each spring depends on spring constant. Each spring carries same force. We can replace sequence of springs with one equivalent spring. This spring has equivalent spring constant k_{eq}.

$$\frac{1}{k_{eq}} = \frac{1}{k_1} + \frac{1}{k_2}$$

b) Parallel combination

If all springs are attached directly to an object, it is called parallel combination, Figure 3.

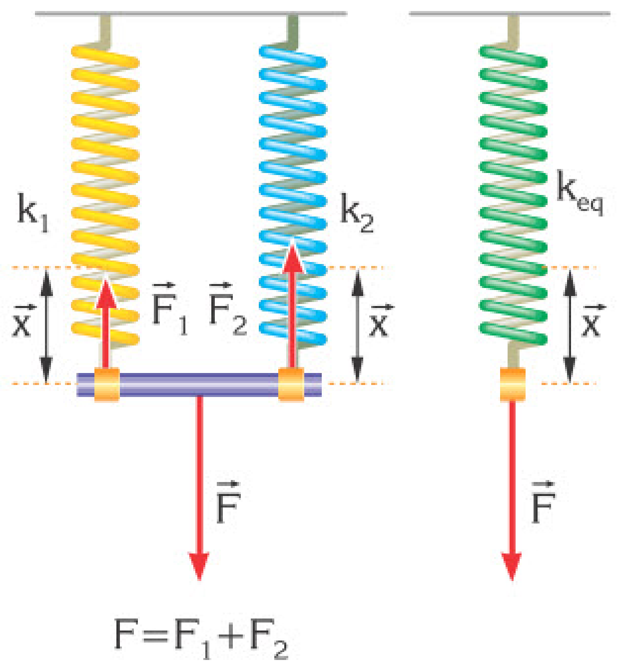


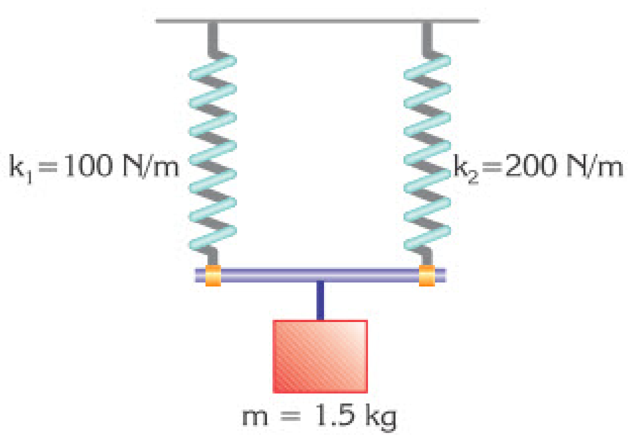
Figure 3

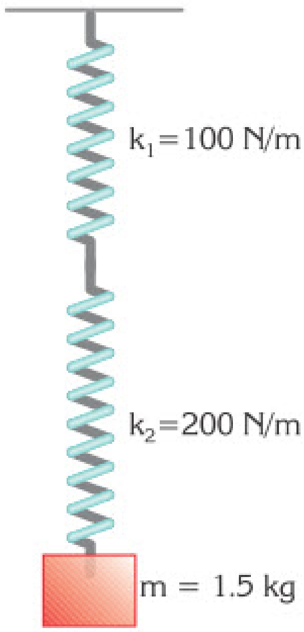
When we stretch several springs, we must apply force that equals to sum of forces in springs. We can find equivalent force by formula

$$k_{eq} = k_1 + k_2$$

Example

Compare the equivalent spring constants in the figure.





Solution:

The equivalent spring constant for springs in series:

$$\frac{1}{k_{eq}} = \frac{1}{k_1} + \frac{1}{k_2} \Rightarrow \frac{1}{k_{eq}} = \frac{1}{100\ N/m} + \frac{1}{200\ N/m} \Rightarrow \frac{1}{k_{eq}} = \frac{3}{200\ N/m}$$

$$k_{eq} = \frac{200}{3} N/m$$

The equivalent spring constant for springs in parallel:

$$k_{eq} = k_1 + k_2 \Rightarrow k_{eq} = 100\ N/m + 200\ N/m \Rightarrow k_{eq} = 300\ N/m$$

Activity

"To damp, or not to damp"
a) Formula of period is important in production of vehicles, Figure 1. Why? Estimate the numbers you need.
b) Vehicles use dampers (straight stick inside spring). Damper reduces period of oscillation with each cycle. For example, first cycle is 5s, second 4s, third 3s, next 2 s, and the last 1.5 s. What if vehicles don't have dampers? Draw a picture.
c) Strong damper works like - 5 s, 3 s,1 s, 0. Weak damper works like - 5 s, 4 s, 3 s, 2 s,1 s,0. Discuss what kind of damper each vehicle needs.
d) Design (do not use existing) a useful mechanism that may use springs or damper. Draw it.

Research time

Design mass-spring system that oscillates with same period as your heart. What are mass and spring constant?

Literacy

1. Earthquake that damaged Fukushima Daiichi Nuclear Power Plant had acceleration of 2.7 g. Because of this earthquake, spring-mass system oscillates with 1 cm amplitude. Spring has 100 N/m constant. Determine mass and period of oscillations.

Fact

Pogo stick is used to jump off the ground.

Art time

Use “music cube buttonbass” and write music piece about earthquake.

Terminology

variety - көптеген / множество
application - қолданыс / применение
suspension - аспа / подвеска
sequence - реттілік / последовательность
attached - бекіту / прикрепленный
to compare - салыстыру / сравнить
to damp - өшу /затухать
earthquake - жер сілкінісі / землетрясение

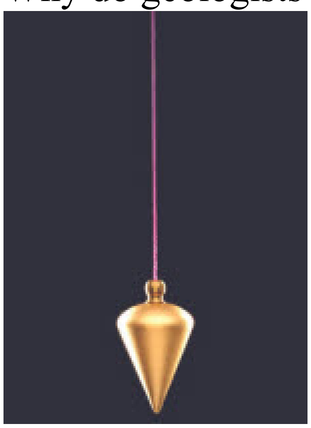
5.4 SIMPLE PENDULUM

You will

- explain reasons for appearance of oscillation in different oscillatory systems;
- investigate parameters affecting the period of pendulum;

Question

Why do geologists use pendulum to determine gravity?



Simple pendulum is a device that consists of a small mass attached to a string with length L, Figure 1.

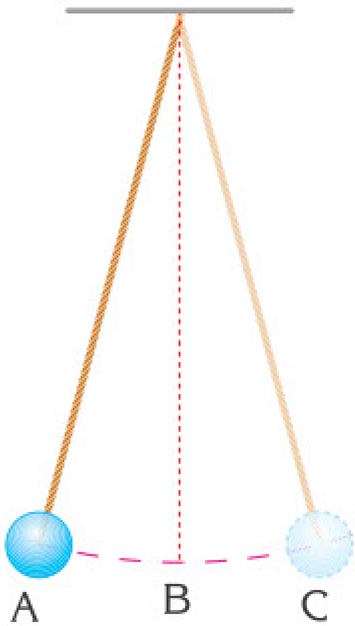


Figure 1

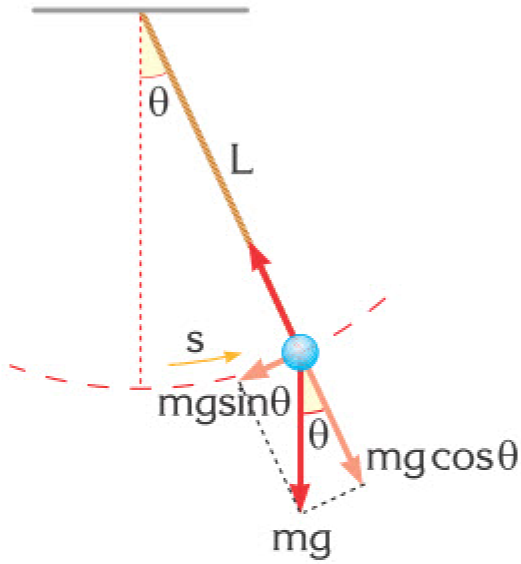
A clock's pendulum is an example of simple harmonic motion.

The formula of pendulum's period is

$$T = 2\pi\sqrt{\frac{L}{g}}$$

Notice that the period of the simple pendulum does not depend on the mass.

The component of weight perpendicular to string provides the restoring force.



$F_{res} = -mg \sin\theta$

The negative sign indicates that the restoring force, F_{res} , is in the opposite direction to the displacement.

The displacement, x, from the equilibrium position is the length along the arc through which the mass swings. It is given by $x = L\theta$

When the angle θ is sufficiently small, sin θ may be approximated by the angle θ in radians.

$\sin\theta \approx \theta$

The restoring force is proportional to displacement through the equation.

$F = -mg\theta = -(mg/L)s$

This equation has the same form as the mass-spring equation, $F = -kx$, except that here, spring constant k is replaced by mg/L. Thus, if mg/L is substituted for k in the equation for the period of the mass-spring system.

We can calculate gravitational acceleration of any planet by using pendulum. For example, 1 metre long pendulum makes 15 oscillations in 10 seconds. So, using these information you can find gravitational acceleration.

During the oscillations we neglect air resistance and any other friction force. Another condition is that angle of inclination must not be great (no more than 10 0). Why?

Activity

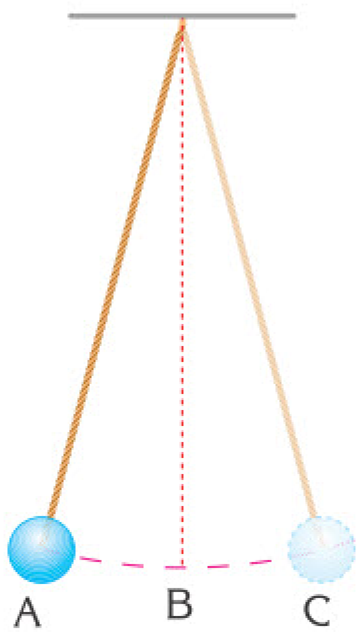
Draw the simple pendulum and determine the points of υ_{max} , a_{max} , x_{max} and υ=0, a=0 and x=0.

Research time

Can you make a simple pendulum that oscillates with the help of gravity? Search “Make a Wizard's Pendulum Clock” in Youtube.

Example

A simple pendulum of length 40 cm is oscillating as in the figure. What is the period of the pendulum? Take π=3.

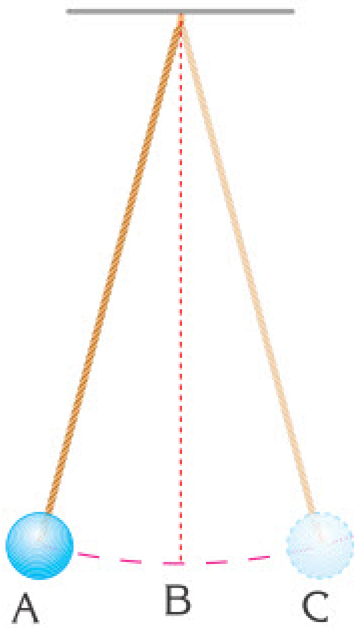


Solution:
First we need to convert length into metres. L= cm=0.4 cm
then by the formula for pendulum we get:

$$T = 2\pi\sqrt{\frac{L}{g}} = 2 \times 3\sqrt{\frac{0.4\ m}{10\ m/s^2}} \Rightarrow T = 1.2\ s$$

Example

A simple pendulum of length 40 cm is oscillating as in the figure.



What is the period of the pendulum? Take π=3.

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then by the formula for pendulum we get:

$$T = 2\pi\sqrt{\frac{L}{g}} = 2 \times 3\sqrt{\frac{0.4\ m}{10\ m/s^2}} \Rightarrow T = 1.2\ s$$

Example

Using a small pendulum of length 1 m, a geophysicist counts 70 complete swings in a time of 140 s. What is the value of g in this location?

Solution:

$$T = 2\pi\sqrt{\frac{l}{g}},\ T = t/n = 2\ s$$

$$T = 2\pi\sqrt{\frac{L}{g}}$$

$$T^2 = 4\pi^2 \frac{l}{g}$$

$$g = \frac{4\pi^2 l}{T^2} = \frac{4 \cdot 3.14^2 \cdot 1}{2^2} = 9.86\, m/s^2$$

Literacy

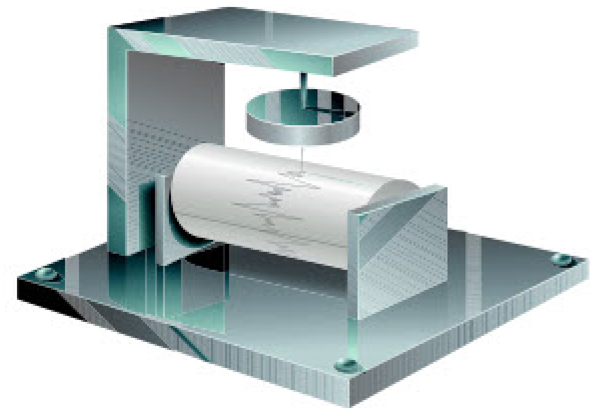
1. Geologist uses two pendulums that have same 1.014 meter length. First pendulum is 1 kg iron ball, second pendulum is 2 kg lead ball. Which pendulum does have bigger period? Why?
2. Geologist uses 1.014 meter long pendulum to determine gravity. Pendulum performs 300 oscillations in 10 minutes. What is gravity that geologist calculates?

Research time

Make two simple pendulums with different masses at the end of string and swing them. Compare their periods and frequencies.

Fact

Seismograph is a device used to detect motion of the ground and to predict earthquakes, volcanic eruption. John Milne (1851-1913) designed the first horizontal pendulum seismograph in 1895.Milne was a brilliant English geologist who lived and worked in Tokyo, Japan, and is considered as the father of seismology.



Art time

Use “online virtual MIDI keyboard” and write music piece about life of geologist. Use different instruments.

Terminology

simple pendulum - математикалық маятник / математический маятник
geologist - геолог / геолог
to consist - құрылу / состоять
air resistance - ауа кедергісі / сопротивление воздуха
to convert - аудару, конверсиялау / переводить, конвертировать

5.5 CONSERVATION OF ENERGY IN OSCILLATIONS

You will

describe conservation of energy in oscillation;

Question

Why speed of girl is zero on the figure? What types of energy are there in oscillations of girl?

We can use the law of conservation of energy in oscillations. In mechanical oscillations energy transforms from potential to kinetic and vice versa, Figure 1.

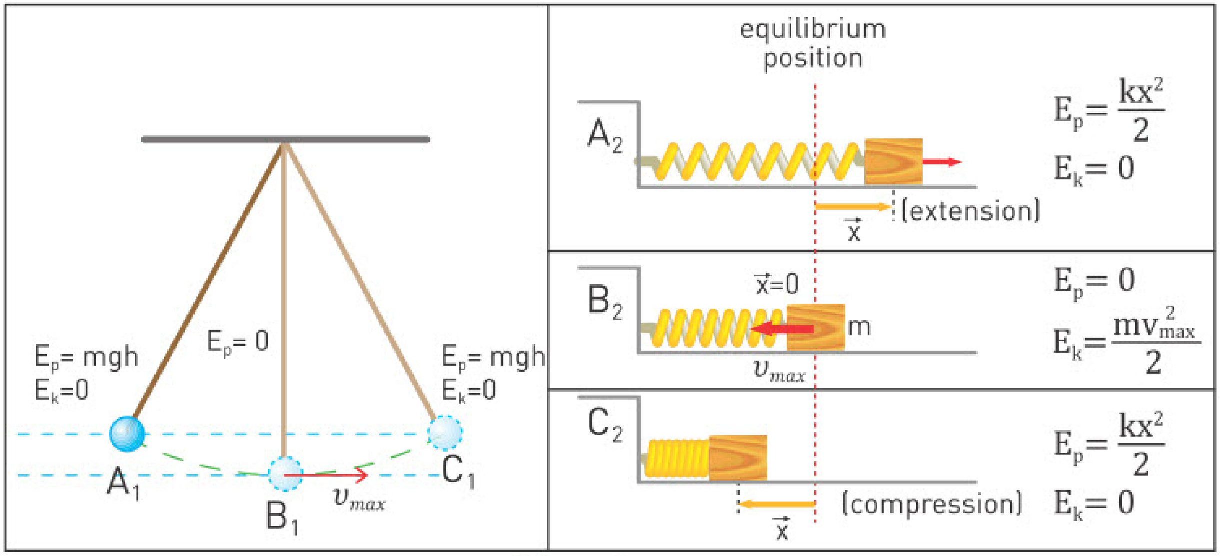


Figure 1

We can state some properties from the picture.

a) υ_{max} is reached at the equilibrium position.

b) At two edges there is no speed. The potential energy (PE) is maximum.

c) When pendulum is in region between A_1 and B_1, it has both potential and kinetic energy (KE).

d) At any point the sum of PE and KE is constant.

PE + KE = const.

We can write conservation of energy as

$PE_1+KE_1=PE_2+KE_2$

Let us use it for mass-spring system at points A_2 and B_2.

$$\frac{1}{2}kA^2 + 0 = 0 + \frac{1}{2}mv_{max}^2$$

Total mechanical energy of a freely oscillating system is conserved, Figure 2. This is because free oscillation implies the absence of friction and other resistive forces.

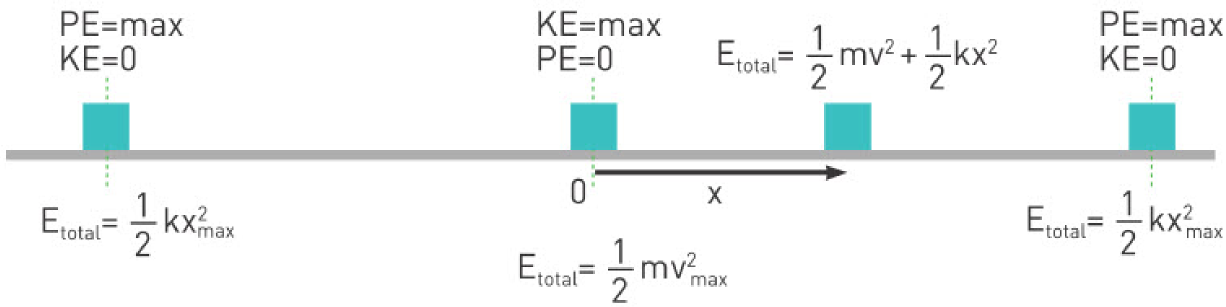
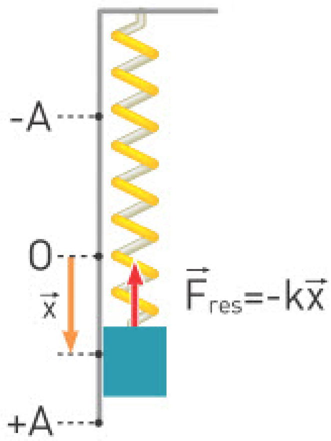


Figure 2. Energy conversion during a harmonic oscillation with spring.

Example

An object of 2 kg mass connected to a spring with k=100N/m, and freely oscillates in the vertical plane.



a) If the amplitude of oscillation is 5 cm, find the total mechanical energy,
b) Find elastic potential energy and kinetic energy at the instant when the object's displacement is x=3 cm.

Solution:

a) Total mechanical energy is always constant and equals the maximum potential energy

$$E_{Total}=\frac{1}{2}kA^2=\frac{1}{2}(100\ N/m)\times(0.05m)^2$$

E_{total} =1.25 J

b) Potential energy at x=3cm

$$PE=\frac{1}{2}kx^2=\frac{1}{2}(100\ N/m)\times(0.03m)^2$$

PE=0.045 J
Kinetic energy can be found by
E_{total}=PE+KE
KE=E_{total} - PE=0.125 J-0.045 J=0.008 J

Activity

1. What forms of energy are involved in the following situations?
a. pendulum
b. mass-spring system
c. swing
d. heart
2. How do the forms of energy in question 1 differ from one another? Be sure to discuss mechanical or nonmechanical energy, kinetic energy and gravitational comparing to elastic potential energy.

Literacy

1. Child moves on a swing. Maximum speed is 5 m/s. What is maximum height that child rises?
2. Bow can shoot 20 gram arrow with 50 m/s speed. Deformation of bow is 1 meter. What is spring constant of bow?
3. What types of energies are involved in motion of “besik” (cradle)?
4. Write conservation of energy between points B_1 and C_1,Figure 1.

Research time

Find the stiffness of rubber by hanging various known masses and measuring the deformation of rubber. Then find the maximum speed of object performing oscillations on rubber.

Fact

Tsunami has huge amount of potential and kinetic energy which can lead to enormous disasters.

Art time

Perform group dance that shows different types oscillations.

Terminology

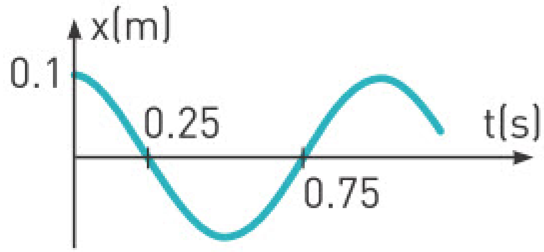
vice versa - керісінше / наоборот
to involve - орын алу / участвовать
to wind - орау / наматывать
spring - серіппе / пружина
comparing to - салыстырғанда / в сравнении с
bow - садақ / лук

5.6 PROBLEM SOLVING. OSCILLATIONS

Question

Why do loudspeakers need cables?

A mass-spring system with mass m=5 kg and spring constant k oscillates as shown on the graph x(t).



a) What are the values of amplitude, period, and frequency?
b) Write the equation for x(t) by using the graph.
c) What is the value of spring constant?
d) What is the value of υ_{max} ?

Solution:
a) From the graph amplitude A=0.1 m.
From the graph a quarter of period is 0.25 s. This means period is 1 s.
If period is 1s, then frequency

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

b)
When t=0, x(0) = 0.1. Therefore, x(t)=Acos(ωt) is the right form. We need to find ω. To find ω we can use the formula ω=2 π/T. We get ω=2π/1=2π rad/s. Then we can write the equation as x(t)=0.1 cos 2πt

c)
The formula of period of mass-spring system is

$$T = 2\pi\sqrt{\frac{m}{k}}.$$

If we combine it with

$$\omega = \frac{2\pi}{T}.$$

We get

$$\omega = \sqrt{\frac{k}{m}}.$$

Then, $k=4\pi^2$ N/m

d) We can find υ_{max} from conservation of energy.

$$\frac{1}{2}m\upsilon_{max}^2 = \frac{1}{2}kA^2$$

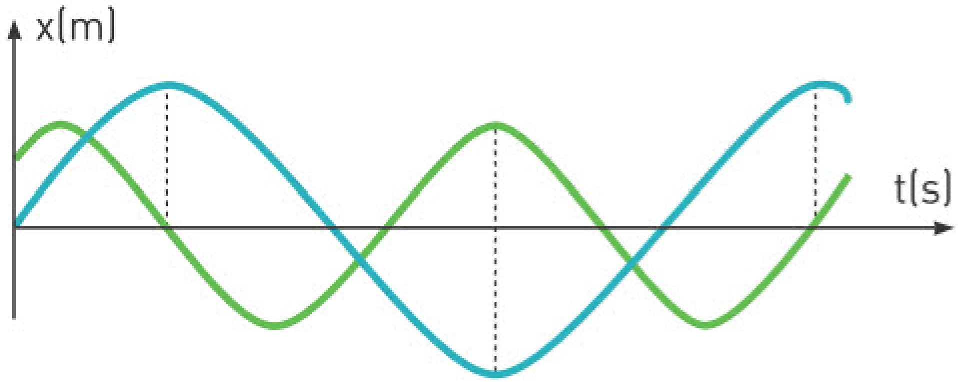
From the equation we get

$$\upsilon_{max} = A\sqrt{\frac{k}{m}}.\ \upsilon_{max} = 0.2\pi\ m/s$$

Now try to solve the following problems.

Exercise 1

Two objects perform oscillations. Their x(t) graphs are given.



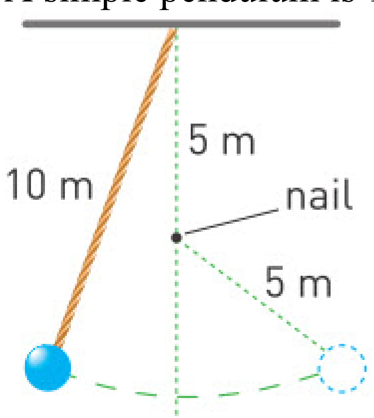
a) What are the amplitudes of the oscillations?
b) What are the periods and frequencies of the oscillations?
c) Find x(t) equation for the green graph.
d) Under what condition(s) you can find the x(t) equation for the blue graph?

Exercise 2

There are 2 simple pendulums. In a certain time interval the first pendulum performs 40 oscillations. In the same period of time the second pendulum performs 50 oscillations.
a) One of the pendulums is 20 cm shorter than another. Which of them is shorter?
b) What are the periods of two pendulums?

Exercise 3

A simple pendulum is 10 cm long. There is a nail 5 cm beneath the ceiling.



a) What region of the pendulum (AB or BC) moves faster? Explain.

b) What is the new period of the pendulum?

Exercise 4

A simple pendulum obeys the equation $x(t) = 2\cos(4t)$ on the unknown planet.
a) What are amplitude, angular frequency, period, and frequency ? (Take $\pi=3$)
b) How many oscillations does pendulum perform in 3 s?
c) If the length of the pendulum is 5 m, what is the gravitational acceleration on that planet?

Activity

Construct 2-3 problems: “equations of SHM, energy of oscillations, mass-spring and pendulum”. Let your classmates solve them.

Literacy

1. Frequency of oscillations of vocal cords is about 125 Hz in males, 210 Hz in females, about 300 Hz in children. What is your frequency?
2. How many oscillations do your vocal cords perform in one minute?
3. 440 Hertz is an international musical standard. Can you make pendulum that has same frequency? What is its length?

Art time

Perform theatre play that shows oscillations in human body and nature.

Terminology

loudspeaker - дауыс зорайтқыш / громкоговоритель
to combine - біріктіру, қосу / комбинировать
nail - шеге / гвоздь
beneath - астында / под
ceiling - төбе / потолок

to obey - бағыну / подчиниться
vocal cord - дауыс желбезегі / голосовая связка
to construct - құрастыру / сооружать

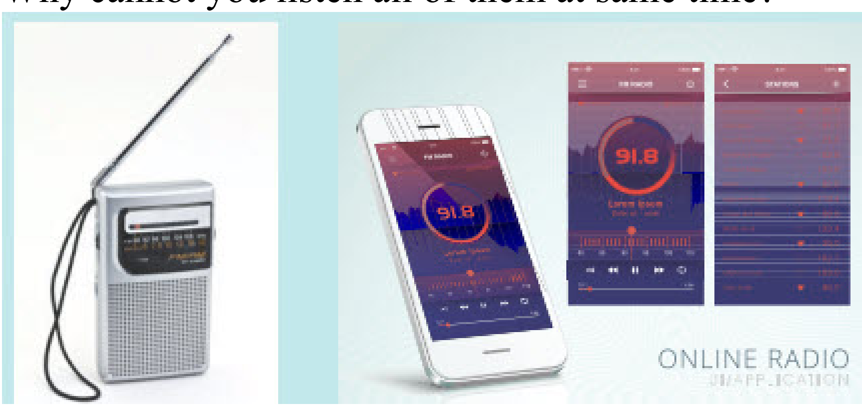
5.7 FREE AND DAMPED OSCILLATIONS. RESONANCE

You will

- describe relationship between amplitude and frequency of forced oscillation by using graph of forced oscillation;
- describe resonance;

Question

There are many radio stations that work at same time.
Why cannot you listen all of them at same time?



Swings are similar to a simple pendulum in SHM. The swings stop due to friction. However, if someone applies force, the swings continue to oscillate, Figure 1. Such oscillations are called forced oscillations.

Figure 1

Another example is yo-yo, Figure 2. If you want to play with it, you need to oscillate your hand (apply force). If you do not apply force, yo-yo will stop eventually.

Figure 2

In these examples, force should be applied at a certain frequency. If the force is applied too slow or too fast, the amplitude of oscillations will decrease. That certain frequency is called f_o - natural frequency of an object.

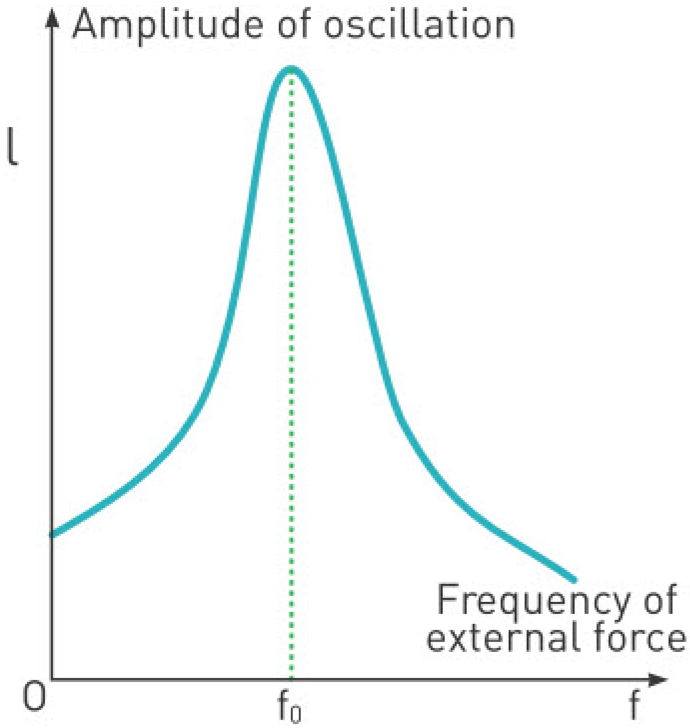
For example, f_o of swings depends on the length of swings. The f_o of yo-yo depends on its mass and dimensions.

Resonance

Imagine a mass-spring system with natural frequency

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{k}{m}}.$$

Then, periodic force at frequency f acts on it. If $f=f_0$ amplitude of oscillation will dramatically increase. This is called resonance. However, if $f<f_0$ or $f_0<f$, the amplitude will become less. This can be shown on the graph.



Resonance can be very dangerous. For example, if frequency of a wind becomes equal to the natural frequency of bridge, the bridge may collapse. Resonance also can be very useful. For example, string musical instruments. Frequency of oscillations of air inside an instrument becomes equal to the natural frequency of a string. As a result, the instrument produces louder sound.

Example

The length of the swing rope is 1.6 m. To make swing go higher what must be the frequency of the force applied? ($\pi=3$, $g=10$ m/s^2)

Solution:
To find the frequency of force which will make swing go higher we need to find resonance frequency. So first calculate the period, then the frequency.

$$T = 2\pi\sqrt{\frac{L}{g}} = 2\pi\sqrt{\frac{1.6\,m}{10\,m/s^2}} = 2\pi \times 0.4 = 2.4\,s$$

$$f = \frac{1}{T} = \frac{1}{2.4s} \approx 0.42\,Hz$$

So according to our calculation we have to push swing once in every 2.4 s.

Activity

Make 5 pendulums that have different lengths. Displace pendulum by 10 o then count number of oscillations and measure time until it stops. Repeat procedure for other pendulums. Which one dampens the quickest?

№	Length of pendulum	Number of oscillations	Time (sec)
1			
2			
3			
4			
5			

Research time

A bucket filled with sand (or another heavy object) is hanging on the ceiling. With your team, try to make the hanging object swinging as much as possible. You are not allowed to touch the object and you have one-minute time to make the vibrations.

1. Try to make the object oscillating with amplitude as large as possible.
2. Determine at which frequency the heavy object is oscillating. This frequency is called the natural frequency of an object and it is the frequency at which an object oscillates when it is disturbed.
3. What do you think would happen if you blow against the object with the following frequencies:

$f = 0.5\ f_{natural}$

$f = 1.5\ f_{natural}$

$f = 2\ f_{natural}$

$f = 0.834\ f_{natural}$

Fact

If frequency of your voice is equal to natural frequency of glass then resonance happens. Glass breaks.

Terminology

damped oscillation - өшетін тербеліс / затухающие калебания
eventually - соңында / в итоге
dangerous - қауіпті / опасно
useful - пайдалы / полезный

allowed - рұқсат етілген / позволен
to disturb - кедергі келтіру / беспокоить
against - қарсы / против
safety - қауіпсіздік / безопасность

Literacy

1. Why do dombyra and guitar have “sound board”, “sound box” and “sound hole”?
2. Why does 101-story “TAIPEI 101” tower in Taiwan have 660 ton pendulum inside?
3. Battalion of soldiers marched across Angers Bridge on 16 April 1850 in France. Bridge collapsed. Why?

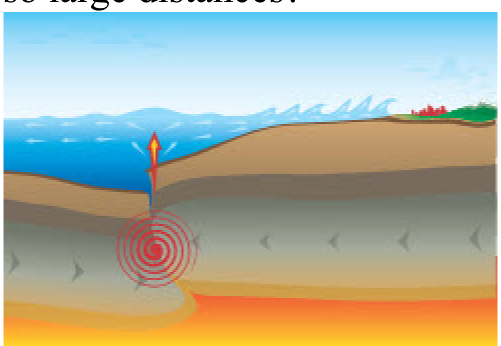
5.8 MECHANICAL WAVES

You will

- apply formulas of speed, frequency and wavelength for problem solving;
- compare longitudinal and transverse waves;

Question

1911 Kebin earthquake destroyed many houses in Almaty. People felt earthquake in Kokshetau, Semey and Pavlodar. How does earthquake travel so large distances?



Wave is the motion of oscillation in a medium. For example, Figure 1.

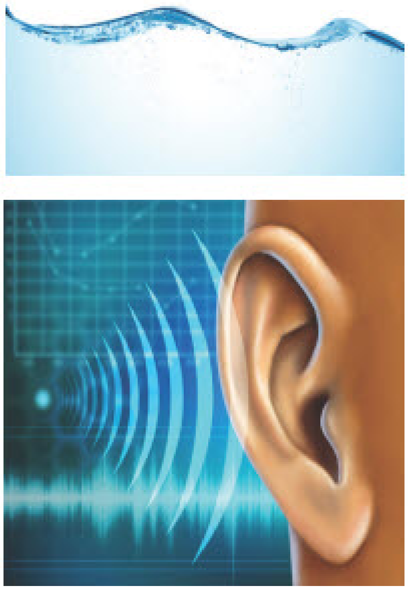


Figure 1

Waves can transfer energy, but they do not transfer the material of a medium. Generally, there are 2 types of waves:

a. Transverse waves

When you move spring as on Figure 2, the spring oscillates in a vertical plane, and wave propagates in a horizontal plane. When oscillation and propagation are perpendicular to each other, this wave is called transverse wave. Examples: water waves.

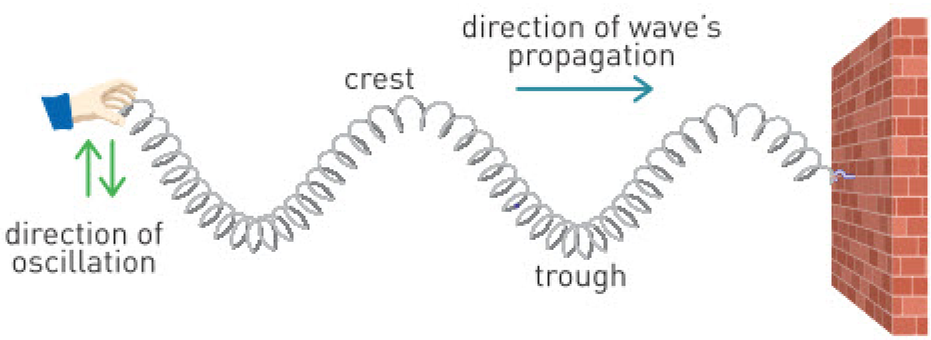


Figure 2

b. Longitudinal wave

When you move spring left and right, Figure 3, in this case oscillation and propagation are both in horizontal plane. This type of wave is called longitudinal. Example: sound waves.

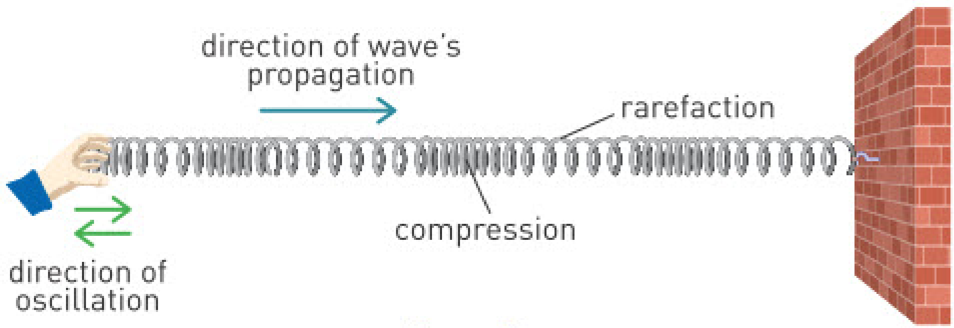


Figure 3

Wavelength

Any wave has a wavelength: the distance between two crests or two troughs. It is denoted as λ, Figure 4.

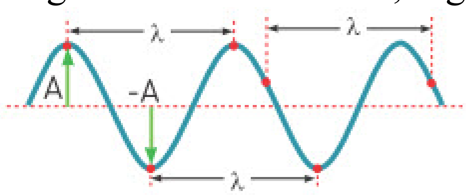


Figure 4

Period and Frequency

Wave is a propagation of an oscillation. Thus, we can apply concept of period and frequency. Time taken to travel a distance λ is called period T. The number of wavelengths (λ) travelled in 1 second is called frequency. The relation of period and frequency is in formula

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

Speed of wave

Wave propagates with a speed. It can be found by the formula

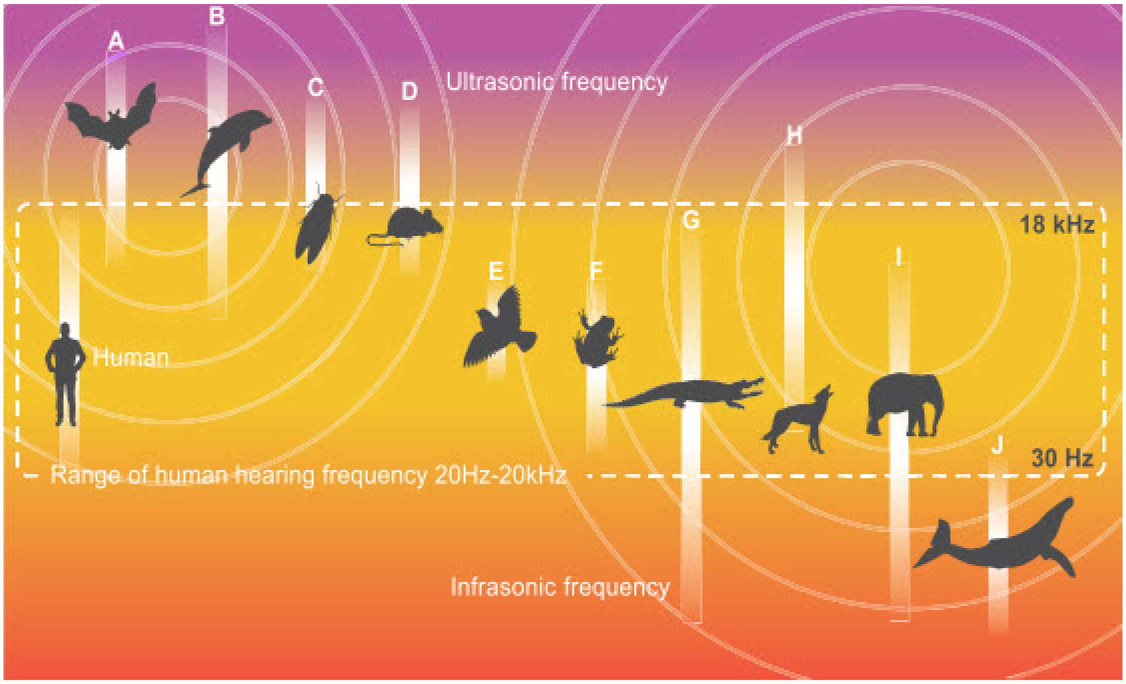
$$Speed = \frac{distance}{time}$$

We can use λ for distance and T for time.

$$Speed = \frac{Wavelength}{Period} \quad or \quad \nu = \frac{\lambda}{T}$$

Example

A sound detector detects a sound with wavelength of 20 m in the air. Which animals can make that sound? Animal hearing frequency range



A.	Bat	2kHz - 120kHz	F.	Frog & Toad	50Hz - 4kHz
B.	Dolphin	75Hz - 150kHz	G.	Crocodile	16Hz - 18kHz
C.	Insect	10kHz - 80kHz	H.	Dog	64Hz - 44kHz
D.	Rat	900Hz - 79kHz	I.	Elephant	17Hz - 10.5kHz
E.	Bird	1kHz - 4kHz	J.	Blue whale	14Hz - 36Hz

Solution:
Let's take speed of sound in air to be 330 m/s. From the equation for mechanical wave

$$v = \frac{\lambda}{T} = \lambda f$$

$$f = \frac{v}{\lambda} = \frac{330\ m/s}{20\ m} \Rightarrow f = 16.5\ Hz$$

From the picture you can see that it may be CROCODILE or BLUE WHALE.

Activity

Answer the following questions by using figure in example.

1. Which animal(s) can hear higher sounds that people cannot?
2. Which animal can hear the widest range of vibrations?
3. Write down why do you not hear a blue whale whistle?

Fact

“Photosounder” and “Virtual ANS” can change image into sound and vice versa.

Research time

Research types of sound that can be dangerous to you. Find how can we protect ourselves against loud noises.

Terminology

wave - толқын / волна
medium - орта / среда
to propagate - таралу / распространяться
wavelength - толқын ұзындығы / длина волны
crest - өркеш / гребень
trough - ойыс / впадина
detector - датчик / датчик
wide - кең / широкий
whistle - ысқырық / свисток
software - бағдарламалық қамтым / программное обеспечение
transverse - көлденең / поперечный
longitudinal - бойлық / продольный

Literacy

1. Speed of sound in air is nearly 340 m/s. By using frequency of your voice determine wavelength.
2. Tsunami has wavelength of about 200 km and speed of about 800 km/h. Calculate period and frequency of tsunami.
3. How many types of waves travel during earthquake? What is difference between these waves?

5.9 SOUND

You will

- tell the conditions for emergence and propagation of sound;
- tell the relationship between pitch, loudness, timbre of sound and frequency and amplitude of sound wave;
- tell condition of resonance and tell examples of application of resonance;
- describe echo and methods of its use in nature and industry;
- tell examples of use of infrasound and ultrasound in nature and industry;

Question

Why do we change tension of strings in dombyra?

Sound wave is a longitudinal wave that can propagate only in a medium: solid, liquid, or gas. The speed of sound wave does not depend on the source, but it depends on the type of medium, Table 1.

Material	Speed of sound (m/s)
Air (0ºC)	331
Air (20ºC)	343
Hydrogen (0ºC)	1286
Water	1493
Methanol	1143
Copper	3560
Iron	5130

Table 1

In order to produce sound we need a source of vibration. For example, speakers, Figure 1.

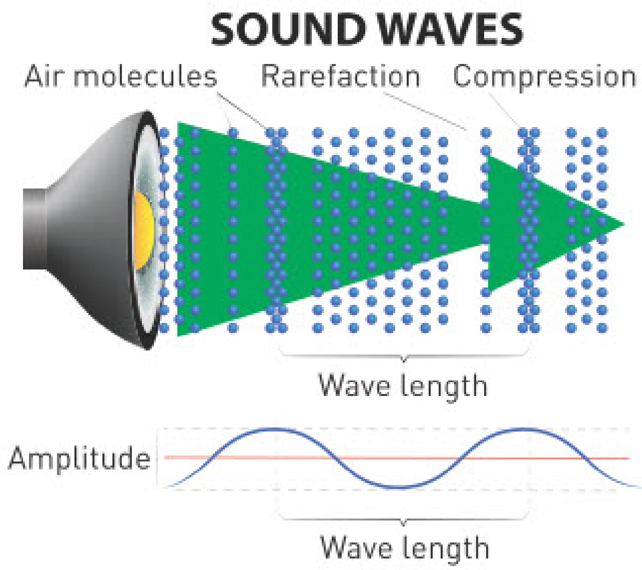


Figure 1

Because of speaker's vibration air molecules compress. Then air expands (rarefaction) and pushes other air molecules.

Amplitude of a sound

Amplitude defines the loudness of a sound. The greater amplitude the louder sound.is.

Pitch of a sound

Frequency of a sound wave defines pitch of a sound. High frequency means high pitch. Low frequency means low pitch. For example, male voice generally has lower pitch than female voice. Males speak at 65 and 260 Hz, and females speak at 100 to 525 Hz.

Echo

Sound waves are reflected from surface. This is called echo, Figure 2.

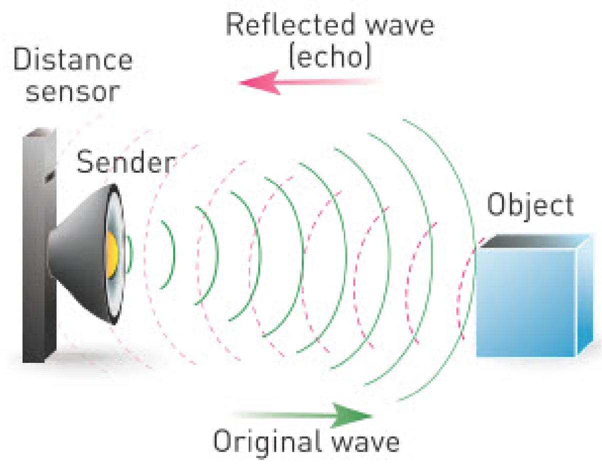


Figure 2

There are animals that use echo for navigation. For example, bats. They can produce sound of 40-100 kHz that reflects from obstacles and goes to bat's ears. This is called echolocation. People use this property of sound to determine depth of ocean, to communicate underwater and for medical purposes, Figure 3.

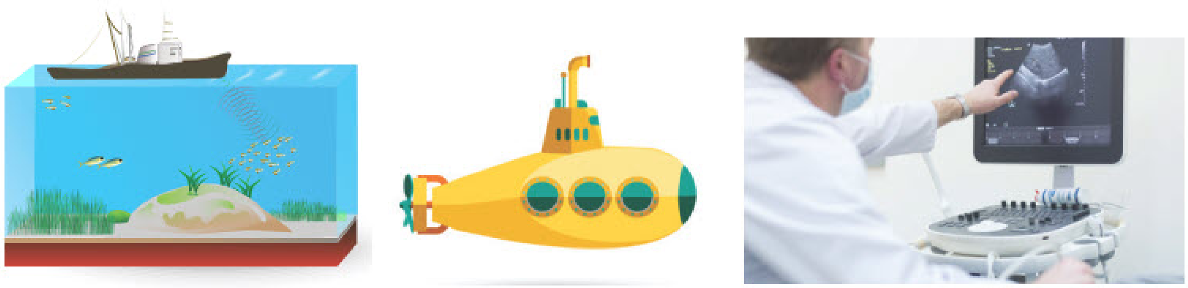


Figure 3

Range of hearing

Human ear can detect a certain range of sound frequencies. This range is about 16 - 20 000 Hz. This means that we can not hear a sound of 16 Hz or 20 000 Hz, Figure 4. A sound with a frequency greater than 20 000 Hz is called ultrasound. A sound with a frequency lower than 16 Hz is called infrasound.

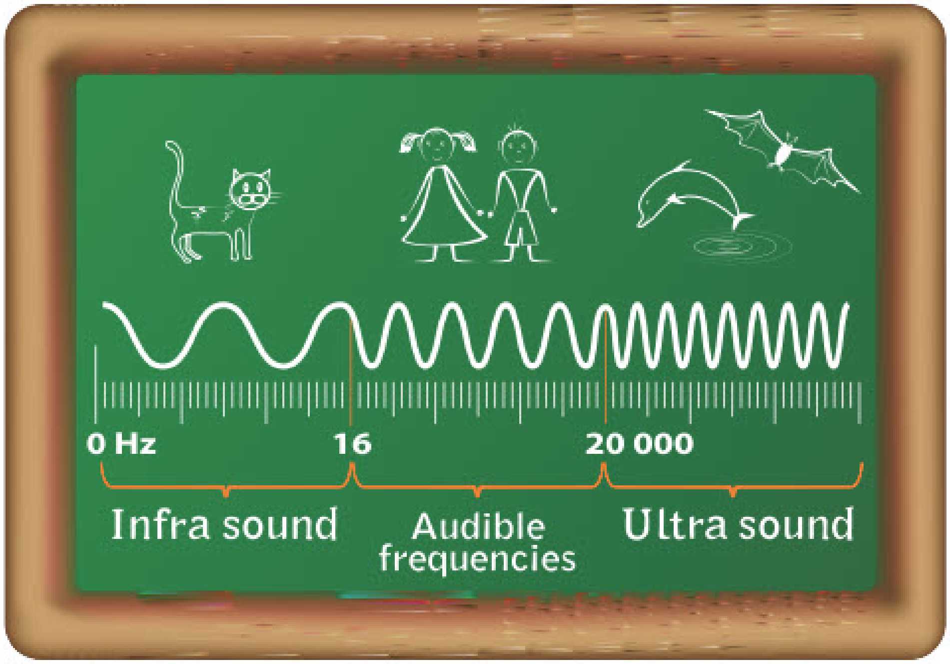


Figure 4

Example

Assume you are standing on one side of Sharyn canyon. You shout " Physics Ruuuulez" and one second later you hear echo. How far is the other side of canyon?

Solution:

Speed of sound in summer time is faster so let us take it as 350 m/s. So if you hear echo it means sound has travelled twice the distance, i.e. forward and then backwards to you.

$2d=\upsilon t=350\ m/s\times 1s$

$d=175\ m$

distance between sides is 175 m.

Literacy

1. You shout in front of mountain. You hear echo after 3.2 seconds. What is distance to mountain?
2. Why do you make sounds? How do you make low pitch sounds? How do you make high pitch sounds?

3. What is difference between frequency and amplitude of sound? What is difference between pitch and loudness?
4. What are positive effects of examples in Figure 3? What if there was not such phenomenon as echo?
5. Imagine you turn on music speakers on the Moon. How will it sound there?

Art time

Use software (for example "photosounder") to change your photo to sound. Then use fractal images to make sound.

Research time

Search online sound generator. Determine minimum and maximum frequencies that you can hear. Compare frequency range of you and other people. Why are they same or different?

Activity

Answer the questions by observing the sound.

1. Can you explain how your ears hear the sound?
2. Can you hear through walls?
3. Knock at one end of a table while your classmate listens with an ear against the other end of the table. Can your classmate hear you knocking? Why?
4. If all air in the classroom was replaced with water could you hear the sounds?

Terminology

order - тәртіп / порядок
rarefaction - сиректету / разрежение
loudness - дауыс қаттылығы / громкость
reflected - шағылысқан / отраженный
echo - жаңғырық / эхо

bat - жарқанат / летучая мышь
obstacle - бөгет / препятствие
ultrasound - ультрадыбыс / ультразвук
infrasound - инфрадыбыс / инфразвук

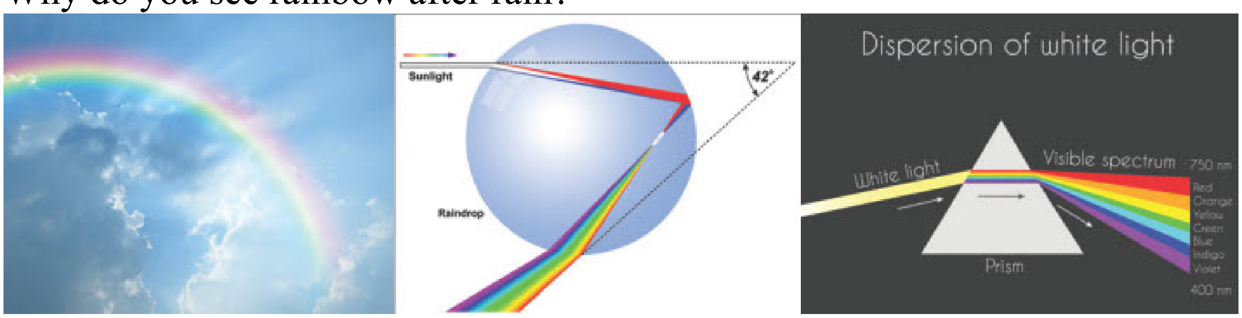
5.10 ELECTROMAGNETIC WAVES. ELECTROMAGNETIC SPECTRUM

You will

- compare properties of electromagnetic and mechanical waves;
- describe properties of different electromagnetic waves and their use in technology;
- describe dispersion of light through glass prism;

Question

Why do you see rainbow after rain?



Stationary electric charge has electric field E. When the charge moves with constant speed it produces magnetic field B, Figure 1.

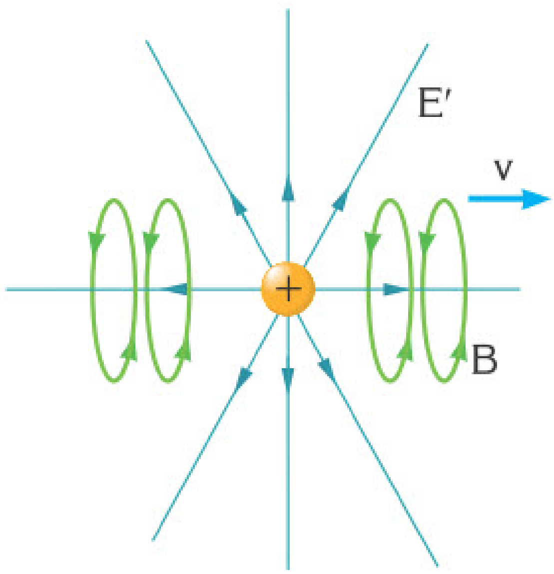


Figure 1

However, if the charge oscillates it will produce oscillating electric and magnetic field. These two fields propagate as a wave and transfer energy. This wave is called electromagnetic wave (EMW), Figure 2.

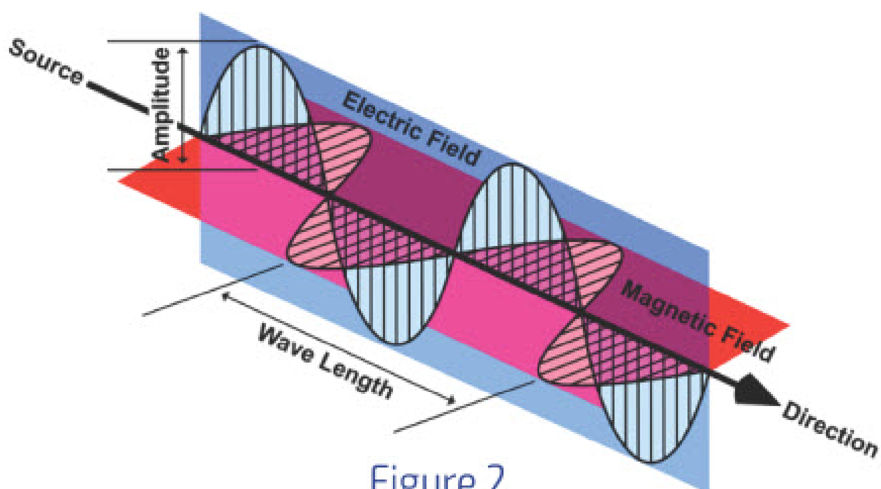


Figure 2

Properties of electromagnetic waves

- EM waves propagate at speed of 300 000 000 m/s or 3×10^{8} m/s. This speed is called “speed of light”.
- EM waves do not require medium
- In EM waves electric and magnetic field oscillate in phase
- EM waves are transverse waves

- Vectors of electric and magnetic fields are perpendicular to each other and they are related to each other by formula E = cB

Electromagnetic spectrum
EM waves have similar properties with mechanical waves: wavelength, frequency, and speed. However, EM waves do not need any medium to propagate. That's why space satellite communication is possible. There are 7 types of EM waves. We categorise them according to their frequency. Their list is called electromagnetic spectrum, Figure 3.

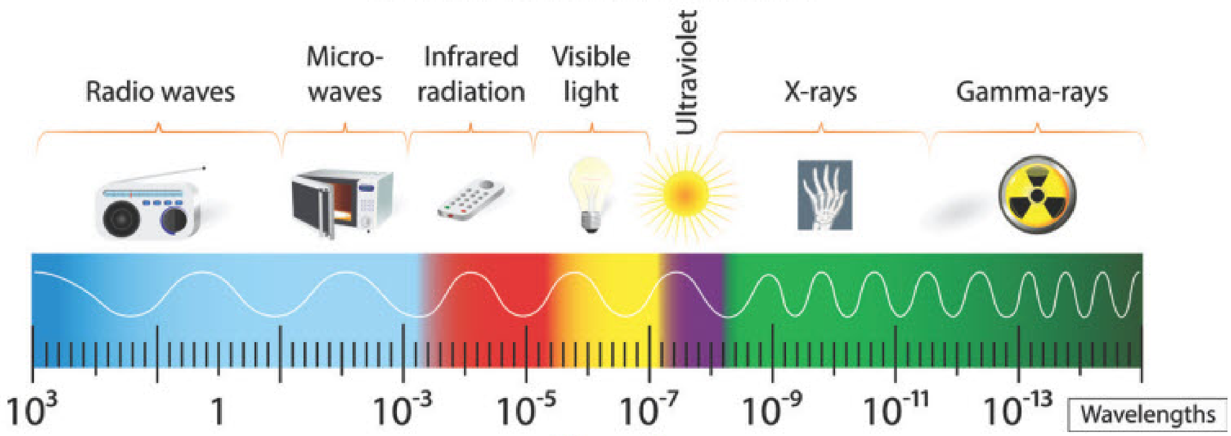


Figure 3

High frequency of EMW means it has high energy. That is why gamma rays are very harmful for us.
Speed of EM wave
Since the main characteristic of EM wave is frequency we use the formula:
$c = f \times \lambda$
c- speed of light [m/s]
f- frequency of EMW [Hz]
λ- wavelength [m]
This formula is derived from equations
$\lambda = c \times T$ and $f = 1/T$.

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

Example

What is the frequency of waves produced by Wi-Fi router if the wavelength is 0.5 m?

Solution:

All electromagnetic waves have speed of light. So

$$c = \lambda f \Rightarrow f = \frac{c}{\lambda} = \frac{3 \times 10^8 \; m/s}{0.5 \; m};$$

$f = 6 \times 10^8$ Hz.

Activity

Complete the table below by matching the types of radiation with its effect on living tissue and its use.

Types of waves	Effects on living tissue	Used for ...
Gamma	High doses can kill living cells Lower doses can cause cancer in cells	
X-rays		
Ultraviolet		Fluorescent tubes Security marking
Visible light		
Infrared		
Microwave		
Radio wave		

- Sterilising hospital equipment.
- Heating. Can cause burning in tissues
- Remote controls and thermal imaging
- Probably none
- Cooking
- Creating images of the inside of the body
- Causes burning of tissues
- Communication RADAR
- Activises sensitive cells in the retina
- Treating tumours
- Seeing Optical fibres and communication

Research time

Try to find or make mnemonic device to memorise the order of the electromagnetic spectrum.

Art time

Choose 7 different genres (types) of music (songs). Listen to them and paint each song on paper. Use several colours for each song. Explain your paintings.

Fact

Red, green, blue colours (RGB) combine to make white light.

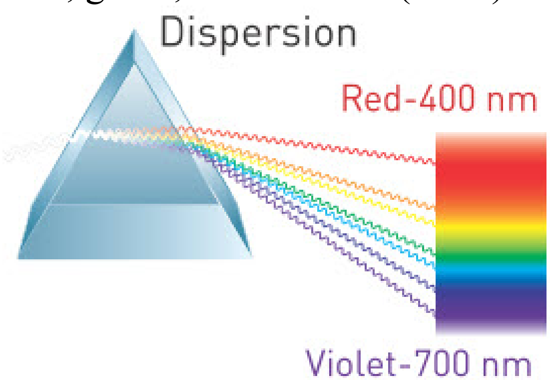


Figure 4

Terminology

charge - заряд / заряд
field - өріс / поле
communication - байланыс / связь
speed of light - жарық жылдамдығы / скорость света
derived - алынған / полученный
prism - призма / призма
dispersion - дисперсия / дисперсия
ozone layer - озон қабаты / озоновый слой
germicidal - бактирицидті / бактерицидный

Literacy

1. Why do we use X-ray scans? Why do X-rays pass through our bodies?
2. Why light cannot pass through our bodies?
3. Which light has more energy, red or violet? Why?

4. Which electromagnetic wave does ozone layer block?
5. Why do we use “germicidal" lamps? What type of EM wave do they use?
6. Why is example with satellite communication good in “EM spectrum” section?

5.11 FREE ELECTROMAGNETIC OSCILLATIONS

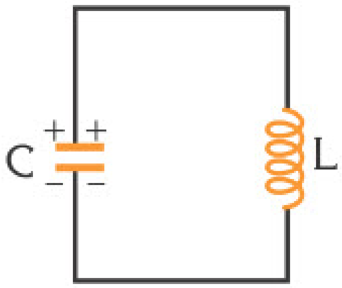
You will

qualitatively describe electromagnetic oscillation in LC circuit;

Question

Why do we use “walkie-talkie”? How does “walkie-talkie” work?

People use wireless devices almost every day. For example, radio, television, cell phones, GPS, Wi-Fi. These devices use EM wave to send or exchange information. These waves are generally produced by oscillation of electric current (electrons) in LC circuit, as shown in the figure.



LC circuit

The LC circuit consists of capacitor (C) and inductor (L), Figure 1a. Capacitor is a device used to store an electric charge. Inductor is a device that stores energy in the form of a magnetic field.

When electrons oscillate, Figure 1b, EM waves are produced. Then these waves propagate and they can be received by another LC-circuit.

Generation of EM waves

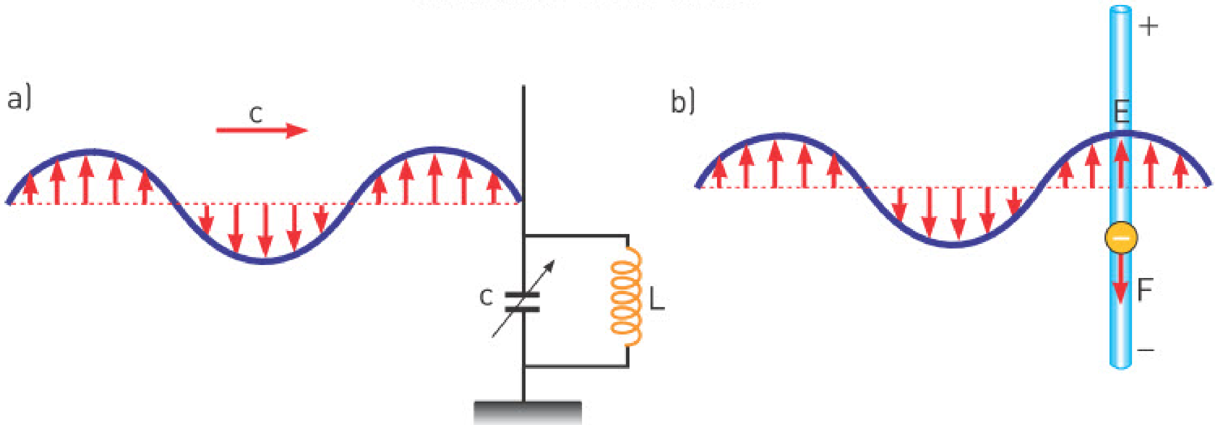


Figure 1

The capacitor is initially charged and the current through the inductor is zero.

The capacitor starts to discharge generating a current through the inductor. The current increases as the charge in the capacitor decreases. When the capacitor is totally discharged, the current reaches its maximum value. In this case, the potential difference across the capacitor (and the inductor) is zero.

Current driven by the inductor charges the capacitor again. The current decreases as the charge in the capacitor increases. When the capacitor reaches its maximum charge once again, only in reverse polarity, the current drops to zero. Then the capacitor starts to discharge again.

This is an oscillation of charge in LC circuit.

An oscillation taking place in an ideal LC circuit without any external energy source is called a free electromagnetic oscillation.

LC circuit has a mechanical analogy: mass-spring system. The similarities are in the table.

Mass-Spring System		LC circuit	
Spring	Stores elastic potential energy	Capacitor	Stores electrical energy
Mass	"Mechanical inertia" Greater mass, lower frequency	Inductor	"Electrical inertia" Greater inductance, lower frequency

In mechanical oscillation the transformation of spring's elastic potential energy and object's kinetic energy takes place. In electromagnetic oscillation there is the transformation of electric energy of the capacitor and magnetic energy of the inductor.

The qualitative comparison of this analogy is in the Figure 2.

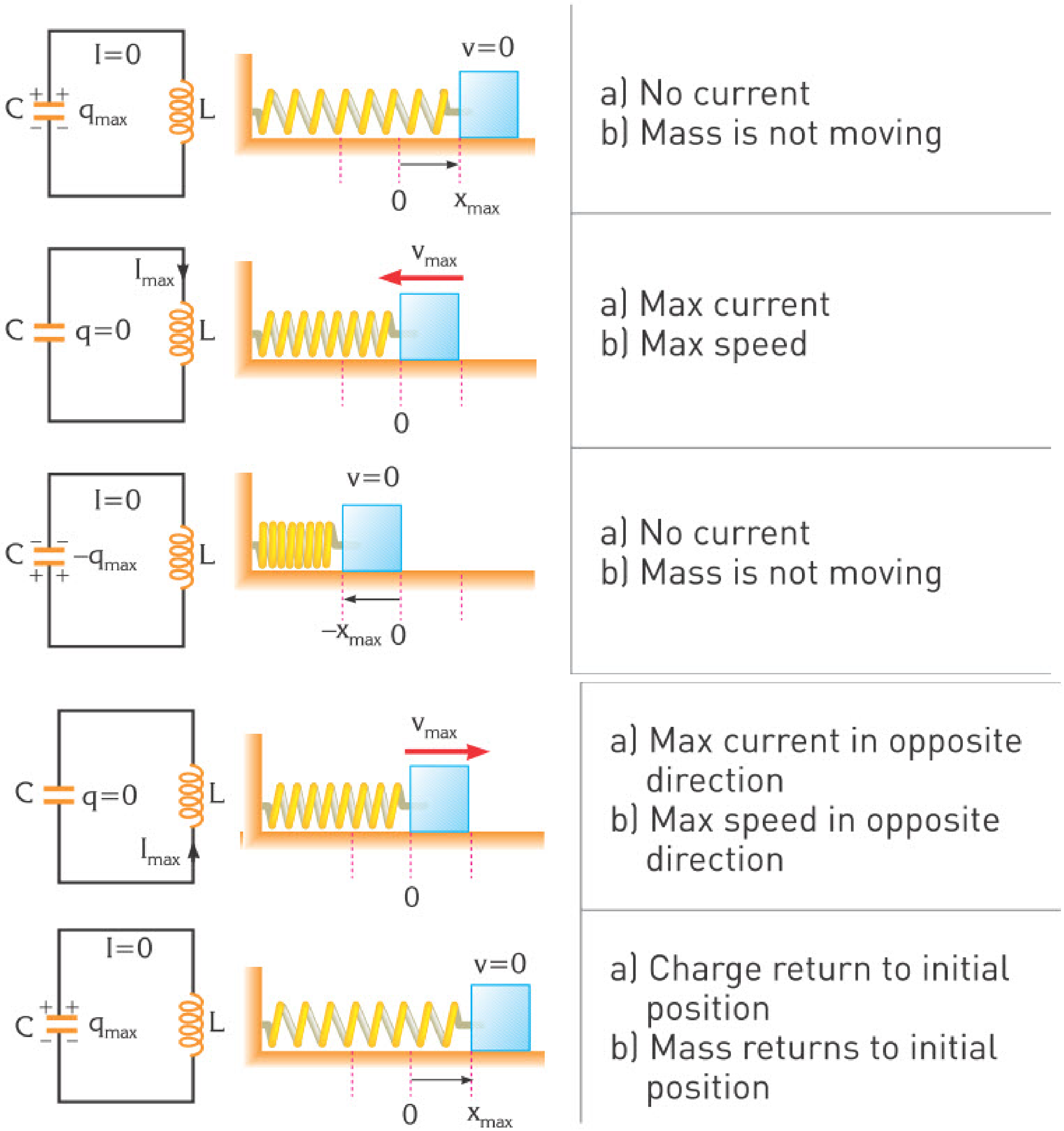


Figure 2

Example

In LC circuit when capacitor (C) is full, current (I) is zero. Why?
Solution:
Current is the flow of charge. If capacitor is full, it means that all charges are in capacitor, therefore charge is NOT flowing through wire. NO flow of charge = NO current.

Research time

Wifi routers have antennas. Why?

Terminology

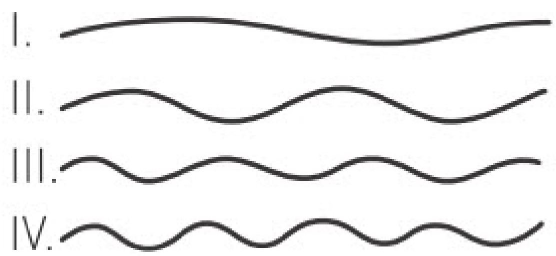
walkie-talkie - тасымалды рация / переносная рация
wireless - сымсыз / беспроводной
current - ток, ток күші / ток, сила тока
circuit - электр тізбегі / электрическая цепь
capacitor - конденсатор / конденсатор
inductor - катушка / катушка
transformation - түрлендіру / преобразование
qualitative - сапалы / качественный

Fact

RFID (Radio Frequency Identification) is used in shops instead of barcodes.

Activity

1. Four different electromagnetic waves are shown in the figure above. When comparing these four waves, all of the following statements are true except —



A. wave I has the longest wavelength
B. wave IV has the highest frequency
C. wave II has a higher frequency than wave I
D. wave IV has a longer wavelength than wave III

Art time

Use software (for example "Audacity") to generate "noise" and "tone". Zoom in and draw their graphs. What is difference between their graph?

Literacy

1. Why does "radio clock" have LC circuit inside?
2. Why do "security tags" in shops have LC circuit inside?
3. Why do libraries use "RFID tags"?
4. Why do we use "e-passports"? How do they work?
5. Why does "graphics tablet" have LC circuit inside?

LAB WORK #3

Title: Acceleration

Goal:

Define gravitational acceleration by simple pendulum.

Equipment:

1. Simple pendulum
2. stopwatch
3. ruler

Safety:

1. Tie back long hair, secure loose clothing, and remove loose jewelry to prevent their getting caught in moving parts or pulleys. Put on goggles.
2. Attach masses to the thread and the thread to clamps securely. Swing masses in areas free of people and obstacles. Swinging or dropped masses can cause serious injury.
Theory:
From formula of period we know:

$$T = 2\pi\sqrt{\frac{L}{g}}$$

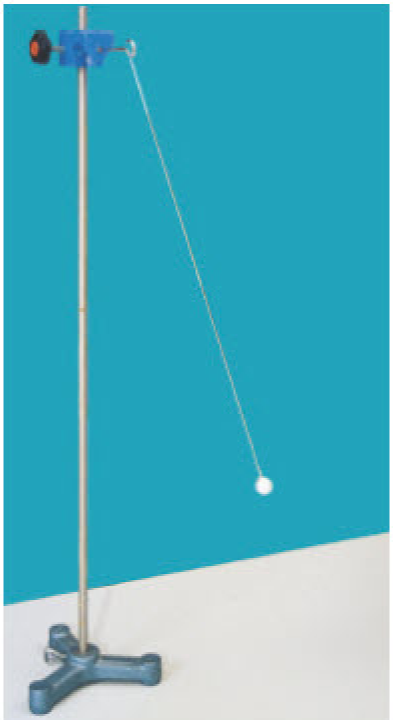
so

$$g=4\pi^2 L/T^2$$

If we have length of thread and period we can calculate gravitational acceleration.

- You should keep the amplitude of the swing less than 15° in each trial.

- Minimum length of string should be 1 meter



Procedure:

1. Make a simple pendulum as shown in the figure
2. Give a little push to object and wait until oscillations become constant
3. Measure by stopwatch 10 oscillations and write time
4. Calculate gravitational oscillation using average period and information given
5. Plot the following graphs: square of period vs. the length
6. Using slope of the graph you can find g

Conclusions:

1. How does the mass of the pendulum bob affect the period of vibration?
2. How does the length of the pendulum affect the period of vibration?
3. Explain why theoretical and experimental values of gravitational acceleration are different?

LAB WORK #4

Title: Speed of surface water waves

Goal:

Finding the speed of a wave

Equipment:

1. big container with water
2. ruler
3. stopwatch

Safety:

Tie back long hair, secure loose clothing, and remove loose jewelry to prevent their getting caught in moving parts or pulleys.
Put on goggles.

Theory:

$v = s/t$
v - velocity [m/s]
s - distance travelled [m]
t - time [s]

Procedure:

1. Measure radius length of container. Record the length in Table 1.
2. Create a single wave pulse by touching centre of water
3. Use a stopwatch to measure the time needed for the pulse to travel at the side of container. Record this measurement in Table 1.
4. Repeat steps 3 and 4 two more times.
5. Calculate the speed of waves

	Radius of container, l, m	Time, t, s	Speed, v, m/s
1			
2			
3			
4			
5			

Conclusions:

- Explain what does speed of surface water waves depends on?

SUMMARY

5.1 When spring is stretched, it will move back and forth continuously in the absence of friction. Such motion is called oscillatory motion.

Time needed to complete one cycle is called period of oscillation (T).

We use angular frequency (ω) to describe how fast the object completes one cycle. ω and T are related as

$$\omega = \frac{2\pi}{T}$$

5.2

Equation of displacement for simple harmonic motion $x(t)=A\times\cos(\omega t)$

Equation of velocity for simple harmonic motion $\upsilon(t)=-\upsilon_{max}\times\sin(\omega t)$, υ_{max} is maximum velocity. $\upsilon_{max}=A\omega$.

Equation of acceleration for simple harmonic motion $a(t)=-a_{max}\times\cos(\omega t)$, a_{max} is maximum acceleration, $a_{max}=A\omega^2$.

5.3

We can find period of oscillation by formula:

$$T = 2\pi\sqrt{\frac{m}{k}}$$

We can find angular speed of oscillation by formula:

$$\omega = \sqrt{\frac{k}{m}}$$

There are 2 common types of combinations:

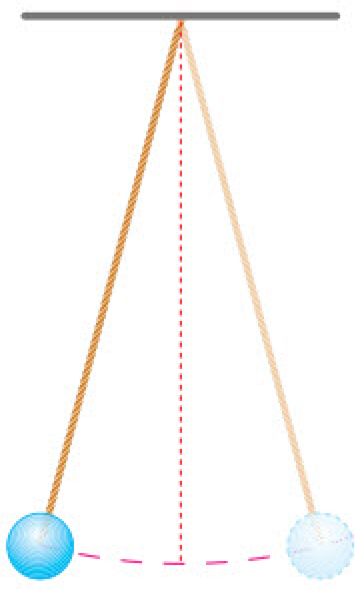
a) Series combination

$$\frac{1}{k_{eq}} = \frac{1}{k_1} + \frac{1}{k_2}$$

b) Parallel combination

$$k_{eq} = k_1 + k_2$$

5.4



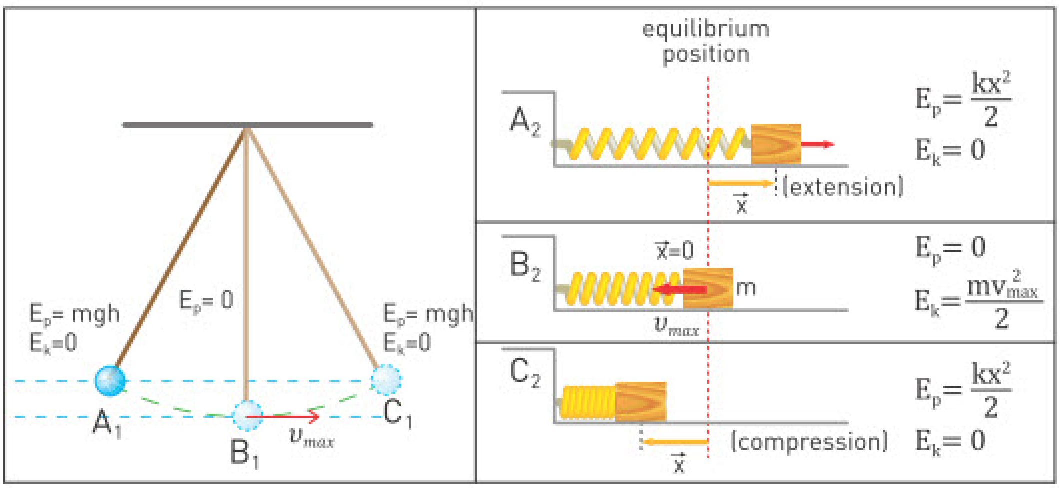
Simple pendulum is a device that consists of a small mass attached to a string with length L, Figure 1. The formula of pendulum's period is

$$T = 2\pi\sqrt{\frac{L}{g}}$$

5.5

We can write conservation of energy as

$PE_1+KE_1=PE_2+KE_2$



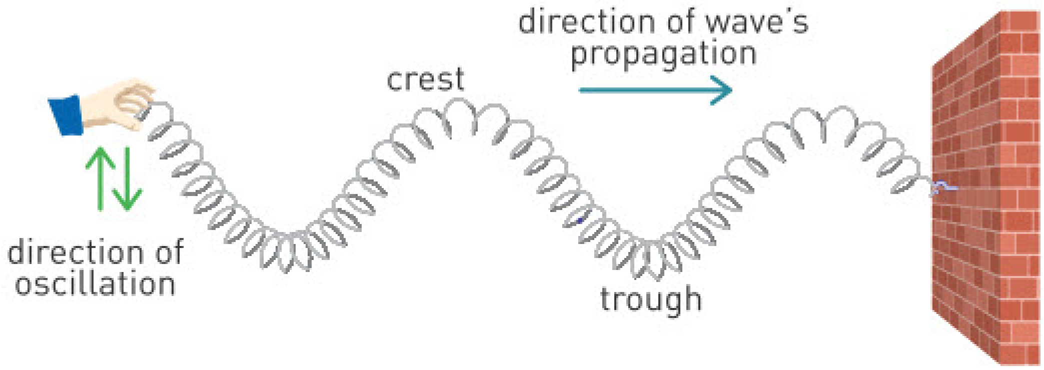
5.7

When $f=f_0$ amplitude of oscillation dramatically increase. This is called resonance.

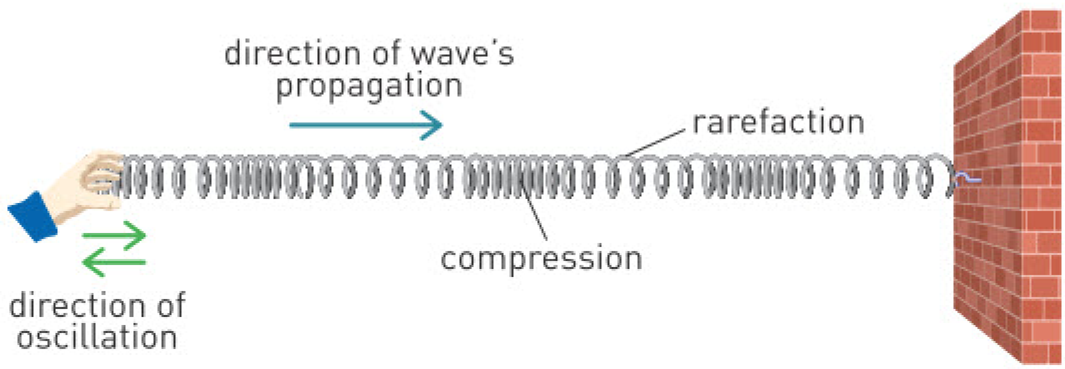
5.8

Waves transfer energy, but they don't transfer the material of a medium. There are 2 types of waves:

a. Transverse waves. When oscillation and propagation are perpendicular to each other.



b. Longitudinal wave. Oscillation and propagation are both in horizontal plane.



Wavelength λ: the distance between two crests or two troughs.

Time taken to travel a distance λ is called period T.

The number of λ's travelled in 1 second is called frequency.

$$Speed = \frac{Wavelength}{Period} \quad or \quad v = \frac{\lambda}{T}$$

5.9

Sound wave is a longitudinal wave that can propagate only in a medium. The speed of sound wave depends on the type of medium.

Amplitude defines the loudness of a sound.

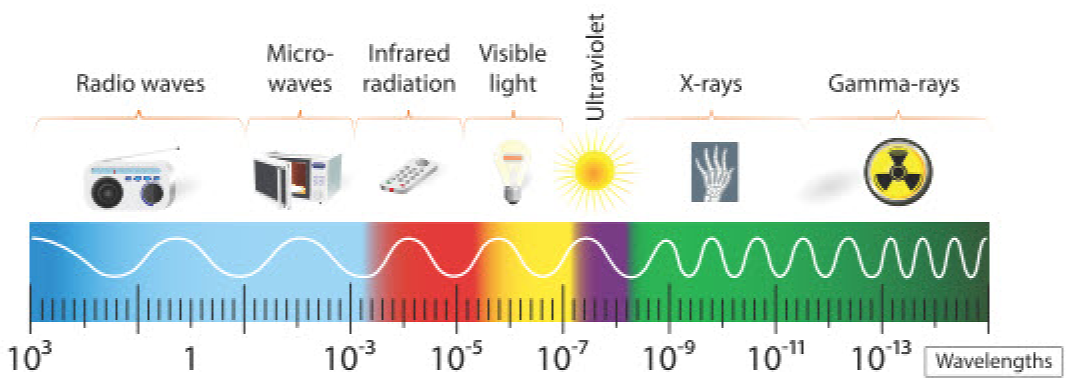
Frequency of sound waves defines a pitch of a sound.

Sound waves are reflected from surface. This is called echo.

5.10

When the charge moves with constant speed it produces magnetic field. However, if the charge oscillates it will produce oscillating electric and magnetic field.

There are 7 types of EM waves which are categorised according to their frequency into electromagnetic spectrum.



EM wave propagates at a certain speed of 300 000 000 m/s or 3×10 8 m/s. This speed is called “speed of light”.

$c=f\times\lambda$

c - speed of light [m/s]

f - frequency of EMW [Hz]

λ - wavelength [m]

5.11

Radio, television, cell phones use EM wave to send or exchange information. These waves are produced by oscillation of electric current (electrons) in LC circuit. LC circuit consists of capacitor (C) and

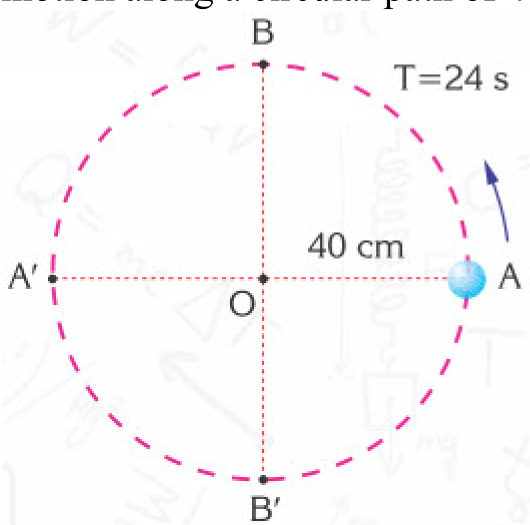
inductor (L).

Mass-Spring System		LC circuit	
Spring	Stores elastic potential energy	Capacitor	Stores electrical energy
Mass	"Mechanical inertia" Greater mass, lower frequency	Inductor	"Electrical inertia" Greater inductance, lower frequency

PROBLEMS

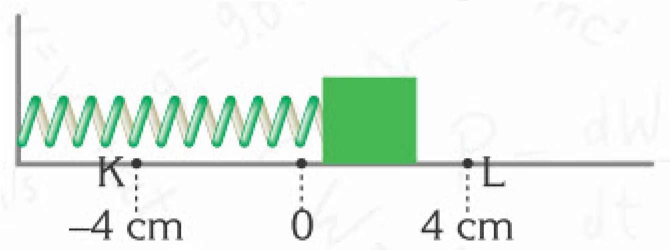
Vibrations and Springs
Simple Harmonic Motion

1. Decide whether the motions below are simple harmonic or not.
a) The marching of soldiers from side to side on guard at the gate of a palace.
b) A door which is regularly opening and closing on a windy day.
c) A boat which rocks up and down on a rough sea.
d) The motion of a piston in an automobile engine
e) Rhythmic beats of a heart
2. Can a body that performs simple harmonic motion along a straight line have:
a) velocity and displacement vectors in the same direction?
b) acceleration and displacement vectors in the same direction?
c) acceleration and velocity vectors in the same direction?
3. A mass-spring system performs 30 oscillations in 10 s. Find its
a) period
b) frequency.
4. The period of an object of mass m, which performs uniform circular motion along a circular path of 40 cm radius, as shown in the figure, is 24 s.

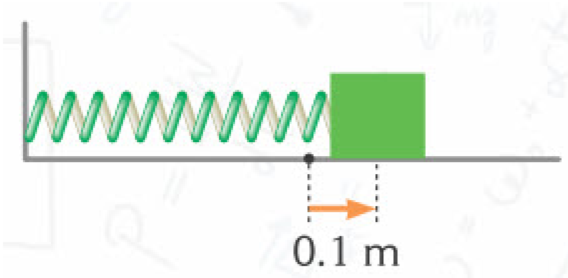


a) If the object starts to move from point A, how many seconds later will it pass point B?

b) What are the projections of its velocity and acceleration on axis BB’ while passing point A?
c) What are the projections of its velocity and acceleration on axis BB’ while passing point B?
5. A mass-spring system is exhibiting simple harmonic motion between points K and L, as shown in the figure. If the mass has a value of 1 kg and covers the distance between points K and O in 3 s, find



a) the period of the system
b) the maximum velocity of the system
c) the maximum acceleration of the system
d) the restoring force acting on the object at point K.
6. An object is exhibiting simple harmonic motion along the y-axis with a period of 1s. Assuming it started its motion by being compressed 50 cm from its equilibrium position
a) how long will it take to arrive at the equilibrium position for the first time?
b) find its maximum speed.
c) find its maximum acceleration.
d) state the equations of its motion as a function of time.
7. When a vertical mass-spring system, at rest in its equilibrium position, is struck slightly by a hammer, it compresses the spring by 20 cm. The system then performs simple harmonic motion with a period of 2 seconds. Find:
a) the maximum acceleration of the object
b) the speed of the object at the moment when it is 6 cm away from its equilibrium position.
8. A 2 kg object is attached to the end of a spring on a smooth plane, as shown in the figure, and is extended 0.1 m from its equilibrium position and then released. If the period of its simple harmonic motion is 2 s

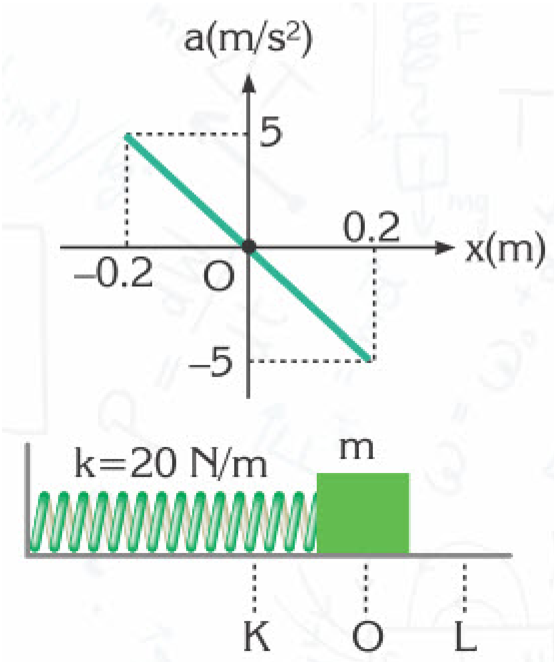


a) what is the maximum force acting on the object?
b) what is the speed of the object at the moment its displacement is 0.05 m?
c) what is the force acting on the object at the moment when its displacement is 0.05 m?

9. When a mass-spring system is stretched 3 cm from its equilibrium position, it starts to perform simple harmonic motion with a frequency of 10 Hz. At what instants does it first pass the following positions?
a) $x_1 = 1{,}5$ cm
b) $x_2 = -3$ cm

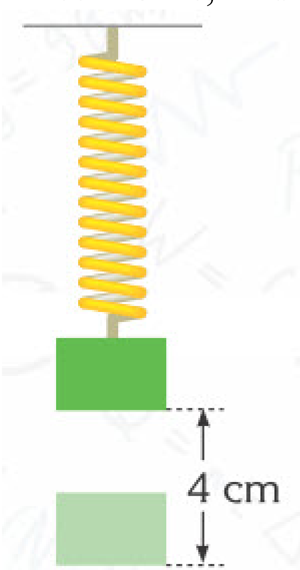
10. A 1 kg object attached to a spring in the vertical is struck slightly by a hammer when it is at rest in its equilibrium position. This results in the mass gaining a velocity of 3 m/s. If the spring constant is 100 N/m, determine
a) the period and frequency of the system
b) the amplitude of the system
c) the maximum acceleration of the system

11. An object is exhibiting simple harmonic motion between points K and L, as shown in the figure. (Take π=3) Assuming that the object starts moving at point L, draw the displacement-time, velocity-time and acceleration-time graphs of the system for a complete oscillation



Simple Harmonic Motion of a Mass-Spring System

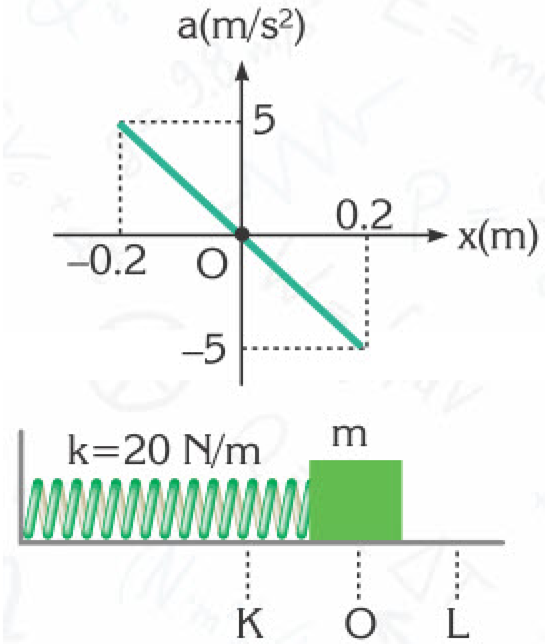
12. When a mass attached to a suspended spring is extended 4 cm from its equilibrium position, as shown in the figure, and then released, the system performs simple harmonic motion. If the spring reaches its lowest point 24 times in 96 s, find the system's



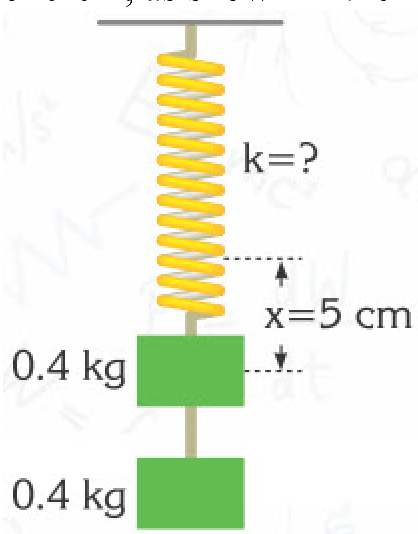
a) period
b) frequency.

13. An object on a smooth plane, as shown in the figure, is exhibiting simple harmonic motion between points K and L, with an amplitude of 0.2

m. The spring constant is 20 N/m. The acceleration-displacement graph of the motion is also shown in the figure.



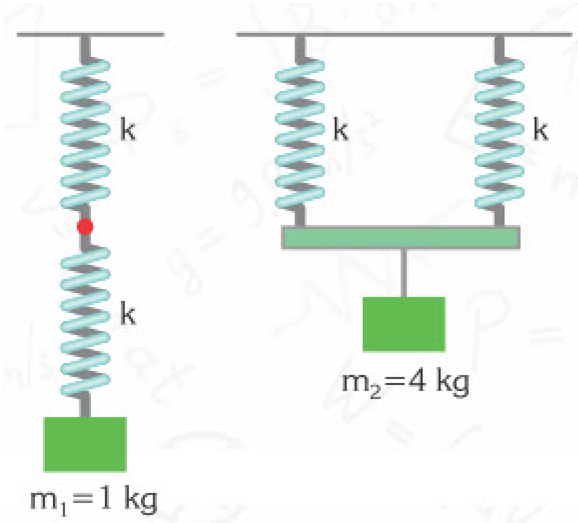
Find
a) the period and frequency of the system
b) the mass of the object
c) the force acting on the object when it is at point K.
14. When two objects of mass 0.4 kg each are attached to the end of a spring whose spring constant is unknown, the spring extends by an amount of 5 cm, as shown in the figure.



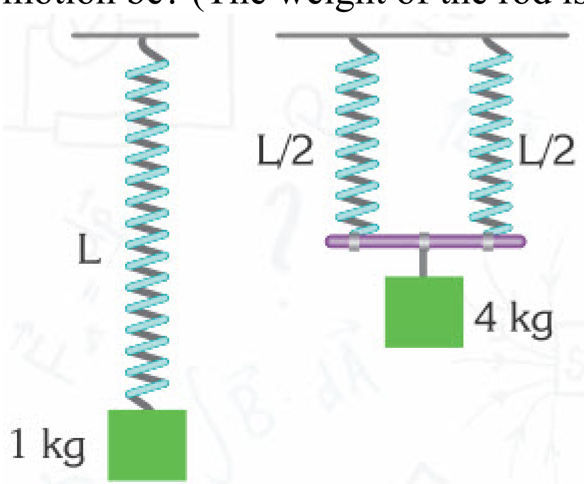
a) Describe the motion of the object when the cord between the objects is cut whilst in equilibrium.

b) Find the spring constant and the period of the motion.

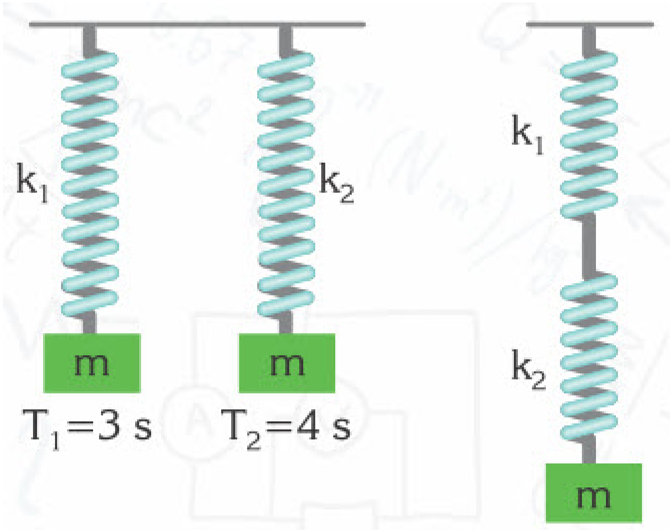
15. Two spring-mass systems are constructed, as shown in Figure I and II, by the use of two identical springs of spring constant k. If the masses are m_1=1 kg and m_2=4 kg, what is the ratio of their periods, T_1/T_2?



16. A 1 kg object is suspended from a spring of length L. The period of its simple harmonic motion is measured to be 3 s. Later the spring is divided into two halves and the pieces are attached in parallel to a ceiling and a 4 kg object is suspended from the springs, as shown in the figure. When this object starts exhibiting simple harmonic motion, what will the period of its motion be? (The weight of the rod is neglected.)



17. The periods of the mass-spring systems in Figure-I of spring constants k1 and k2 are 3 s and 4 s, respectively. If the springs were connected to each other, as shown in Figure-II, what would the period of the system be?



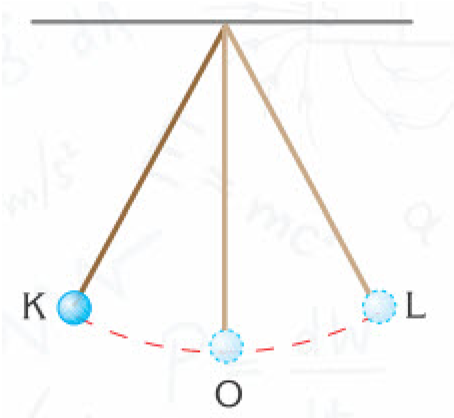
18.

An object with mass m=1 kg is placed between two springs of spring constants k_1=50 N/m and k_2=50 N/m, as shown in the figure. Neglecting the effects of friction, calculate the period of the simple harmonic motion that will occur when the mass is pulled along the direction of the springs and then released. (Take π=3).

Simple Pendulum

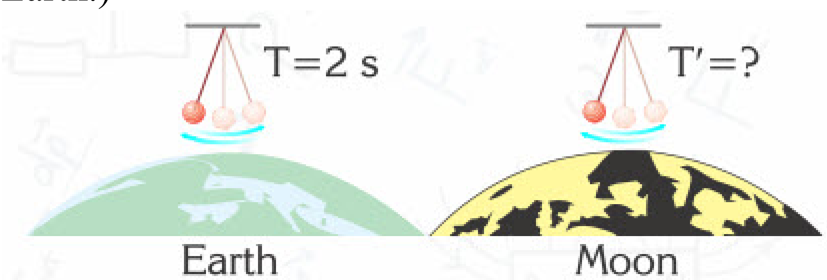
19. A pendulum performs 40 oscillations in 50 s. What is its
a) period?
b) frequency?
20. How long must a simple pendulum be if it is to complete one oscillation in 2 seconds on the Earth?
21. What is the period of a 40 cm long simple pendulum
a) on the Earth where g = 10 m/s 2 ?
b) on the Moon where g = 1,6 m/s 2 ?
22. The period of a 0.5 m long simple pendulum on unknown planet is 2 s. What must the length of the pendulum be, so that its period is 1 s in the same plane?
23. The simple pendulum in the figure is exhibiting simple harmonic motion between points K and L with a period T=2.8 s, as shown in the

figure. If it starts oscillating from point K, at which point will the pendulum be after

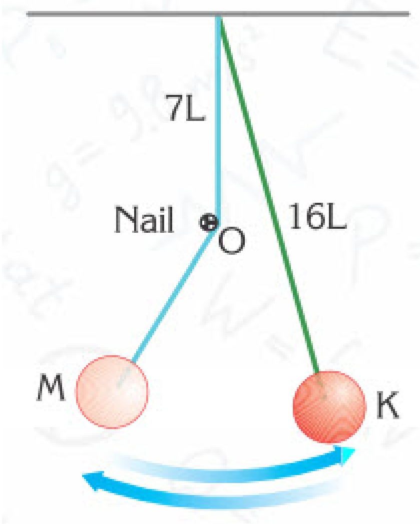


a) 1.2 s?
b) 2.1 s?

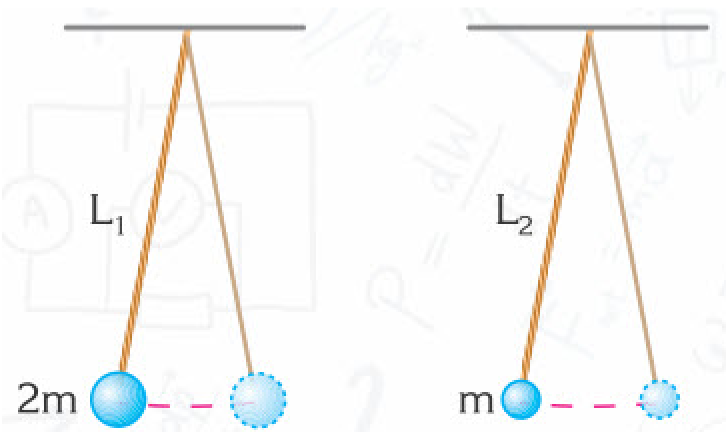
24. If the period of a simple pendulum on the Earth is 2 s, what is its period on the Moon? (The gravitational acceleration on the Moon is 1/6 of that on Earth.)



25. A simple pendulum of length 16L is released from point K and can reach point M after being obstructed by a nail at point O, as shown in the figure. In this case the period of the simple pendulum is 7 s. What would the period of the pendulum be if the nail were removed? (Take π to be 3)



26.

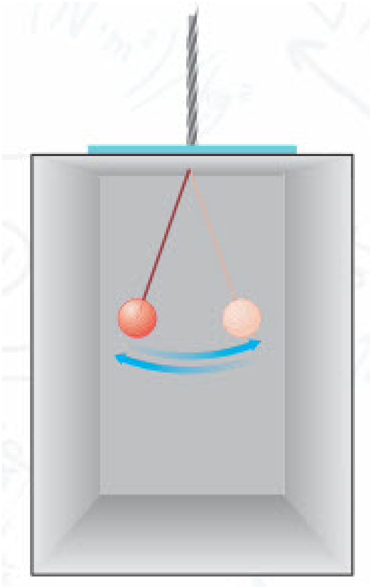


The simple pendula of lengths L_1 and L_2, as shown in the figure, are exhibiting simple harmonic motion. The ratio of their frequencies is

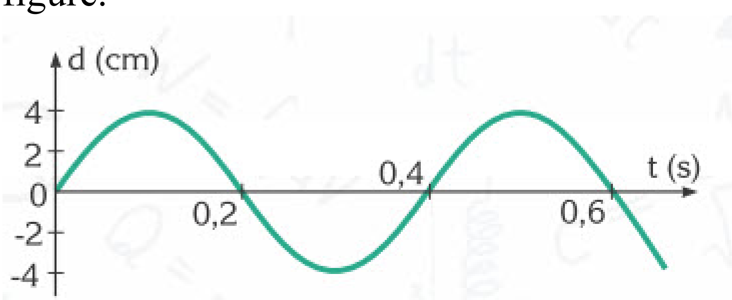
$$\frac{f_1}{f_2} = \frac{1}{4}.$$

What is the ratio of the lengths of the pendula L_1/L_2?

27. The simple pendulum, which is suspended from the ceiling of a lift, oscillates with a period T, as shown in the figure. What is the period of the simple pendulum in terms of T while the lift is



a) ascending with an acceleration which equals g?
b) descending with an acceleration which equals g/2?
c) falling freely?
28. A mass-spring system performs 20 oscillations in 5 seconds. What are the period and frequency of oscillations?
29.
a) What is the net force on an oscillating object, when it has its maximum speed?
b) What is the speed of an oscillating object when it reaches maximum displacement?
30. A particle performs simple harmonic motion with a 10 cm amplitude and 4 s period. What distance does the particle travel in 8 s?
31. The position-time graph of an object performing SHM is given in the figure.



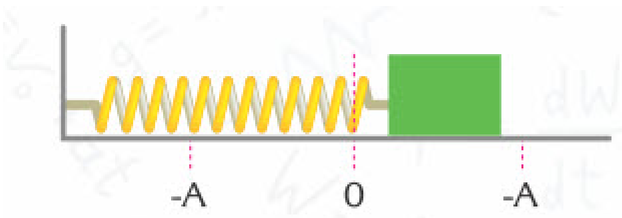
a) What is the frequency of oscillation?
b) What is the amplitude of oscillation?

32. What is the general relation between amplitude of oscillation and period of oscillation in simple harmonic motion?

Conservation of Energy in SHM

33. The maximum potential energy of a system performing SHM is given as 20 J.
a) What is the total mechanical energy of the system?
b) What is the maximum kinetic energy of the system?

34.



An object is attached at the end of a spring as shown in figure. The spring constant is k=1200 N/m. Then the object is displaced 20 cm from equilibrium and released.
a) What are the initial values of potential energy and kinetic energy of the system?
b) What are the values of kinetic energy and potential energy of the system as the object passes through equilibrium?

35. A 200 g object oscillates with a 10 cm amplitude at the end of a spring. The spring constant is 400 N/m. What are the maximum acceleration and velocity of the object?

36. The amplitude of a simple harmonic oscillator is doubled. How does its maximum speed change?

37. Two objects of masses m and 2m are attached to identical springs and the two systems are set to oscillate with equal amplitudes. What is the ratio of the total mechanical energies of the two oscillating systems?

38. A spring is fixed at one end on a horizontal frictionless surface and a force of 50 N is applied from the free end, which horizontally stretches the spring for 20 cm. An object of 2 kg mass is then attached to the free end and released.
a) What are the initial values of velocity and acceleration?
b) What are the values of velocity and acceleration as the object passes the equilibrium point?

39. Two objects of equal mass are attached to two springs. The ratio of the spring constants is given as $k_1/k_2= 4$. What is the ratio of the amplitudes of

oscillation of the two systems such that the maximum speeds of the objects are equal?

40. An object of 5 kg mass performs harmonic oscillations of 10 cm amplitude, at the end of a spring. The spring constant is k=2000 N/m. What is the speed and acceleration of the object, when the displacement is
a) 6 cm?
b) -6 cm?

41. A mass-spring system has m=5 kg, k=2000 N/m. The mass is displaced 50 cm from the equilibrium position and released. Find the speed and acceleration of the mass when it has travelled a distance of 20 cm.

42. Show that the SI unit for k/m ratio is $1/s^2 = s^{-2}$.

43. A mass-spring system performs SHM with a 20 cm amplitude. The oscillation starts from x=10 cm at t=0, with an initial speed. What is the initial speed, if the k/m ratio is given as 12 s^{-2}?

44. A spring of 25 cm unstretched length and 100 N/kg spring constant hangs freely from the ceiling. An object of 1 kg mass is connected to the lower end of the spring, and suddenly released. (Take g=10 N/kg)
a) What is the amplitude of vertical oscillations?
b) What is the speed of the object when the spring's length is 41 cm?

45. A 4-kg object attached to a spring (k=1000 N/m) is stretched by a force of 200 N on a horizontal surface and released. Find the displacement when the potential energy of the system equals its kinetic energy.

Waves

46. What is a wave? What is the main characteristic of wave motion?

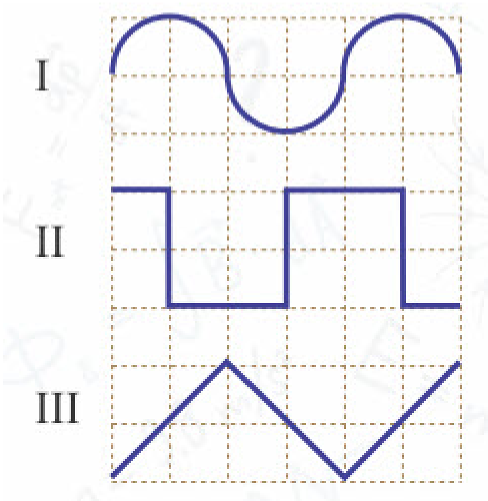
47. Define the wavelength and frequency of a wave.

48. The period of a wave is given as 0.5 s. How many wavelengths pass a given point in 5 s?

49. What is the difference between a wave pulse and a periodic wave?

50. A source produces 40 waves in 8 seconds. What are the period and frequency of the waves?

51.



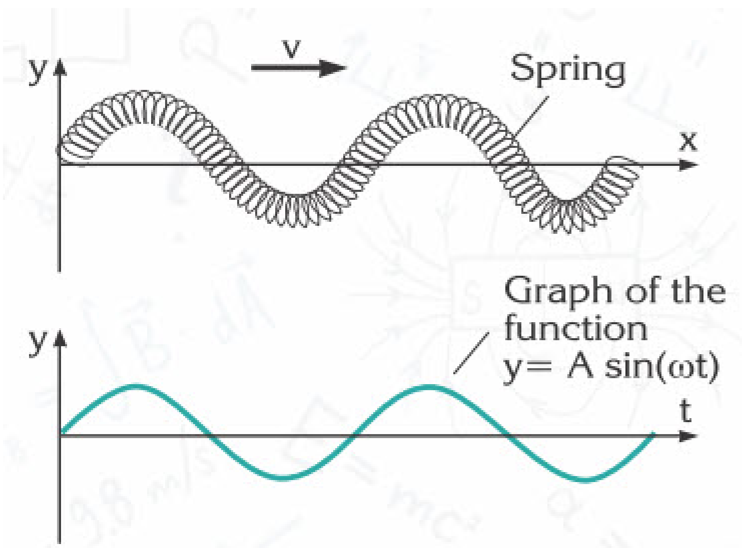
Compare the wavelengths of the waves shown in the figure.

52.

The direction of motion of a particle on a wave pulse at a given instant is shown in the figure. What is the direction of motion of the pulse?

53. What is the difference between transverse and longitudinal waves?

54.



The first figure above is the picture of a sinusoidal wave on a spring. The second figure is the graph of a sine function. The figures are similar in shape. Clearly express how the graph is related to the picture

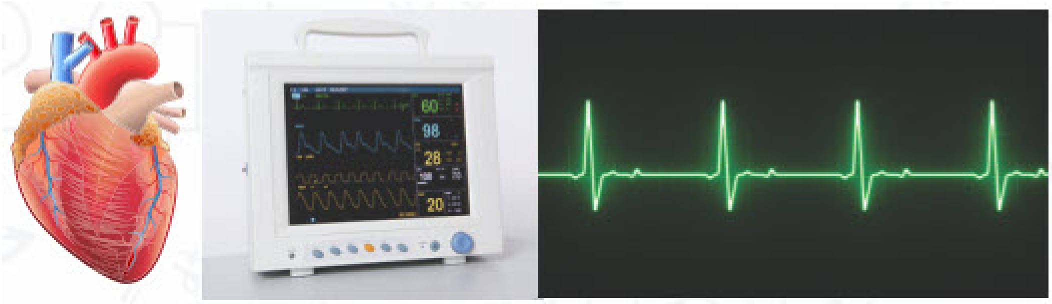
Speed of Mechanical Waves

55. A heavy rope hangs from the ceiling. A pulse is produced at the free lower end. It is observed that the pulse gets faster as it travels up the rope. Explain why.
56. A wave has a frequency of 300 Hz and a speed of 1200 m/s. What is the wavelength of this wave?
57. The speed of waves propagating over the surface of water is 75 cm/s. What is the period and frequency of the waves if their wavelength is 5 cm?
58. A fisherman notices that the float on his fishing line oscillates 20 times in 10 seconds, and the distance between two adjacent wave crests is 90 cm. What is the speed of water waves?
59. 5 wave crests pass through a point on the water surface in 1 second. What is the wavelength, if the speed of waves is 1.2 m/s?
60. What is the frequency of radio waves having a wavelength of 300 m? The speed of radio waves in a vacuum is the speed of light, $c=3\times10^8$ m/s.
61. The distance between two adjacent wave troughs over the sea surface is 3 m. When a boat moves in the same direction as the waves, 6 waves strike its stern (rear end) in 2 seconds. If the boat moves in the direction opposite the direction of propagation of waves, 10 waves strike the stern in the same time interval. What is the speed of the boat given that the boat is slower than the waves?
62. What is the distance between a crest and the adjacent trough of a sinusoidal wave, if the wavelength is 16 cm and the amplitude is 3 cm?
63. Suppose we produce sinusoidal waves over a long, stretched spring, by sending pulses down one end. How do the frequency, speed and wavelength of the waves on the spring change if the pulses are sent at shorter intervals?
64. A sharp object is dipped into shallow water twice a second, producing harmonic waves over the water surface. The speed of the water waves is measured to be 1.1 m/s. What is the speed and wavelength of water waves if the object is dipped into the water three times a second?
65. Which travels faster in air, the sound of a machine gun or birdsong?
66. Five wavelengths of a transverse wave pass through a point in a second. What is the frequency of oscillation of the particles in the medium?67. The frequency range of the human voice is between (approximately) 80 Hz and 1350 Hz. What are the longest and shortest wavelengths of the human voice in air? Take the speed of sound in air as 340 m/s.
68. A pulse travelling on a string eventually disappears. What happens to the energy carried by the wave?

69. What is the condition for an electric charge to produce
a) Electric field
b) Magnetic field
c) Electromagnetic waves
70. Under what circumstances does an electric charge emit EM waves?
71. What is the wavelength of 1.5 MHz radio waves?
72. The pendulum of an old style wall clock is positively charged. What is the wavelength of the EM waves as it swings?
73. A short-wave radio transmitter generates radio waves in the short wave range, λ=10 – 100 m. What is the frequency range of this transmitter?
74. Arrange the given EM waves in order from low frequency to high frequency.
a) Radar waves
b) UV rays
c) Gamma rays d. Radio waves
e) Infrared rays
f) X-Rays
g) Visible waves
75. An airport radar system detects an unidentified flying object (UFO). What is the distance to the object if 100 ms passes between transmission and reception of radar signals?
76. The minimum Jupiter-Earth distance is 588.5 million km. How long does it take a radar signal sent from an observatory to return to earth after reflecting from Jupiter?

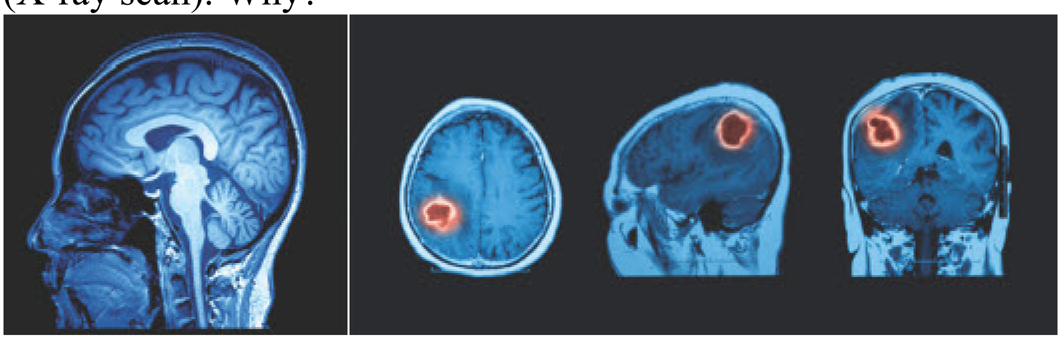
PHYSICS IN LIFE

1. Your heart does oscillations. For what reason?

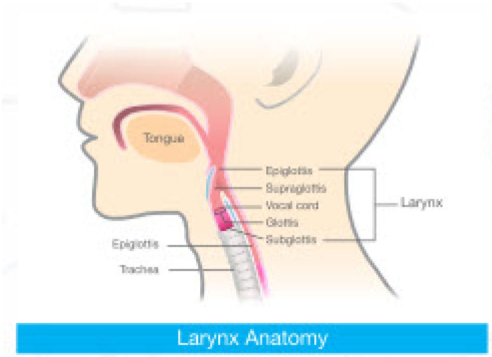


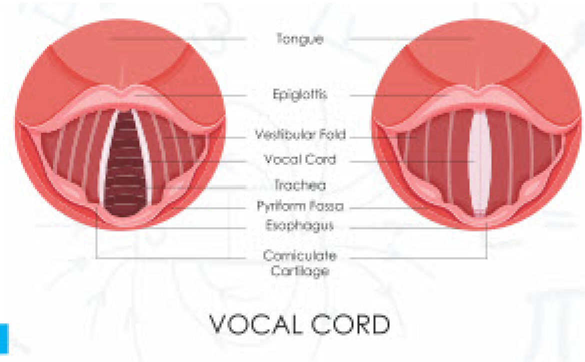
2. Some people can break glass with sound of their voice. How?

3. Magnetic resonance imaging (MRI) is safer than computed tomography (X-ray scan). Why?

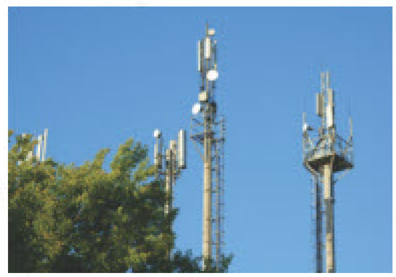


4. Vocal cords produce sound. How?





5. Electrons in smartphones, tablets, laptops, WiFi routers and cell towers oscillate. Why?



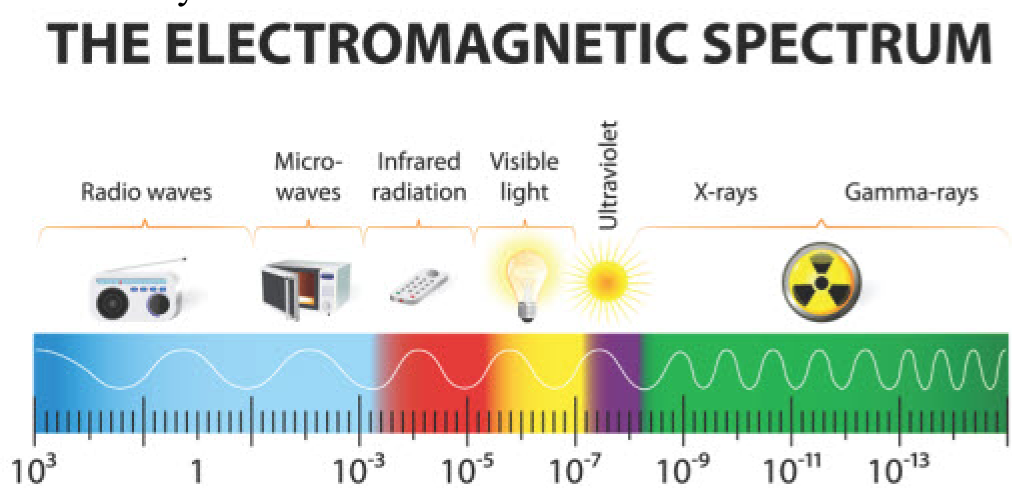
6. Microwave oven is not hot, but it heats food. Why?

7. Hot metal emits light. Why?

8. Tsunami are large waves that do a lot of damage. Why do they appear?

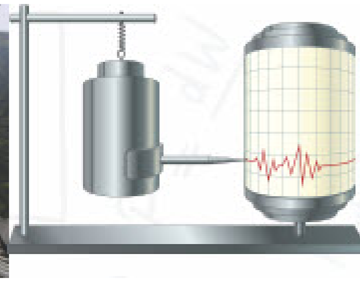
9. Strings in musical instruments vibrate. Why?

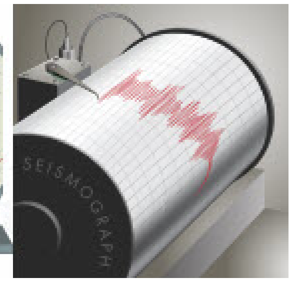
10. Smartphones, microwave ovens, our eyes, X-ray scanners use same waves. Why?

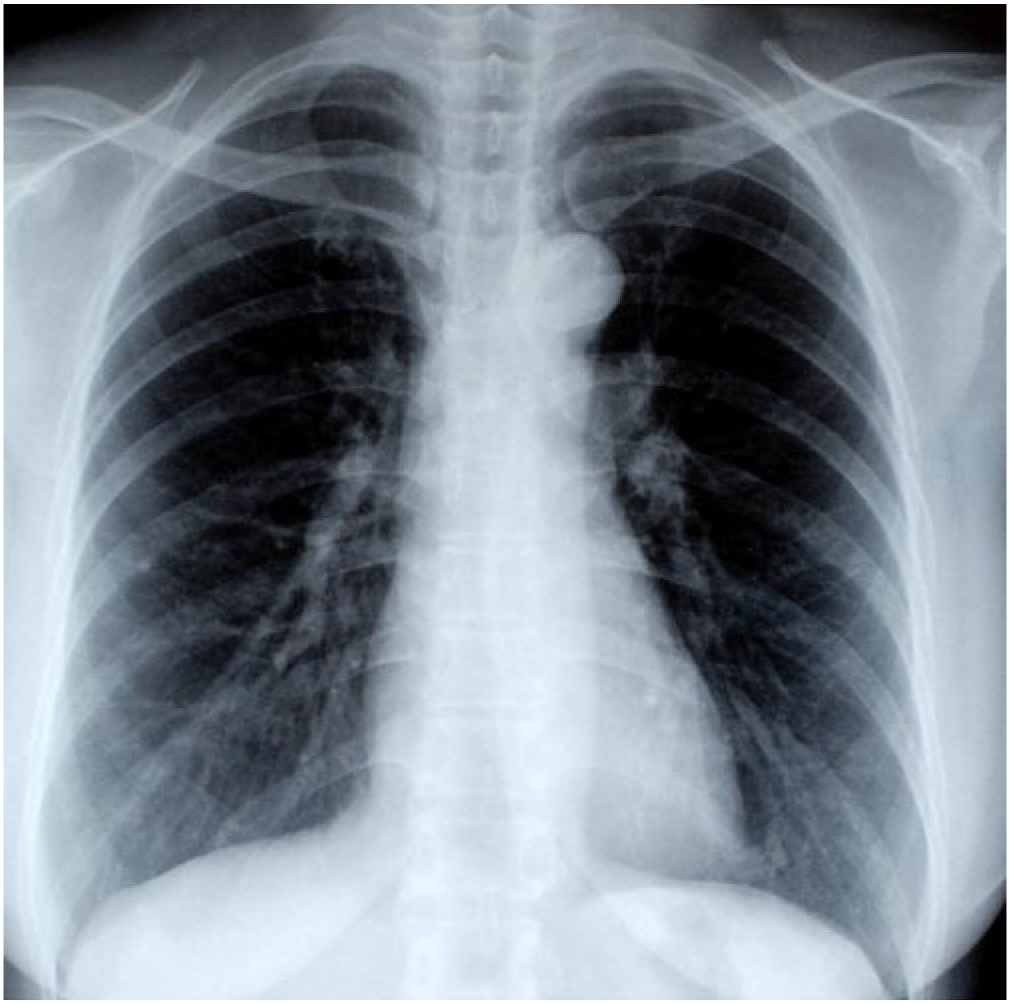


11. Bats use ears to “see” in the night. Why?

12. Seismographs are used to record earthquakes. Earthquakes do a lot of damage. What principles stand for it?




SEISMOGRAPH



CHAPTER 6. ATOMIC PHYSICS

6.1 THERMAL RADIATION

6.2 LIGHT QUANTA

6.3 PHOTOELECTRIC EFFECT

6.4 X-RAY

6.5 TYPES OF RADIOACTIVE DECAY

6.6 RUTHERFORD'S GOLD FOIL EXPERIMENT. STRUCTURE OF ATOM

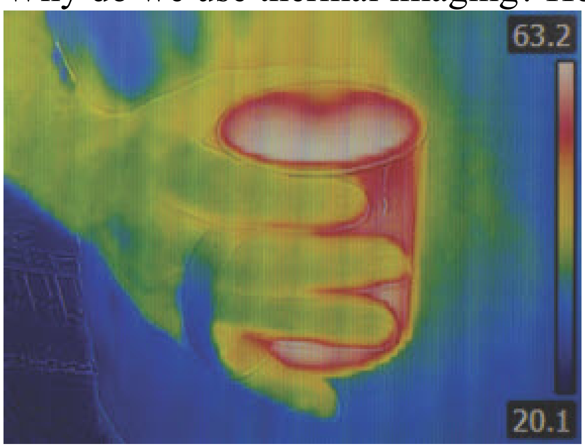
6.1 THERMAL RADIATION

You will

- describe relationship between energy of thermal radiation and temperature;

Question

Why do we use thermal imaging? How does it work?



Object having a temperature above 0 K emits electromagnetic waves. This is called thermal radiation. Hot objects emit radiation in the proximity of a single wavelength called the peak wavelength (Figure 1).

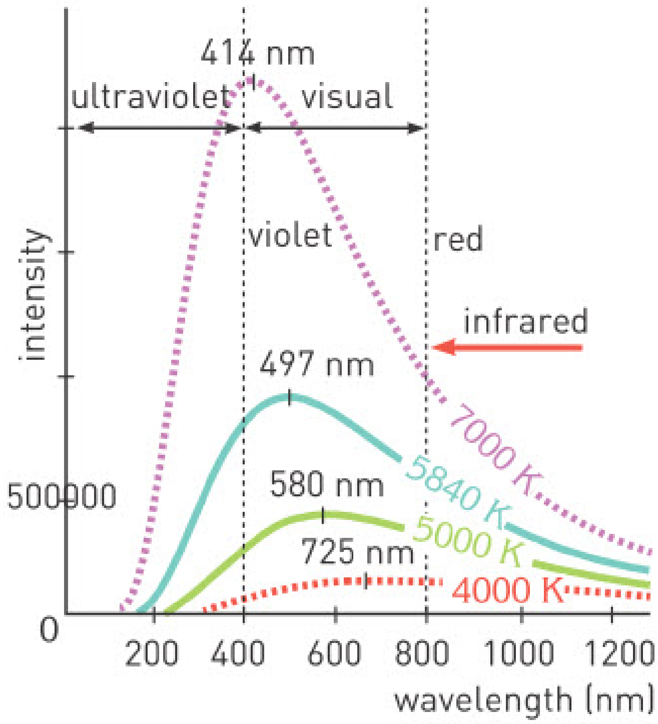


Figure 1. Some peak wavelengths in the visible range

According to Stefan-Boltzmann law, all the energy emitted by one square metre of the object's surface in a second (R) is proportional to the fourth power of temperature (T). For an ideal object:

$R=\sigma\times T^4$

where σ is a Stefan–Boltzmann constant:

$\sigma=5.67\times10^{-8}\ J/m^2K^4s$

The brightness and colour of a hot object changes with temperature. Hotter objects are brighter and their colour shifts to blue as temperature increases, Figure 2. This does not mean that every blue object is at high temperature because objects also reflect light.

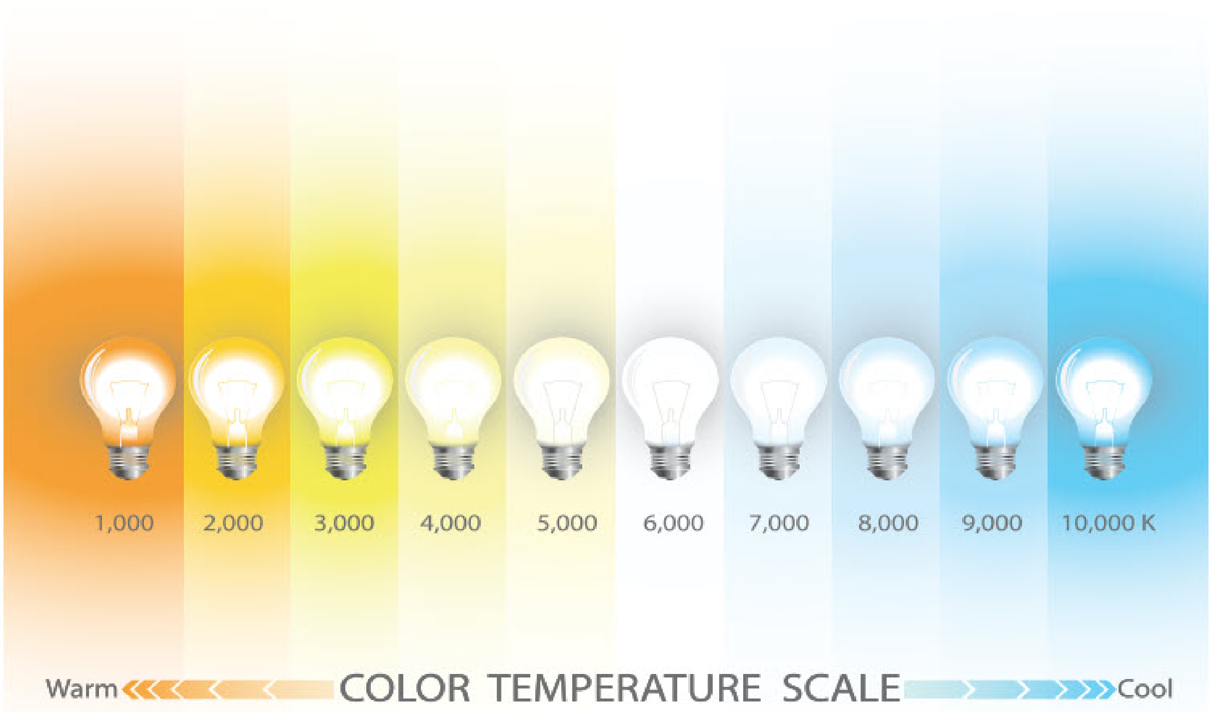


Figure 2

The peak wavelength of thermal radiation is calculated by Wien's displacement law:

$$\lambda = \frac{b}{T}$$

λ: peak wavelength of radiation [metre]

T: temperature of body [Kelvin]

b: Wien's displacement constant, it is equal to 2.9×10^{-3} K·m

Example

Glass manufacturer heats a glass to 527 o C degrees to melt it. What is the energy emitted by glass per square metre in every second?

Solution:
Using Stefan-Boltzmann law we can get the answer
$R=\sigma\times T^4=5.67\times10^{-8}\ J/m^2K^4s\times([273+527]K)^4=23224.32\ J/m^2s$

Activity

Imagine that you are snake. You can see (feel) the temperature. Draw somebody's thermal image.

Research time

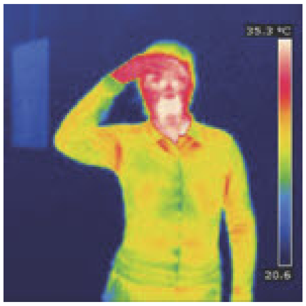
Choose one substance and determine the temperature-colour relationship. Make a video and share it with your classmates. (Make this activity with your group).

Art time

Make theatre play that shows difference between "infrared radiation" and visible light.

Literacy

1. Object emits infrared radiation because it has temperature of 36 °C (309 K). How much more (or less) energy does it emit if its temperature becomes 618 K?



2. Why you cannot see “light” of remote control? Why camera can see “light” of remote control?

Fact

A black body is an object which absorbs all the light incident upon it.

Fact

You can clearly see a pit in front of the snake’s eye. At the bottom is a patch of tissue that is sensitive to temperature changes, allowing the snake to detect thermal radiation.

Terminology

thermal - жылулық / тепловое
to emit - шығару / испускать
brighter - жарығырақ / ярче
to reflect - шағылу / отражаться
manufacturer - өндіруші / производитель
incident - түсетін / падающий
black body - абсолютті қара дене / абсолютно черное тело
to absorb - жұту / поглощать
pit - шұңқыр / впадина
sensitive - сезгіш / чувствительный

6.2 LIGHT QUANTA

You will

apply Planck's law for problem solving;

Question

Why do photographers use “photometer”?

Experiments have shown that classical mechanics can not be applied to subatomic and elementary particles. Scientists needed something new. Einstein proposed that visible light, similar to every type of electromagnetic wave, was composed of elementary particles called photon. They have no charge and no rest mass. But they have energy and momentum. This proposition was the beginning of quantum mechanics. Quantum mechanics replaced classical mechanics for such small particles.

Max Planck proposed that energy is not continuous, Figure 1. Energy is discrete like electric charge. Planck called the smallest possible energy a quantum. It is derived from the word quantity, a quantum of an electromagnetic wave, is called a photon. Photon is a light particle which carries the energy.

Figure 1

Formula of the energy (Planck's law) of photon is:

$E=h\times f$

where h is Planck’s constant. And it is equal to

$h=6.626\times10^{-34}$ J·s

Since light carries energy and propagates in all directions, it has been acknowledged to be a wave for over a century. However, light quanta says that light could be a particle. This is known as particle-wave duality of light.

When electron shifts from higher energy level to low energy level, light quantum is generated, Figure 2.

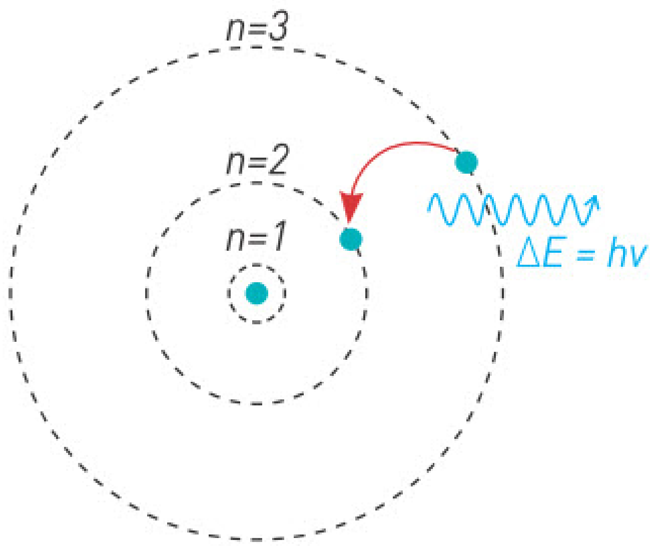


Figure 2

It is well-known from chemistry that electrons have fixed energy levels and they are discrete. If there are many shifts in one time there will be great intensity of light energy. This light energy is called laser. Lasers are used in medicine, industry, space, electronics and etc.

Example

81.99×10^{2} J of energy was gained when a stationary electron is converted into energy. What will the frequency of the resultant radiation be?

Solution:

From Planck's photon energy equation:

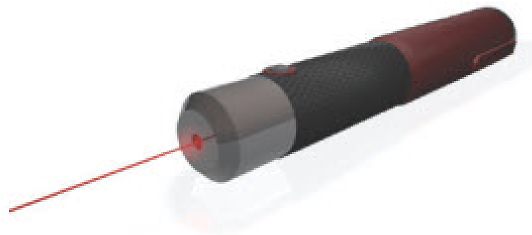
81.99×10 2 J = h × f, therefore,

Since $h = 6.63 \times 10^{-34}$ J·s we get that $f = 1.24\times10^{20}$ Hz.

This frequency falls in the electromagnetic spectrum in the region of both x-rays and gamma rays.

Example

Laser pointer emits red light. Red light has wavelength of 671 nm. Power of laser pointer is 5 mW. How many photons does laser emit in one second?



Solution:
Laser pointer emits many photons. Each photon has energy
E=h×f
We can find frequency by formula
$f = \frac{c}{\lambda} = \frac{3\times10^8}{671\times10^{-9}} = 4.47 \times 10^{14} Hz$
So energy of one photon is
$E=h\times f=6.26\cdot10^{-34}$ J·s×$4.47\cdot10^{14}$=$2.96\cdot10^{-19}$ J
Total energy that laser emits in one second is
$E_{laser}=P\cdot t=5\cdot10^{-3}\times1=0.005$ J
Energy of laser is equal to energy of all photons.
Elaser=N×E
Where N is number of all photons.
$$N = \frac{E_{laser}}{E} = \frac{0.005}{2.96\times10^{-19}}$$
$N=1.7\times10^{16}$ photons

Example

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So energy of one photon is

$$E = h \times f = 6.626 \times 10^{-34} \times 4.47 \times 10^{14} = 2.96 \times 10^{-19} J$$

Total energy that laser emits in one second is

$$E_{laser} = P \times t = 5 \times 10^{-3} \times 1 = 0.005\, J$$

Energy of laser is equal to energy of all photons.

$$E_{laser} = N \times E$$

Where N is number of all photons.

$$N = \frac{E_{laser}}{E} = \frac{0.005}{2.96 \times 10^{-19}}$$

$$N = 1.7 \times 10^{16} \text{ photons}$$

Activity

How do you think is light wave or particle? Make a discussion.

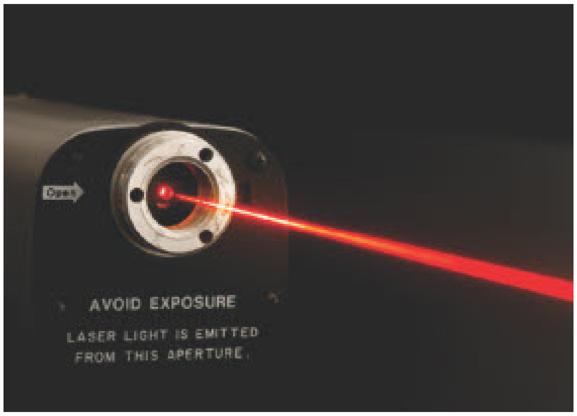
Literacy

1. Photon of red light has wavelength of 700 nanometers. Photon of violet light has wavelength of 400 nanometers. What are energies of these photons?
2. “Richard Of York Gave Battle In Vain” (ROYGBIV) is mnemonic that shows seven colours. Red, orange, yellow, green, blue, indigo and violet. Determine energy of photon for each colour.

Art time

Use red, blue and green flashlights to produce other colours.

Fact



Word laser is an abbreviation. It stands for Light Amplification by Stimulated Emission of Radiation.

Research time

Write an essay about the role of the colour in our life.

Terminology

subatomic elementary particle - субатомдық элементар бөлшек / субатомная элементарная частица
quantum mechanics - кванттық механика / квантовая механика
to propose - ұсыну / предлагать
discrete- үзікті / дискретный

6.3 PHOTOELECTRIC EFFECT

You will

- describe photoelectric effect and tell examples of its use in industry;
- apply Einstein's formula of photoelectric effect for problem solving;

Question

Why are there no other colours in night vision?

The emission of electrons from a metal surface due to electromagnetic radiation (like light) is called the photoelectric effect. The emitted electrons are called photoelectrons, Figure.

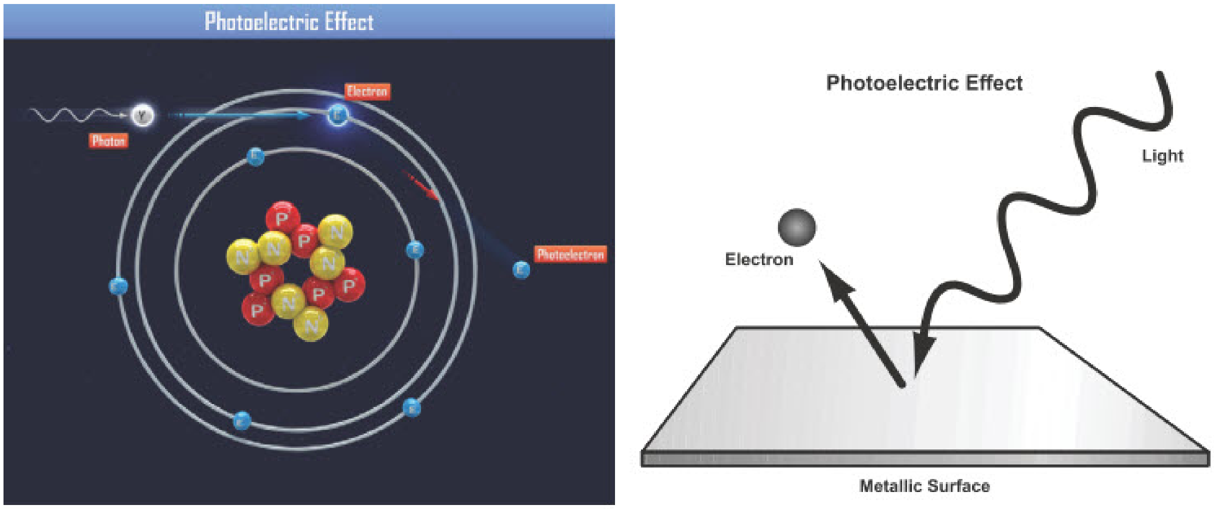


Figure 1

Similar photoelectric experiments above show that:

1. If the wavelength of light is held constant an increase in light intensity causes an increase in the number of electrons emitted. However, the kinetic energy of the emitted photoelectrons does not change.
2. If the intensity of light is held constant when the wavelength of light is changed the number of emitted photoelectrons remains the same, but their kinetic energies change.
3. When a different metal is used, depending on the wavelength of light, sometimes no emission is observed.4. Electrons are emitted from the surface almost instantaneously.

These results were explained by Einstein in 1905.

Einstein's equation describing the photoelectric effect is stated as:

$h \times f$	$=$	E	$+$	W
Energy of Incident photon		Kinetic energy of electron		Work function of the metal

hf is the energy of photon absorbed by an electron in order to escape from the surface of the metal.

W is the minimum energy needed to remove one electron from the metal surface, it is called the work function of the metal, Table 1.

Materials	Work function W (in eV)
Silver	4.26
Barium	4.08
Barium oxide	1.00
Calcium	2.87
Cesium	1.80
Copper	4.70
Iron	4.50
Potassium	2.20
Lithium	2.40
Sodium	2.46
Lead	4.14
Platinum	5.65
Tungsten	4.50
Zinc	4.31

Table 1

E is the kinetic energy of a photoelectron

$$E = \frac{mv^2}{2}.$$

$$m = 9.11 \times 10^{-31}\ kg$$

and unit of velocity is m/s.

From the photoelectric equation above, the minimum energy required by the photon to observe the photoelectric effect must be equal to the work function.

In this relationship, the frequency f 0 is called the minimum frequency or cut-off frequency of the photoelectric effect.

Since the work function of a metal has a very low value, it is expressed in terms of electron-volts (eV). One electron-volt is the energy gained by an electron when placed between a potential difference of one volt.

$$1\ eV = 1.6 \times 10^{-19}\ J$$

Example

What is the cut-off frequency for copper? (W_{Cu} =4.7 eV)

Solution:

The equation for the work function of a given metal is given by

$W = h\,f_0.$

The work function for copper is 4.7 eV. Convert this energy into Joules

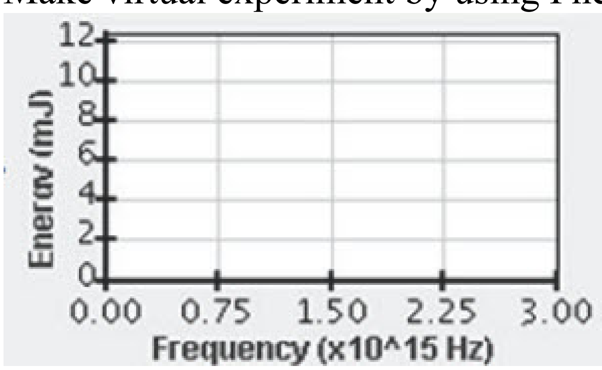
$$W = 4.7\ eV = 4.7 \times (1.6 \times 10^{-19} J) = 7.52 \times 10^{-19} J$$

Now by using Planck's constant we obtain

$$f_0 = \frac{W}{h} = \frac{7.52 \times 10^{-19} J}{6.63 \times 10^{-34}} \Rightarrow f_0 = 1.13 \times 10^{15}\ Hz$$

Activity

Make virtual experiment by using Phet Photoelectric Effect.



1. Plot graph of energy of electron versus frequency of light.
2. Set the wavelength to 500 nm and calculate the frequency.
3. What variables can you change in this simulation? List the answers below.
4. Can you think of any application of the photoelectric effect in daily life?

Literacy

1. 100 photons strike night vision device. How many electrons does night vision device emit?

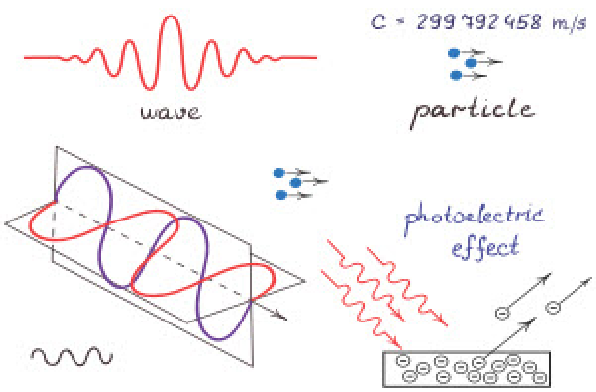
2. Photon that strikes night vision device has wavelength of 700 nm. Work function of night vision device is 1 electron-Volt. Night vision device emits electron. How many kilometres per second is speed of electron?

Research time

Construct model of your own solar panel farm. Present it to your classmates.

Fact

The concept that wave also could be a particle was developed because of the photoelectric effect.



Art time

Perform dance that shows interaction between photon and atom during photoelectric effect.

Terminology

intensity - интенсивтілік / интенсивность
to remain - қалу / оставаться
to gain - ие болу / приобретать
cut-off frequency - фотоэффекттің қызыл шекарасы / красная граница фотоэффекта
simulation - модельдеу / моделирование
effect - әсер / влияние

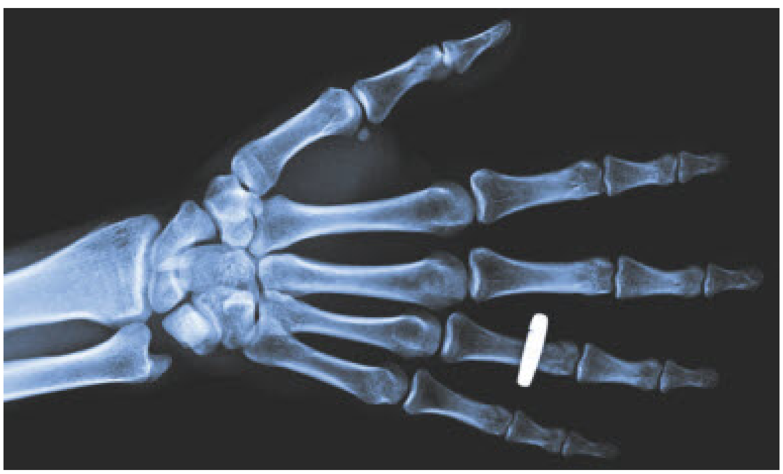
6.4 X-RAY

You will

- compare X-rays with other types of electromagnetic radiation;
- tell examples of use of X-rays;

Question

Why do X-rays pass through muscles, but do not pass through bones? Why does ring appear to be white on X-ray scan?



X-rays are electromagnetic waves that have wavelength shorter than 10 -8 m. X-rays originate from sudden deceleration of high energy electrons striking metal targets, or from energy changes of electrons in the atom. X-rays can penetrate living tissue and are used in medicine, Figure 1.

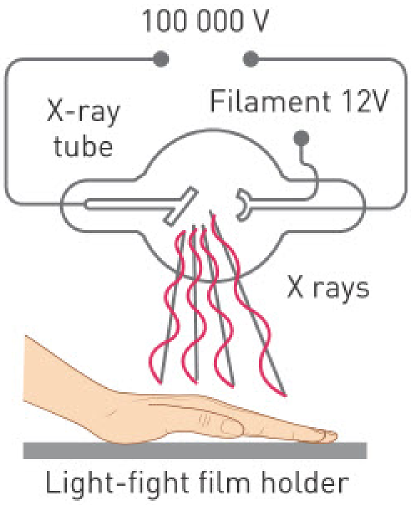


Figure 1

As the wavelengths of electromagnetic waves decrease, the associated photons increase in energy. X-rays have very short wavelengths about the size of atoms.

In 1895 Wilhelm Conrad Roentgen discovered X-rays. A week later he took an X-ray photograph of his wife's hand. Photo clearly showed her wedding ring and her bones. Roentgen called the phenomenon X-ray to indicate that it was an unknown type of radiation. The name remains in use today. You are probably familiar with the use of X-rays in medicine and dentistry. Airport security also uses X-rays to see inside luggage, Figure 2 .

Figure 2

X-ray photons have high energy and can penetrate many layers of atoms before being absorbed or scattered. X-rays pass through your soft tissues to produce images of the bones inside of your body.

Applications of X-rays

In radiography low frequency X-rays are used to procedure the X-ray images used by doctors to diagnose the fracture of a broken arm or even tooth decay. X-rays are also used in everyday applications like X-ray scanners in airports, Figure 3. They can penetrate through all types of materials except for lead.

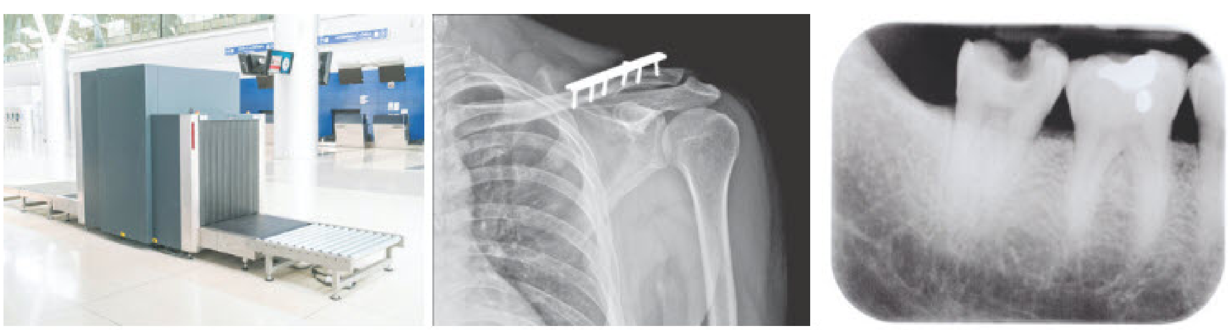


Figure 3

Example

What is the energy of X-ray with wavelength of 5 nm?
Solution:
Using Planck's formula

$$E = h \times f = h \times \frac{c}{\lambda}$$

$$E = (6.63 \times 10^{-34} Js) \times \frac{3 \times 10^{8} m/s}{5 \times 10^{-9} m} = 3.98 \times 10^{-17}\, J$$

Activity

How else can we use X-rays in daily life? Make your list and present it to your classmates.

Research time

How can you become a radiographer? Make presentation and show it to your classmates.

Literacy

1. Fill the table. How many times are X-rays more energetic than visible light?

	Radio	Microwave	Infrared	Visible	Ultraviolet	X-ray	Gamma
Wavelength	100 km	1 cm	10000 nm	500 nm	100 nm	1 nm	10 pm
Energy (eV)							

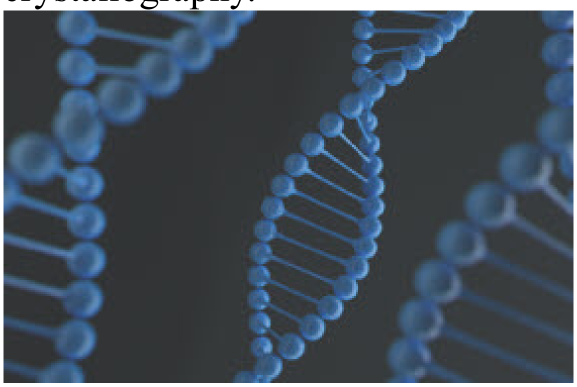
2. How can you build X-ray machine? What materials do you need?

Fact

"Aktubroentgen" (www.aktubroentgen.kz) is one of the oldest X-ray equipment producing company.

Fact

The first photos of double helix shape of DNA were taken by X-ray crystallography.



Terminology

bone - сүйек / кость
to originate - болу / происходить
to penetrate - өте алу / проникать
accidentally - кездейсоқ / случайно
existence - бар болу / существование
beam - сәуле / луч
content - құрамы / содержание

Art time

Make theatre play that shows interaction between human body, X-rays and visible light.

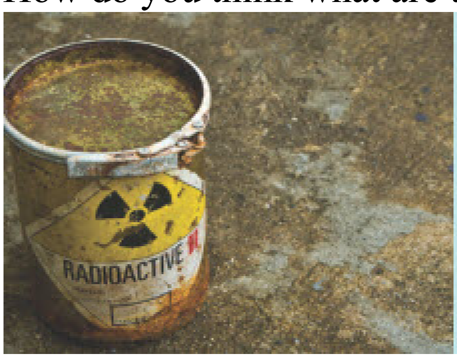
6.5 TYPES OF RADIOACTIVE DECAY

You will

 explain nature and properties of alpha, beta and gamma radiation;

Question

Why do scientists keep radioactive elements in special boxes?
How do you think what are these boxes composed of?



The various types of radiation emitted from a radioactive isotope can be determined experimentally. The radioisotope is located in a chamber where its radiation can pass through a magnetic field to strike a photographic plate. The three different darkened spots appear on the photographic film, which indicates three different types of radiation, first positively charged (alpha), second neutral (gamma) and third
negatively charged (beta), as shown in Figure 1.

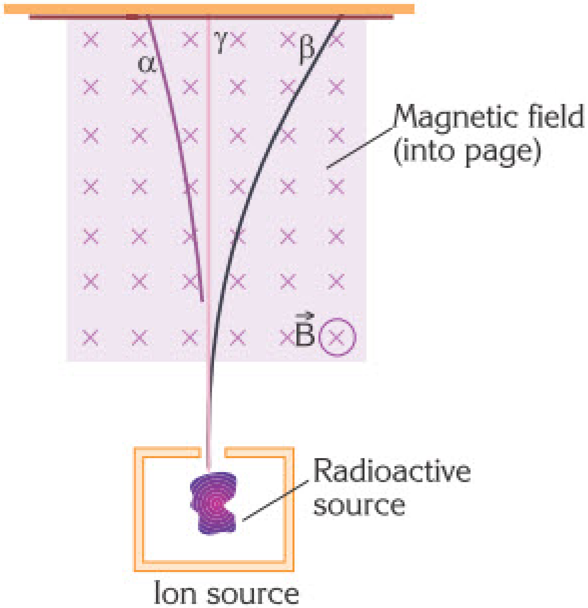
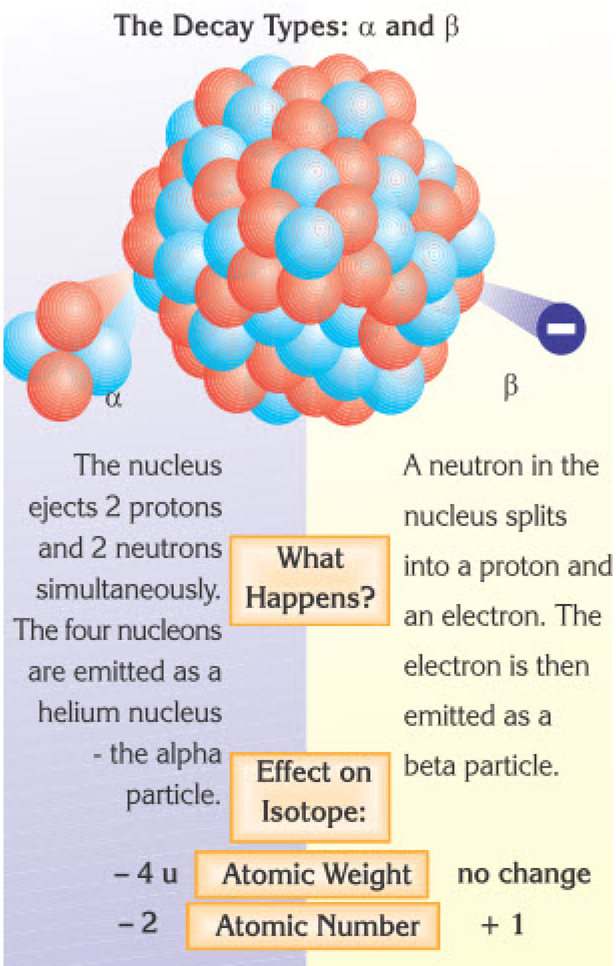
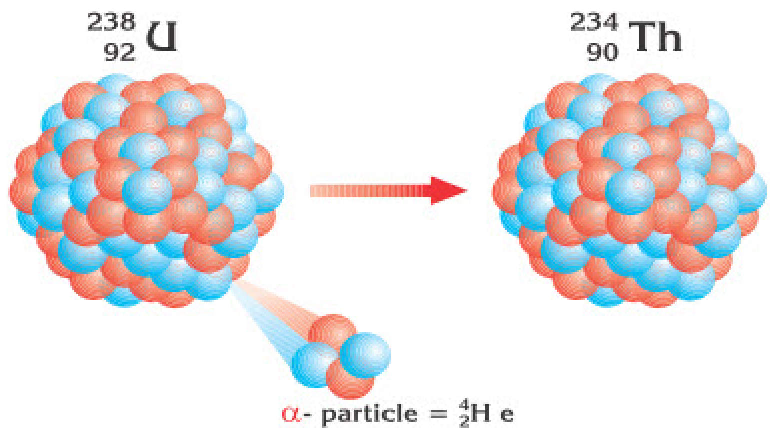


Figure 1. The three types of radiation are α-alpha, β-beta and γ-gamma radiations



1. Alpha rays are a stream of fast moving alpha particles. They are double charged (2+) particles containing two protons and two neutrons. They are actually the nucleus of a helium atom, for example, alpha decay of uranium-238 to thorium.

$$\underset{\text{uranium}}{{}^{238}_{92}U} \rightarrow \underset{\text{thorium}}{{}^{234}_{90}Th} + \underset{\text{a-particle}}{{}^{4}_{2}He}$$



The general equation for alpha decay is then

$$^{A}_{Z}X \rightarrow {}^{A-4}_{Z-2}Y + {}^{4}_{2}He^{+2}$$

parent → daughter + a-particle

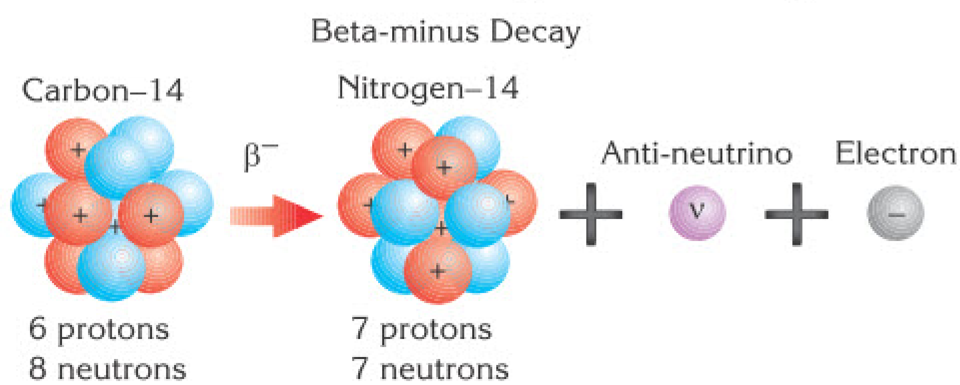
2. Beta rays are fast moving electrons (β-particles).

$$^{1}_{0}n \rightarrow {}^{1}_{1}p + {}^{0}_{-1}e$$

neutron → proton + beta particle

$$^{14}_{6}C \rightarrow {}^{14}_{7}N + {}^{0}_{-1}e$$

carbon → nitrogen + beta particle

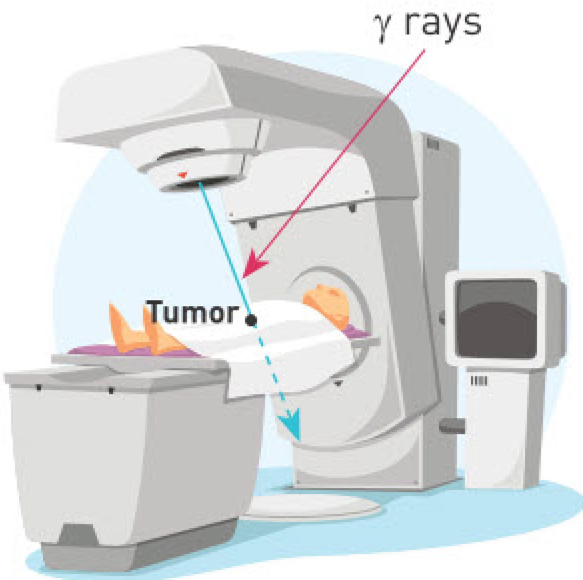


3. Gamma rays are a kind of very energetic electromagnetic radiation.

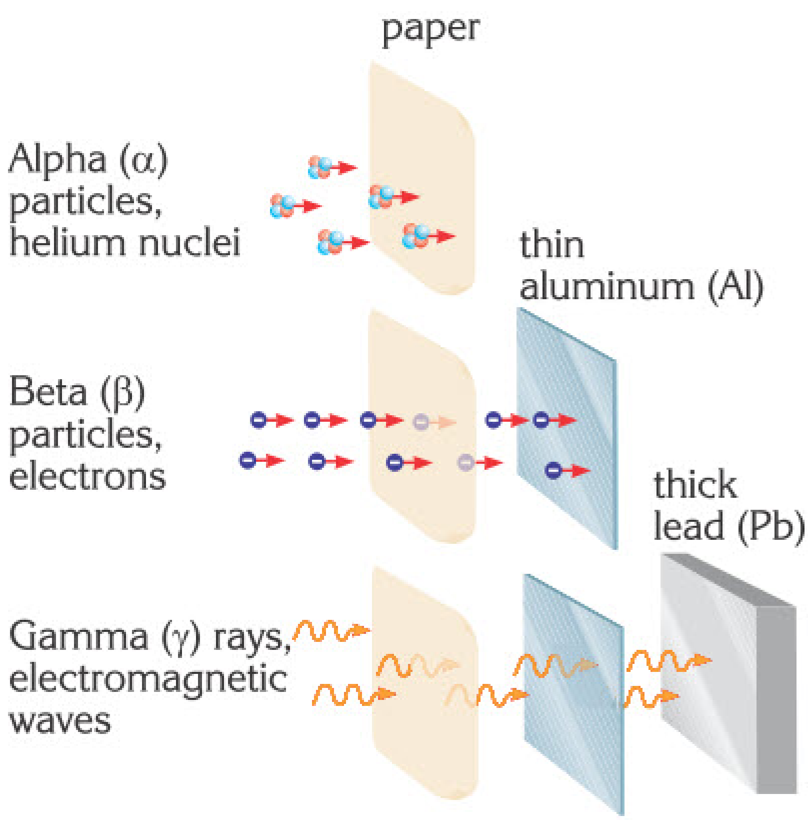
$$^{240}_{94}Pu^{*} \rightarrow {}^{240}_{94}Pu + \gamma$$

Excited plutonium → Plutonium + Gamma ray

The mass and charge of gamma rays are both zero. Therefore, when gamma radiation is emitted, the atomic mass number and the atomic number of an atom remain unchanged. The daughter nucleus is simply the parent nucleus at a lower energy.



Radioactive substances can be useful. They emit gamma rays that kill cancer cells or change genetic codes so that cancer cells cannot grow. Alpha, beta and gamma radiation have different rate of penetration that are shown in the figure.



Common properties of α, β and γ radiation:
1. They ionise gas particles
2. They affect photographic films
3. They produce light on striking a fluorescent screen
4. They affect living things

Example

When a radioactive $^{230}_{90}Th$ isotope undergoes α-decay, what is the resulting daughter nucleus?

Solution:

The nuclear equation for this radioactive decay can be written as

$$^{230}_{90}Th \rightarrow \; ^{A}_{Z}X + \; ^{4}_{2}He$$

Since the sum of the A on both sides of the equation must be equal; the A of X is found as 230=A+4 ⇒ A=226. The sum of the Z on both sides of the equation must also be equal, 90=Z+2 ⇒ Z=88, so this is Radium. Thus

$X = {}^{226}_{88}Ra$

Activity

Download an application on your mobile phone that detects a radiation (EMF counter). Explain how your phone detects a radiation? Which type of radiation is this?

Art time

Perform dance that shows reaction of human body to alpha, beta and gamma decay.

Fact

Geiger counter is a gas-filled tube, which generates an electrical pulse when radiation interacts with its wall or the gas in its tube. These pulses are converted to a reading on the instrument.

Research time

What is "lead castle"? How can you build it? Why people use it?

Terminology

various - әртүрлі / различный
chamber - камера / камера

decay - ыдырау / распад
cancer - обыр / рак

Literacy

1. Why piece of paper stops alpha decay?
2. Why aluminium foil stops beta decay?
3. Why several centimetres of lead stop gamma decay?
4. What is the difference between gamma decay and X-rays?
5. What are electrical charges of alpha, beta, gamma decays?

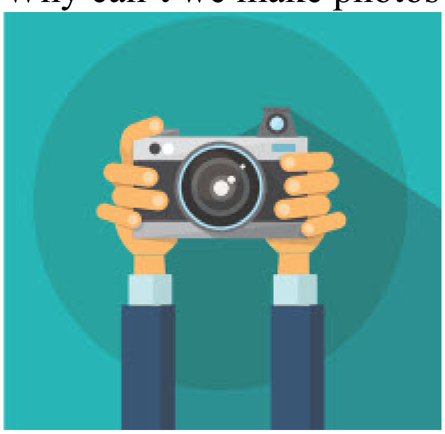
6.6 RUTHERFORD'S GOLD FOIL EXPERIMENT. STRUCTURE OF ATOM

You will

describe Rutherford scattering;

Question

Why can't we make photos of proton, neutron and electron?



Geiger and Marsden performed experiments with α-particles (positively charged) under the guidance of Rutherford. Figure 1 is a simple model of the apparatus used in their experiments. They sent a stream of α-particles from a radioactive element called radium towards a very thin gold foil, nearly 400 atoms thick. They observed the scattered particles on a fluorescent screen. Most of the particles passed through the gold foil without deflecting or travelled along almost straight paths. However, few particles came straight back or were deflected at large angles, as shown in Figure 2. Rutherford used these results to establish a new model of the atom. Positive particle in the centre of the atom was called nucleus. The results showed that most of the atom was empty. This was the reason that particles passed through the foil without being deflected.

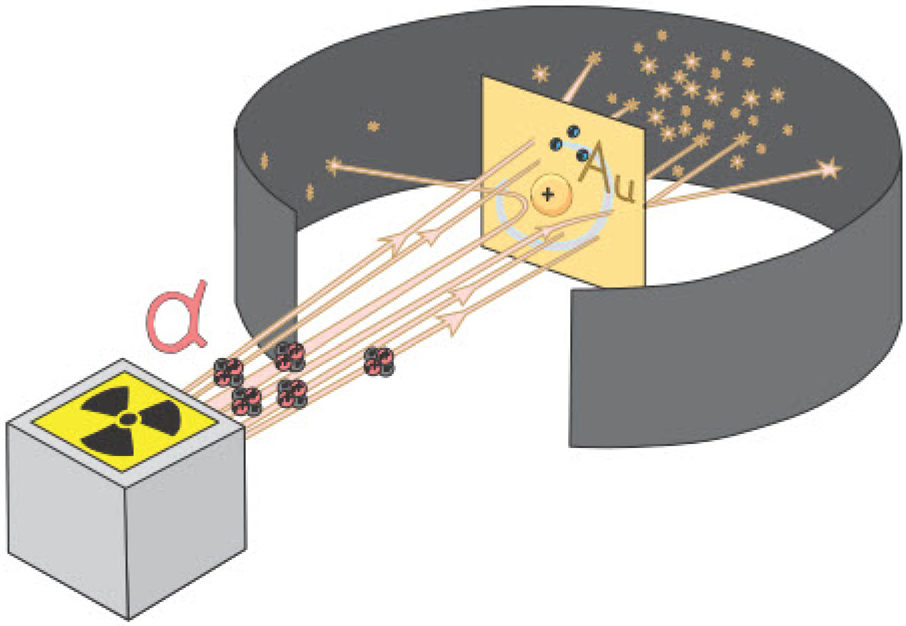


Figure 1

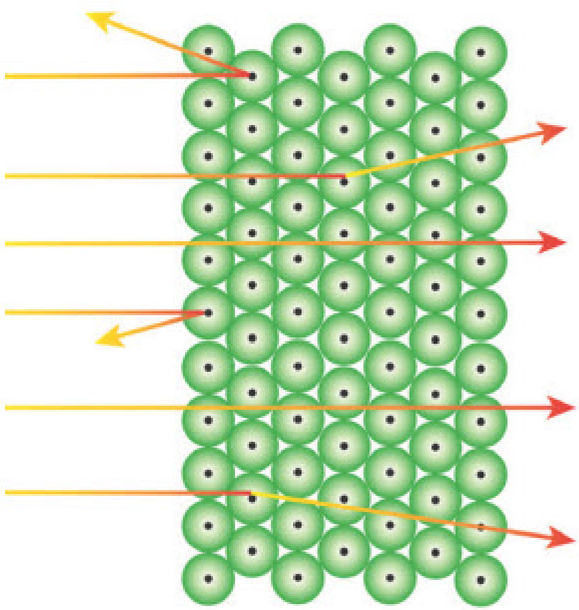


Figure 2

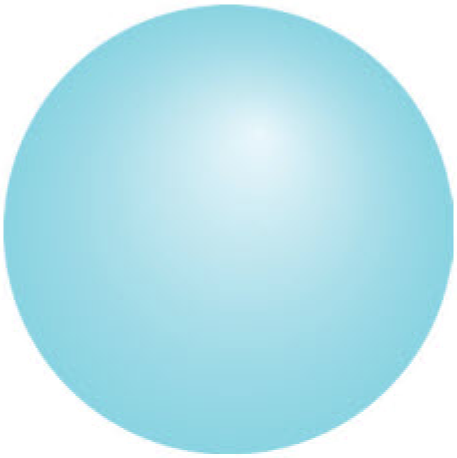
History of atom

The Greek philosopher Democritus thought that all matter was composed of small particles called atoms. The word atom comes from the Greek word "atomos" which means indivisible. Democritus thought that atoms of each substance differed from those of another substance.

In the 17th century scientists led by Galileo and Newton suggested that all matter was in fact composed of small, hard, indivisible solid spheres.

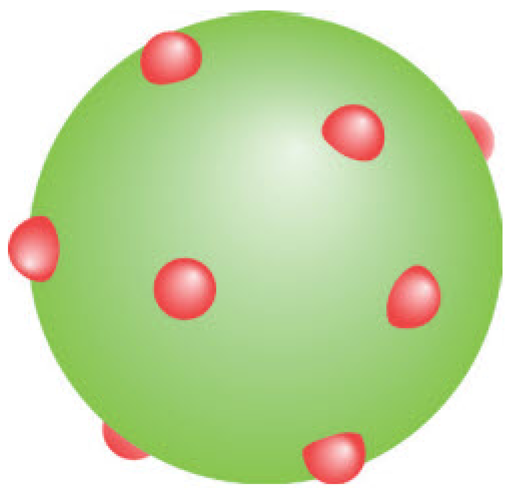
Atomic theories from the early nineteenth century will now be discussed in historical order.

a) Dalton's model



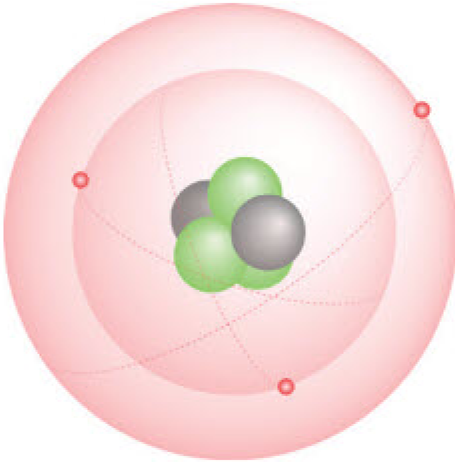
In the early 1800's John Dalton introduced a scientific model of the atom. He suggested that all elements were composed of tiny, indestructible, indivisible particles; each had fixed mass, size and chemical properties. These tiny particles were called atoms, these atoms were the same within each element, but from element to element they changed.

b) Thomson's model



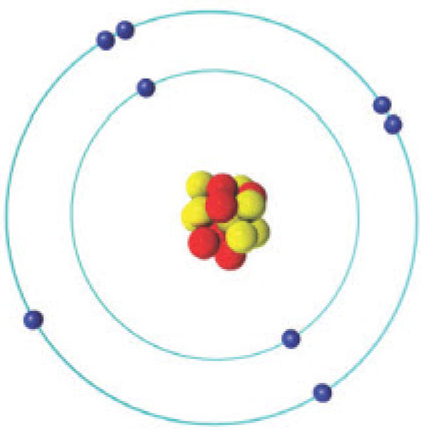
Thomson is recognised as the scientist who discovered the electron. Before this scientists believed that atoms were solid. Thomson carried out an experiment in which he observed that cathode rays were deflected by charged plates or magnets. Later these particles were called electrons. This model of the atom was called as the 'plum-pudding' model; Plums scattered in the cake (atom) were the electrons.

c) Rutherford's model



Positively charged nucleus is at the centre of the atom. Almost the whole mass of the atom is contained in the nucleus. The nucleus has a very small volume, therefore the atom is almost completely empty. Since negatively charged electrons revolve around the nucleus they do not fall into the nucleus.The radius of a gold nucleus is nearly 3×10^{-14} metres.

d) Bohr's model



Niels Bohr studied under the guidance of Rutherford. He tried to correct the deficiencies of the Rutherford model concentrating on the hydrogen atom. Bohr's model was valid only for the hydrogen atom and atoms with a single electron. He suggested that electrons revolve around the nucleus in circles without radiating energy.

Literacy

1. Why did Rutherford's team use gold in their experiment?

2. Why did Rutherford's team use fluorescent screen in their experiment?
3. Why did many alpha particles pass through gold foil?
4. Why did some alpha particles bounce back from gold foil?
5. Why did Rutherford's team use "radium" in their experiment?

Research time

Open Phet Rutherford Scattering. Describe the motion of alpha particles. Does any alpha particle go backwards? (phet.colorado.edu)

Activity

Open Phet Build an Atom. Make a competition by using this game. (phet.colorado.edu)

Fact

Ernst Rutherford received Nobel prize in Chemistry. Moreover his 11 students received Nobel prize.

Terminology

guidance - жетекшілік / руководство
foil - жұқалтыр / фольга
indestructible - берік / нерушимый
plum - мейіз / изюм
tiny - ұсақ / крошечный
nucleus - ядро / ядро

Art time

Make theater play that shows Rutherford’s gold foil experiment.

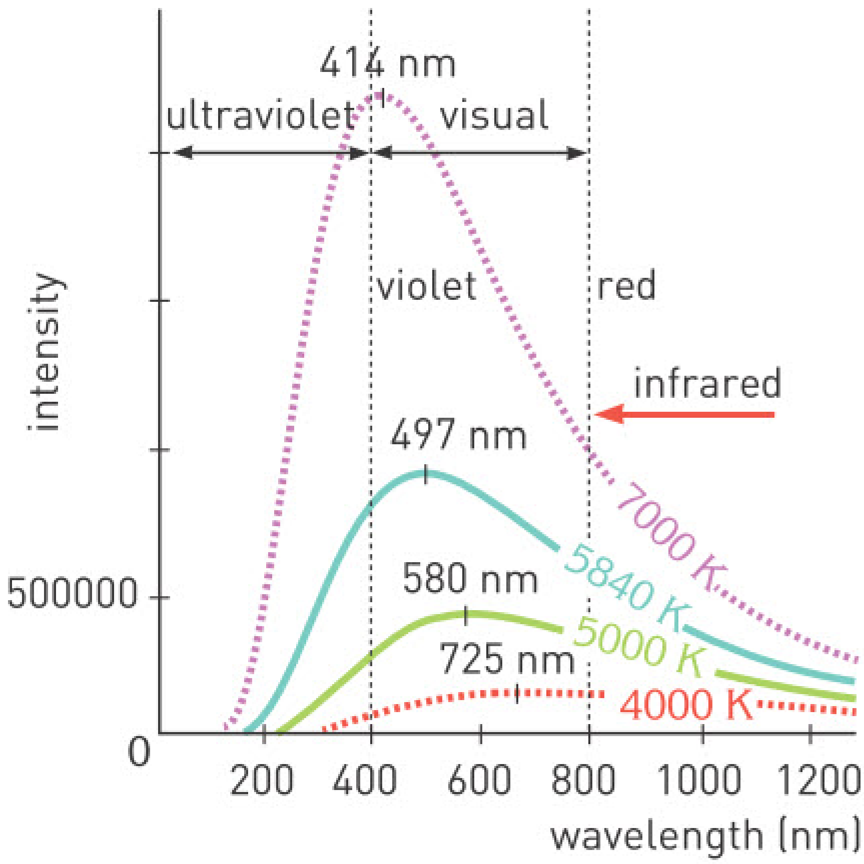
SUMMARY

6.1. Object having a temperature above 1 K emits electromagnetic waves, this is called thermal radiation.

$$R = \sigma \times T^4$$

where σ is a universal constant of nature

$$(\sigma = 5.67 \times 10^{-8} J/m^2K^4s)$$



6.2. Planck called the smallest possible energy a quantum. It is coming from the word quantity. Formula of the energy is:

$$E = h \times f$$

where h is Planck's constant. And it is equal to

$$h = 6.626\,20\ (\pm 0.000\,05) \times 10^{-34}\ Js$$

Amount of energy is taken to be quantum of an electromagnetic wave, it is called a photon. Photon is a light particle which carries the energy.
6.3. The emission of electrons from a metal surface due to electromagnetic radiation (light) is called the photoelectric effect and the emitted electrons are called photoelectrons. Einstein's equation describing the photoelectric effect is stated as:

$$h \times f = E + W$$

$h \times f$	=	E	+	W
Energy of Incident photon		Kinetic energy of electron		Work function of the metal

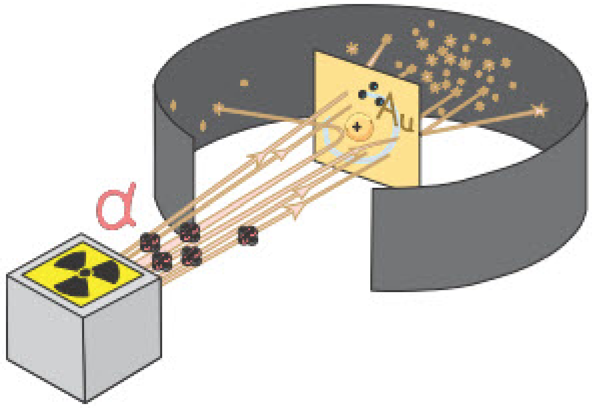
if is the energy of photon absorbed by an electron in order to escape from the surface of the metal.
W is the minimum energy needed to remove one electron from the metal surface, this is called the work function of the given metal.
E is the kinetic energy of a photoelectron. Since the speed of a photoelectron is low relative to the speed of light in a vacuum.

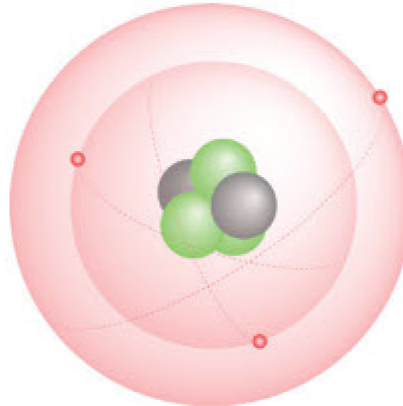
$$1\ eV = 1.6 \times 10^{-19}\ J$$

6.4. X-rays have wavelengths shorter than 0.01 μm. X-rays originate from sudden deceleration of high energy electrons striking metal targets, or from energy changes of electrons in the atom. X-rays can penetrate living tissue and are used in medicine.
6.5. The three types of radiation are α-alpha, β-beta and γ-gamma radiations.
- Alpha rays are a stream of fast moving alpha particles. They are doubly charged (2+) particles containing two protons and two neutrons. They are actually the nucleus of a helium atom $({}^{4}_{2}He)$
- Beta rays are fast moving electrons (β-particles).
- γ- rays are a kind of very energetic electromagnetic radiation.

6.6. Rutherford's model
• Positive charge is concentrated at the centre of the atom. Almost the whole mass of the atom is contained in the nucleus
• The nucleus has a minute volume, therefore the atom is almost completely empty.
• Since negatively charged electrons revolve around the nucleus they don't fall into the nucleus.

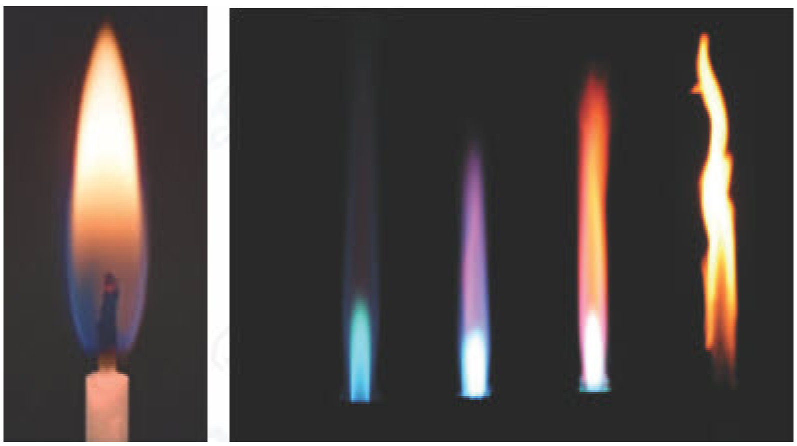
• The radius of a gold nucleus is nearly 3×10^{-14} m.





P R O B L E M S

1. Write down two differences between the atomic models of Thomson and Rutherford.
2. Why did Rutherford believe that most of the atom was empty?
3. What led Rutherford to believe that the nucleus contained positive charge?
4.



Which part of the flame is hotter in the left-hand photograph, the top or bottom portion? Which of the flames is the hottest in the right-hand photograph? Compare the temperatures of the top of the four flames.
5. If all objects emit radiation because of their temperature, why can't we observe them in the dark?
6. Discuss whether the spectra produced by sodium vapour, molten iron, an operating light bulb and mercury vapour are
a) Discrete or continuous
b) Absorbtion line or emission line
Black body Radiation
7. A black body has a temperature of 500 K. If the heat radiation rate has been increased 5 times, how the temperature has been changed?
8. A black body's temperature has been increased from 100 0 C to 300 0 C. How many times the radiation rate has been increased?
9. On a cold day adult person starts feeling uncomfortable and says "I am frozen" after losing 15% of the body's total heat energy. Suppose a passionate scientist named Nursultan is performing experiments on his own

body with average surface area of 1.73 m^2 and temperature of 37 °C. Initial amount of body heat energy is 240,000 J.
a) Calculate amount of energy that Nursultan's body loses before he says "I am frozen"
b) Calculate the heat radiation rate.
Stefan-Boltzmann's constant is
$\sigma = 5.67 \cdot 10^{-8} J / s \cdot m^2 \cdot K^4$
c) How many seconds later Nursultan will say "I am frozen" ?
d) Suppose that Nursultan is performing this crazy experiment again on another day. However, this time he has an electrical heater having spherical shape with a radius R=0.2 m. If the radiated energy from the sphere is completely absorbed by the Nursultan's body, what must the temperature of the sphere be so passionate scientist will not be able to say "I am frozen"? Take π= 3.14
($A_{sphere} = 4\pi R^2$; use the answer of the part "b")

The Photoelectric Effect

10. Photons of energy 2.1 eV cause a photoelectric current on the surface of caesium, which has a work function of 1.9 eV. How many times should the energy of the photon be increased in order to double the maximum kinetic energy of the photoelectrons?
11. What must the minimum energy of photons falling on a copper plate be in order to observe the photoelectric effect?
12. What is the maximum kinetic energy of electrons emitted from caesium (Cs), when light of frequency 1×10^15 Hz falls upon the metal?
13. In the photoelectric effect, does the ejection of electrons from the cathode reduce the mass of the metal?
14. In the photoelectric effect, how do the brightness and frequency of the light affect the number of electrons ejected from the cathode per second?
15. Do all photoelectrons ejected from a metal as a result of the photoelectric effect, have the same kinetic energy?
16. The photoelectric effect is observed on barium oxide (BaO) at a minimum frequency of 0.24 PHz (P for peta means 10^15). Find the work function of barium oxide in eV.
17. The cut-off wavelength for the photoelectric effect of platinum is 220 nm. Find the work function of platinum in eV.
18. Find the cut-off wavelength for the photoelectric effect in tungsten.

19. Green light with a wavelength of 5 461 Å, emitted from a mercury lamp, ejects photoelectrons with a maximum kinetic energy of 0.13 eV from a metal surface.
a) Calculate the work function of the metal.
b) Calculate the cut-off frequency of the metal.
c) Calculate the cut-off wavelength of the metal in angstroms.
20. If light of wavelength 5166 Å falls on the cathode of a photocell lamp, the maximum kinetic energy of the scattered electrons is 0.8 eV.
a) What is the work function of the metal in eV?
b) What is the cut-off wavelength in angstroms?
c) What is the cut-off frequency in Hz?
21. Photons of energy 5 eV, cause the emission of electrons from the surface of a metal. The work function of the metal is 4.7 eV. What is the maximum momentum of the photoelectrons on the surface of the metal?

Extra Problems

c. A Photoelectric Circuit

22. In a photoelectric experiment, a zinc plate connected to an electroscope is negatively charged and illuminated with a perpendicular beam of light. How does the number of photoelectrons change if;
a) the light beams fall on the plate at an angle.
b) the light intensity is increased.
c) a filter rejecting the infrared portion of the spectrum is placed between the plate and the light source.
d) an optical filter rejecting the ultraviolet portion of the spectrum is placed between the plate and the light source?
23. Design an experiment to charge a zinc plate positively using the photoelectric effect. The materials available are a light source, a glass rod and a sheet of paper.
24. What is the wavelength of light directed onto the surface of barium oxide, if the maximum speed of the photoelectrons is 1800 km/s?
25. Ultra-violet light having a wavelength of 2537 Å causes the emission of electrons from a sodium surface. What is the maximum kinetic energy of these ejected photoelectrons?
26. If green light from a mercury lamp, of wavelength 5 461 Å was emitted from a mercury lamp, would it be able to cause the ejection of photoelectrons from a sodium surface?

PHYSICS IN LIFE

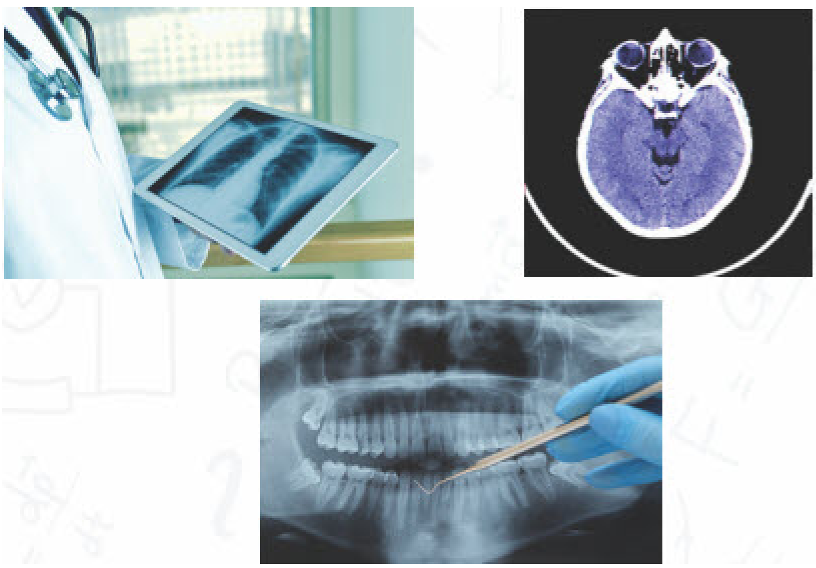
1. Hot metals give light. Why?

2. Nowadays we use electronic computers. But people want to make "quantum computers". Why?

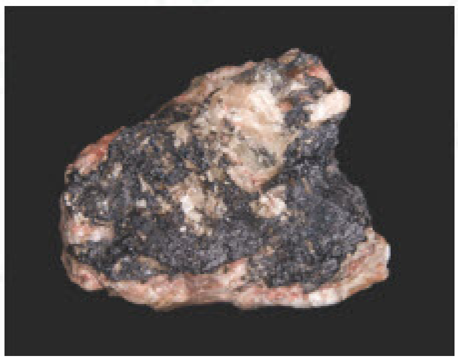
3. Soldiers and hunters use night vision devices. How do these devices work?

4. Solar panels change light into electricity. How?

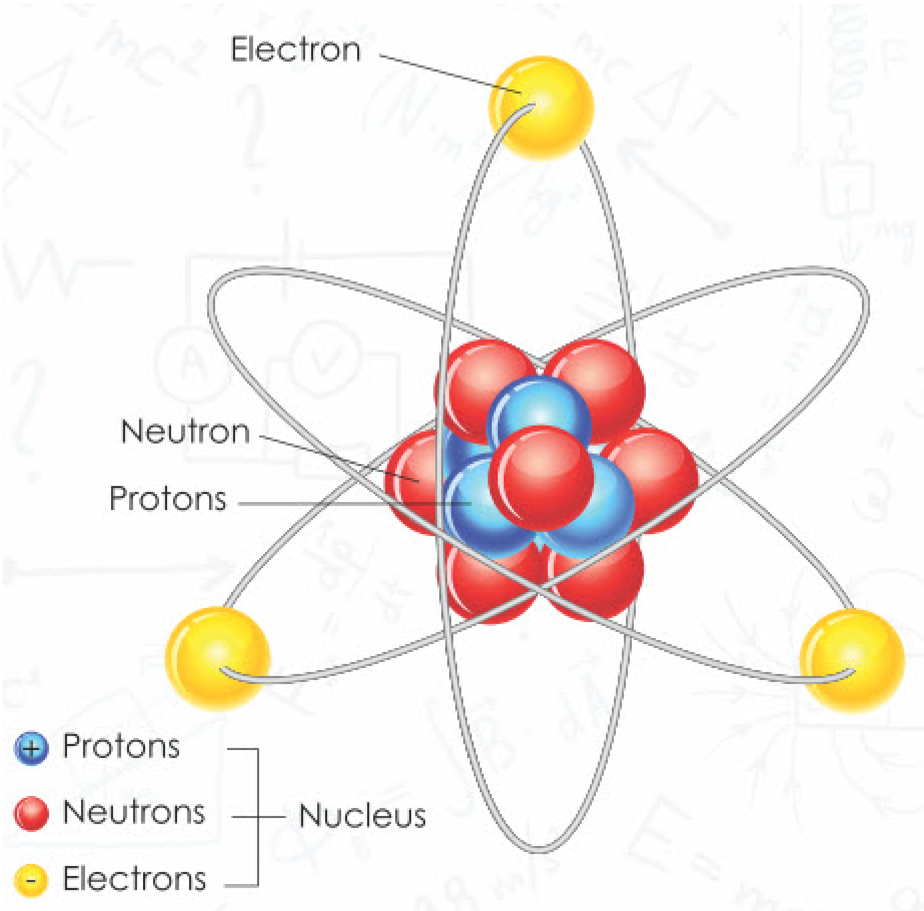
5. We use X-rays in medicine and other areas. Why do X-rays pass through our bodies?



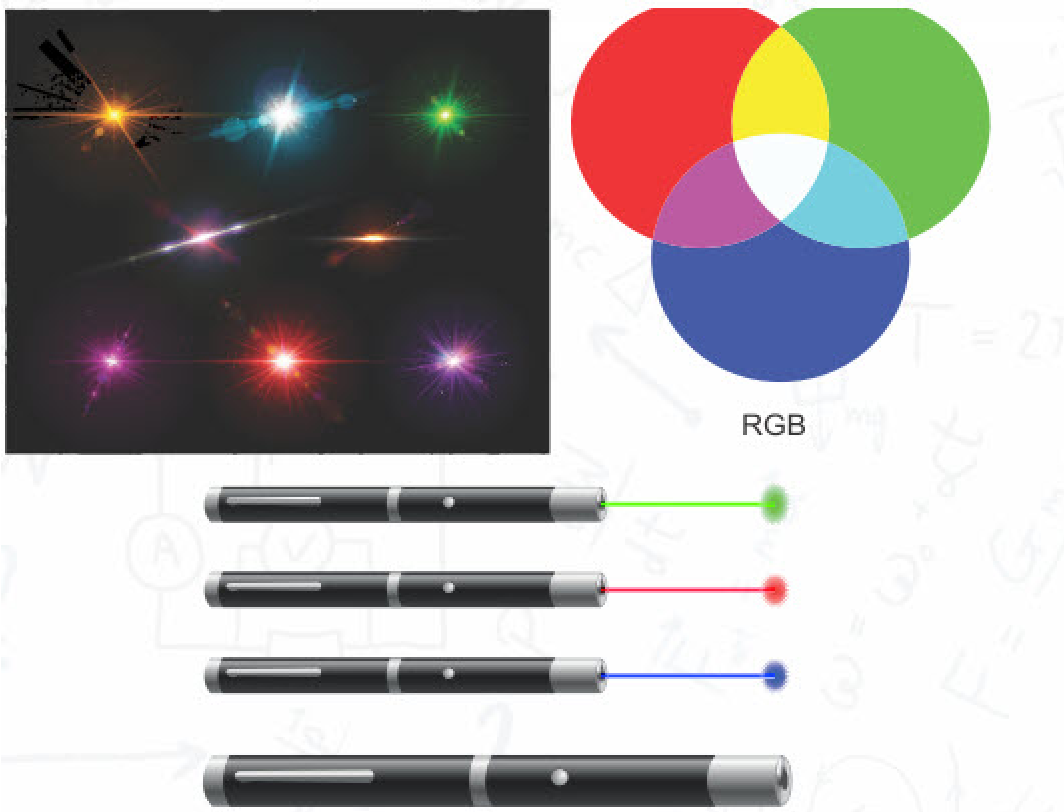
6. Pierre and Marie Curie analysed and studied several tons of uranium ore. Why?

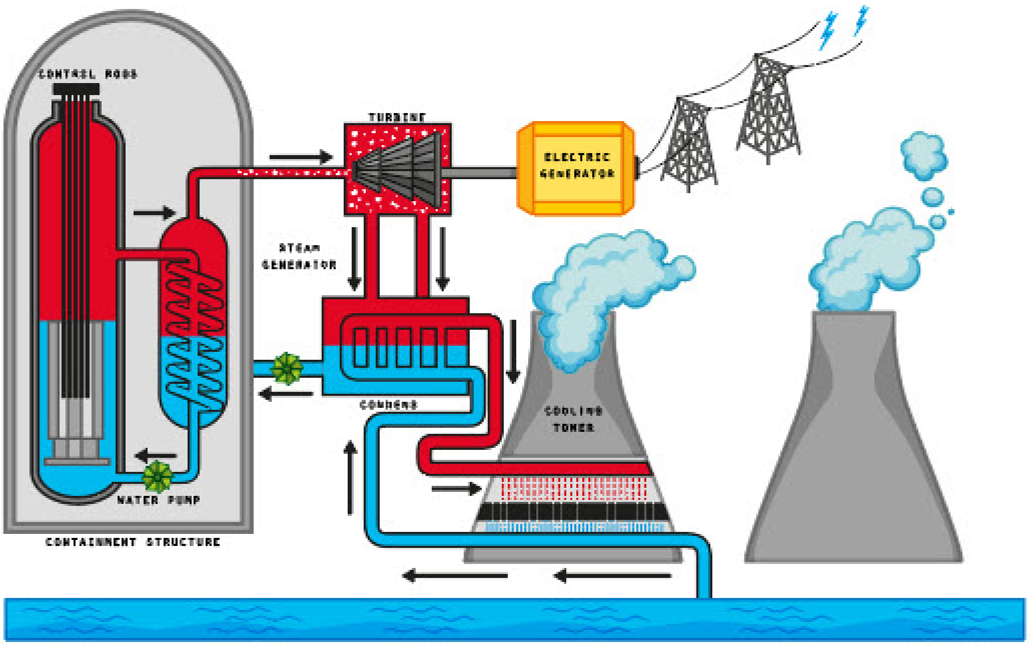


7. We think that atom consists of protons, neutrons and electrons. Why?



8. Light has different colours. Why? What is the difference between colours?


RGB


CONTROL RODS
TURBINE
ELECTRIC GENERATOR
STEAM GENERATOR
CONDENS
COOLING TOWER
WATER PUMP
CONTAINMENT STRUCTURE

CHAPTER 7 NUCLEAR PHYSICS

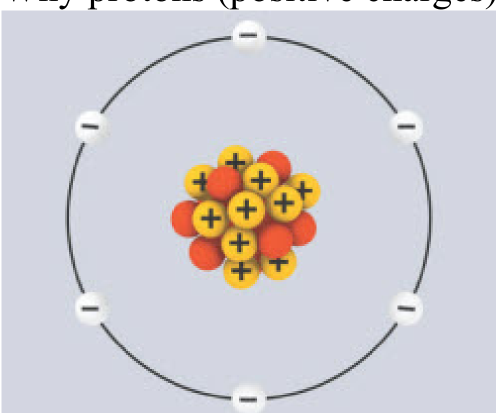
7.1 NUCLEUS AND NUCLEAR FORCES

You will

describe properties of nuclear forces;

Question

Why protons (positive charges) do not push each other out from nucleus?



Nucleus of an atom is composed of protons (p) and neutrons (n). They are called nucleons. The charge of proton has same magnitude as charge of electron but it is positive. Neutron has no charge.

Mass of nucleons is too small to be measured in kilograms. That's why we use special unit of mass called the atomic mass unit (u). Mass of neutral atom of Carbon-12 is defined as having an exact value of 12.000000 u.

Thus,

1 unit (u)= 1.6606×10^{-27} kg

Also, the mass of the proton is

$m_p = 1.673\times10^{-27}$ kg = 1.007276 u

and the mass of the neutron is

$m_n = 1.675\times10^{-27}$ kg = 1.008665 u.

Electron's mass is:

$m_e = 9.1094\times10^{-31}$ kg = 5.486×10^{-4} u

The number of protons in an atom is called the atomic number. It is denoted by Z. Elements in periodic table are arranged according to their atomic number. The total number of protons and neutrons in the atom is the atomic mass number and it is denoted by A. Element X is represented as:

1A	2A
1 H 1.00794	
3 Li 6.941	4 Be 9.01218
11 Na 22.9898	12 Mg 24.3050
19 K 39.0983	20 Ca 40.078
37 Rb 85.4678	38 Sr 87.62
55 Cs 132.905	56 Ba 137.327
87 Fr (223)	88 Ra 226.025

If nucleus of an element contains Z protons and N neutrons, then the relationship between A, Z and N is:

A=Z+N

For example, the third element in the periodic table is Lithium and it is represented as:

$^{7}_{3}Li$

Thus, its atomic number is Z=3 and its atomic mass number is A=7. Number of neutrons N in the Lithium atom is

A=Z+N, 7=3+N, N=4

Protons are positively charged. That means they repel each other. There must be force of attraction between protons so that they remain in the nucleus together. Gravitational force is very small to overcome repulsion. There must be another force that attracts the nucleons. This force is called the nuclear attractive force or nuclear strong force, Figure 1.

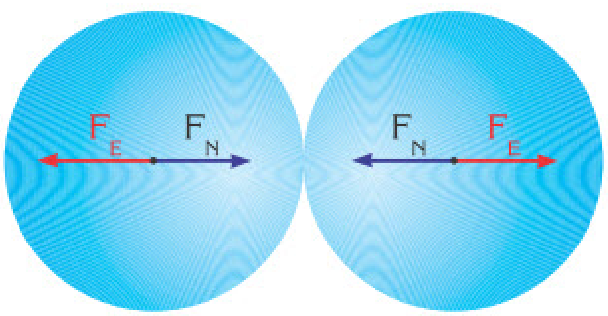


Figure 1. F_E - electric force,
F_N - nuclear force

The nuclear force is much stronger than the electrostatic and gravitational forces.

It is short-range force, so nucleon only interacts with its nearest neighbours.

It acts between any two nucleons.

For atom this force acts between:

- two protons
- proton and neutron
- two neutrons

within a short range.

Nuclear strong force becomes zero, if the distance between the nucleons is greater than 5×10^–15 meter.

Example

If Z is 20, what element is this?

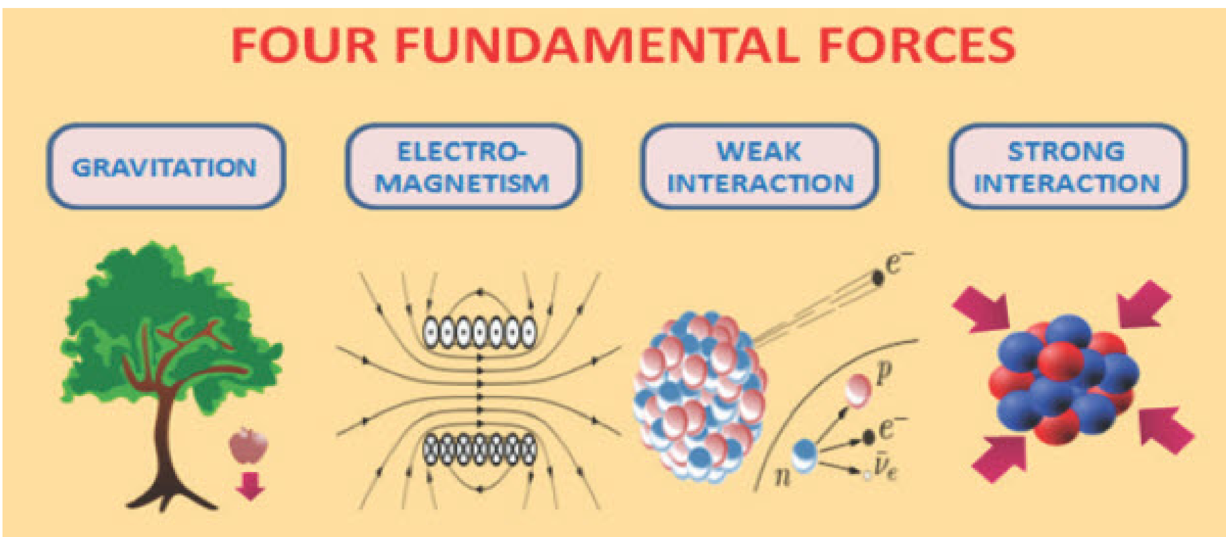
$$^{A}_{Z}X$$

Solution:

Z is the number of protons and the order in Periodic table too. Calcium (Ca) has 20 protons and it is 20th in Periodic table.

Research time

Look at the picture below. Compare these forces. Make a research about weak interaction.



Literacy

1. What does happen if repulsion between protons is greater than nuclear force?

2. Why are number of protons and neutrons approximately equal in elements?
3. Why doesn't nuclear force act between people?
4. Which force is the strongest: nuclear, electric or gravitational? Why?
5. Which one is the heaviest: electron, neutron or proton? Why?

Fact

The mass of an electron is nearly 1836 times smaller than that of a proton.

Activity

Make a model of the Helium atom. Why protons are so close to each other?

Art time

Perform dance that shows force between protons when they approach each other.

Terminology

nucleus - ядро / ядро
nucleon - нуклон / нуклон
periodic table - химиялық элементтердің периодтық жүйесі / периодическая система химических элементов
atomic number - атомдық нөмір / атомное число
atomic mass number - ядроның массалық саны / массовое число ядра
to repel - итеру / отталкивать
to attract - тарту / притягивать

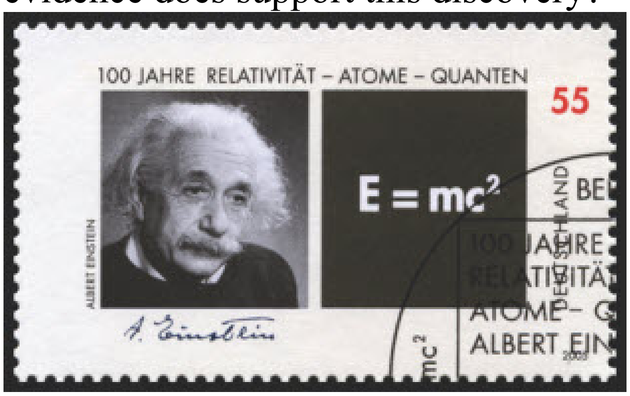
7.2 MASS DEFECT AND NUCLEAR BINDING ENERGY

You will

- determine nuclear mass defect;
- apply formula of nuclear binding energy for problem solving;

Question

Einstein discovered that mass and energy are equivalent. What kind of evidence does support this discovery?



Mass can be transformed into energy. Energy can be transformed into mass. Mass converted into energy inside nucleus is called the mass defect.

Total mass of the nucleus is always smaller than the mass of separated nucleons, Figure 1.

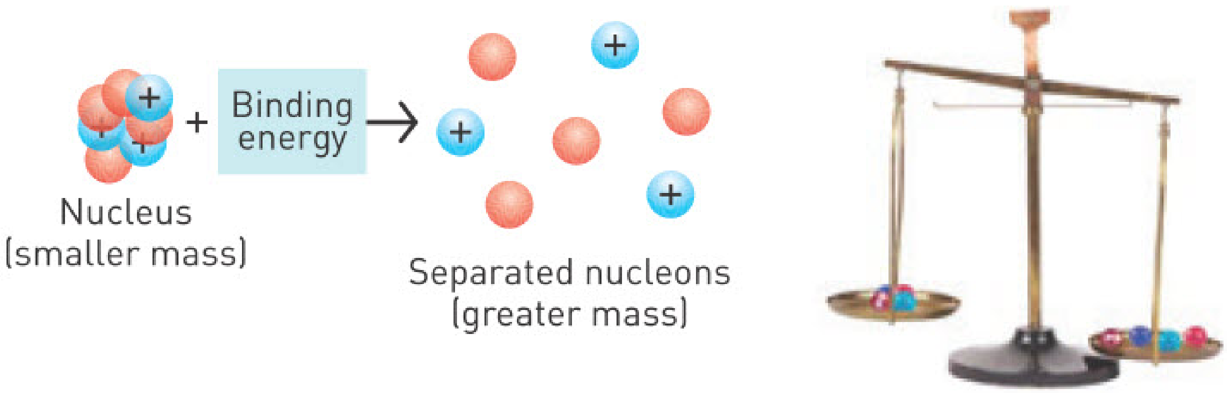


Figure 1. The mass difference gives rise to a nuclear binding energy.

Simply we could write it like this:

$$(Z \times m_p + N \times m_n) > A$$

where Z - proton number, N - neutron number and A - mass number.

Here m_p , m_n and A represent the measured masses of proton, neutron and atom, respectively.

Mass defect (lost mass) is mass difference between the separated nucleons and the fully formed nucleus of atom. It can be calculated by

$$\Delta m = (Z \times m_p + N \times m_n) - A$$

The energy of this 'lost mass' is the same energy preventing the nucleus from breaking up. The energy which binds the protons and neutrons together is called the nuclear binding energy. It is represented by E_b.

For deuterium atom we can write mass defect like this, Figure 2:

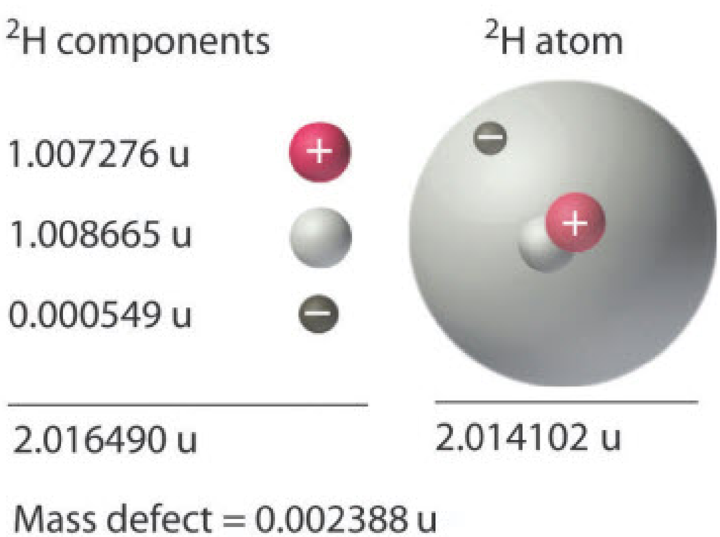


Figure 2. Calculation of mass defect

From Einstein's mass-energy equation $E = \Delta m \times c^2$, the magnitude of the nuclear binding energy is:

$$E_b = \Delta m \times c^2$$

Where, Δm is the amount of mass defect and c=3 x 10^8 m/s is the speed of light.

Energy corresponding to 1u of lost mass is given by
m = 1 u=1.6606 ×10^–27 kg

$$E_b = m \times c^2 = (1.6606\times10^{-27}\ \text{kg}) \times (3 \times 10^8 \text{m/s})^2$$

$$E_b = 1.492 \times 10^{-10}\text{J} = 931.5\ \text{MeV where } 1\ \text{J} = 6.25\times10^{18}\ \text{eV}$$

The average binding energy per nucleon is obtained by following formula.

$$\text{Average binding energy per nucleon} = \frac{\text{total binding energy}}{\text{nucleon number (mass number)}} = \frac{E_b}{A}\ \frac{\text{MeV}}{\text{nucleon}}$$

The average binding energy per nucleon expresses stability of atom, Table 1 . If average binding energy per nucleon is high, then stability of nucleus is also high, Figure 3.

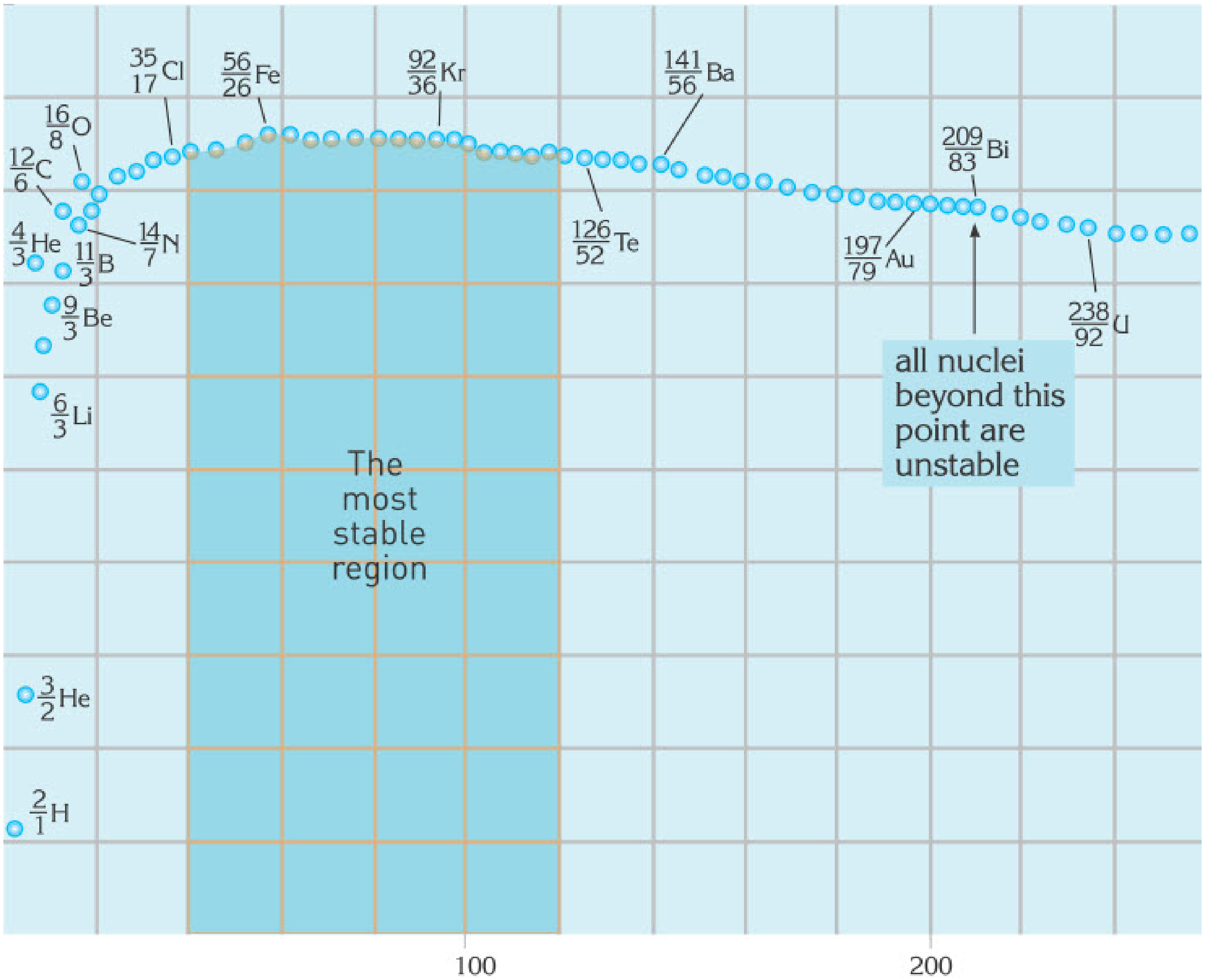


Figure 3. A map of nuclear binding energies.

Element	E_b (MeV)	E_b/A (MeV/nucleon)
$^{2}_{1}D$	2.2	1.1
$^{12}_{6}C$	92.1	7.7
$^{16}_{8}O$	127.5	8.0
$^{56}_{26}Fe$	492.3	8.8
$^{63}_{29}Cu$	552.1	8.8
$^{238}_{92}U$	1803.0	7.6

Table 1. Binding energies for various nuclei.

Example

What is the binding energy of the He atom?
Solution:
1 u=1.6606×10^–27 kg

$$\Delta m = (2 \cdot m_p + 2 \cdot m_n) - A_{He}$$

$$\Delta m = (2 \times 1.007276u + 2 \times 1.008665u) - 4.002602u$$

$$\Delta m = 0.030378 \text{ u}$$

$$1u \cong 932\frac{MeV}{c^2}.$$

The total binding energy of the helium nucleus is

$$E_b = \Delta m \cdot c^2 = 0.030378 \cdot 932\frac{MeV}{c^2} = 28.31 \text{ MeV}$$

Research time

Make research about stellar evolution. How do stars form? Why do some elements come to Earth with meteorites?

Fact

Iron is the most stable element, because it has the greatest binding energy.

Activity

Using a table of nuclear binding energies find most stable elements. How does this fact affect universe?

Art time

Make “allegorical” theatre play about connection of protons and neutrons. Instead of protons and neutrons use persons.

Terminology

mass defect - масса ақауы / дефект массы
nuclear binding energy - ядролық байланыс энергиясы / ядерная энергия связи
nuclei - ядролар / ядра
stellar evolution - жұлдыз эволюциясы / эволюция звезд

Literacy

1. Imagine your body is 100% water. One water molecule has 10 electrons. How many Joules do you get if all electrons become energy? Is it big energy or small energy?
2. Why do protons and neutrons lose mass to connect to each other?

7.3 RADIOACTIVE DECAY AND HALF-LIFE

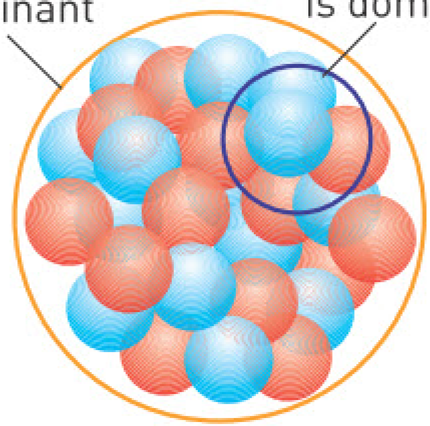
You will

- explain probabilistic nature of radioactive decay;
- use law of radioactive decay for problem solving;

Question

How can you determine age of “Altyn Adam”?

In the nucleus there is competition between the repulsive electrostatic force and the attractive strong nuclear force.



1) The electrostatic force between protons tends to divide the nucleus.
2) The strong nuclear force keeps the nucleus within certain borders, shown on the figure on the right.

In this competition neutrons play an important role. Neutrons in the nucleus separate protons and they increase the distance between protons.

In a large nucleus the electrostatic force acting on a proton could be greater than strong nuclear force. This is because the strong force is a short range force. As the number of protons increases the nucleus gets bigger. That means electrostatic force would be greater than nuclear force. So nucleus becomes unstable. Such elements are called radioactive elements. Radium, uranium and plutonium are the most well-known examples of such elements.

"Radio" refers to the emitted nuclear radiation. While radiation is emitted, the radioactive isotope is "active".

All isotopes of atomic number greater than 83 Bi (Bismuth) are radioactive.

Proton number (atomic number) versus neutron number determines the stability of the nucleus Figure 1. In stable nuclei proton numbers and neutron numbers are approximately equal.

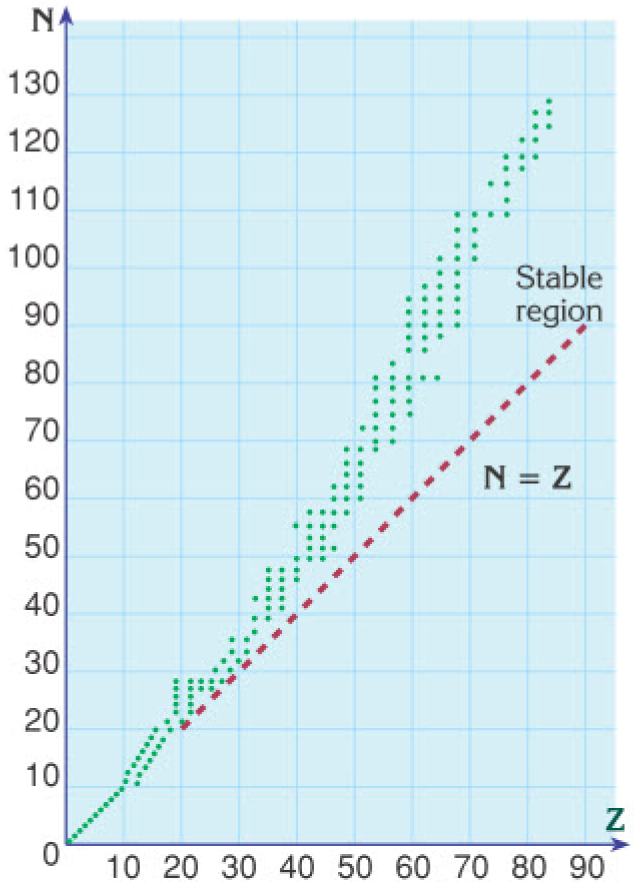


Figure 1. Graph of the number of neutrons versus the number of protons.

During nuclear decay processes:

1. The number of nucleons is conserved
2. Charge is conserved
3. Energy is conserved

Why atoms decay
Some nuclear arrangements less stable than others.
A radioactive isotope decays form a more stable nucleus
An isotope decays by emitting: -mass (alpha particles) -charge (beta particles) -energy (gamma rays)

Nuclear decay

The most common types of radiation are α-alpha, β-beta and γ-gamma radiations.

Half-life is the period of time over which the number of radioactive nuclei decreases by half.

Half-life is a characteristic property of each radioactive element.

The graph in Figure 2 represents the change in the number of radioactive atoms with time.

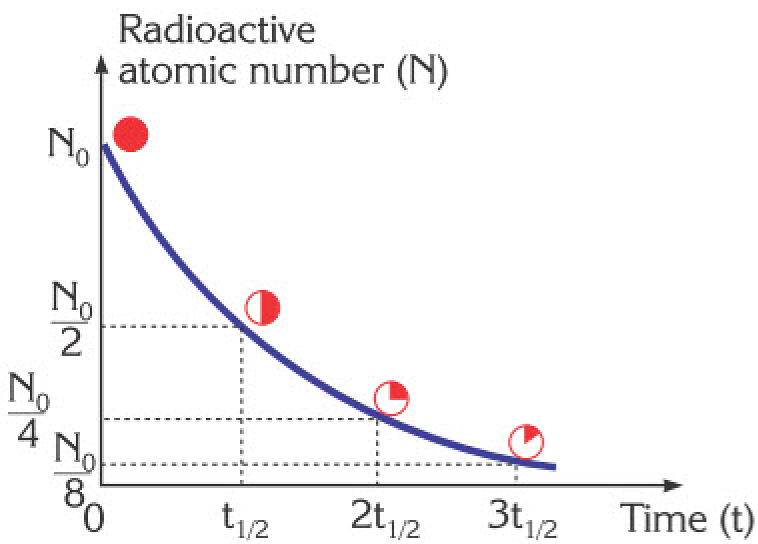


Figure 2

In order to derive the formula for half-life, imagine a fixed number of nuclei, N_0 . After one half-life the number of nuclei in the sample becomes:

$$N = \frac{N_0}{2} \qquad (T_{1/2} : \text{half-life})$$

This is a simpler method for solving half-life problems:

$$N = N_0 \quad \text{when} \quad t=0$$

$$N = \frac{N_0}{2^1} \quad \text{when} \quad t=1 \cdot T_{1/2}$$

$$N = \frac{N_0}{2^2} \quad \text{when} \quad t=2 \cdot T_{1/2}$$

$$N = \frac{N_0}{2^n} \quad \text{when} \quad t=n \cdot T_{1/2} \ \left(\text{or } \frac{t}{T_{1/2}}=n\right)$$

So we can use general formula of radioactive decay:

$$N=N_0 \times 2^{-t/T}$$

Example

The half-life of a radioactive substance is 3 days. How many days does it take for 93.75% of this substance to decay?

Solution:

Undecayed portion of substance is;

(100–93.75)%=6.25%, so,

$$\frac{N}{N_0} = \frac{6.25}{100} = \frac{1}{2^n}$$

$$2^n = \frac{100}{6.25} = 16$$

$$n=4$$

$$\text{then } t=n \times T_{1/2} = 4 \times 3 = 12 \text{ days}$$

Research time

Research alpha, beta and gamma radiation. Then design “radiation suit” that can protect from alpha, beta, gamma decays.

Fact

Radioactive decay allows dating an organic objects that are up to 25000 years old.

Fact

"Tamgaly” is near Almaty. There are a lot of petroglyphs (pictures on stone) of ancient people. Their age is determined by using C-14 dating.

Terminology

radioactive decay - радиоактивті ыдырау / радиоактивный распад
repulsive - итеруші / отталкивающий
attractive - тартқыш / притягивающий
range - қашықтық / расстояние
stability - беріктілік және орнықтылық / устойчивость
half-life - жартылай ыдырау периоды / период полураспада
radiation - радиациялық сәуле шығару / радиационное излучение

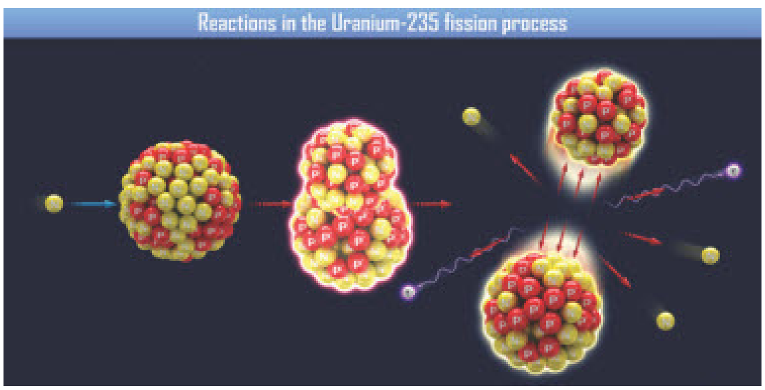
7.4 NUCLEAR CHAIN REACTION

You will

describe conditions for nuclear chain reaction;

Question

Why do we use uranium in nuclear power plants? What will happen when uranium ends?



Nuclear reactions take place inside the nucleus of an atom. There are two types of nuclear reaction:
1) Fission (division, splitting)
2) Fusion (combining)

When nucleus is bombarded with neutrons it splits into several parts. This process is called nuclear fission (nuclear division). In the process, energy and neutrons are released, Figure 1 .

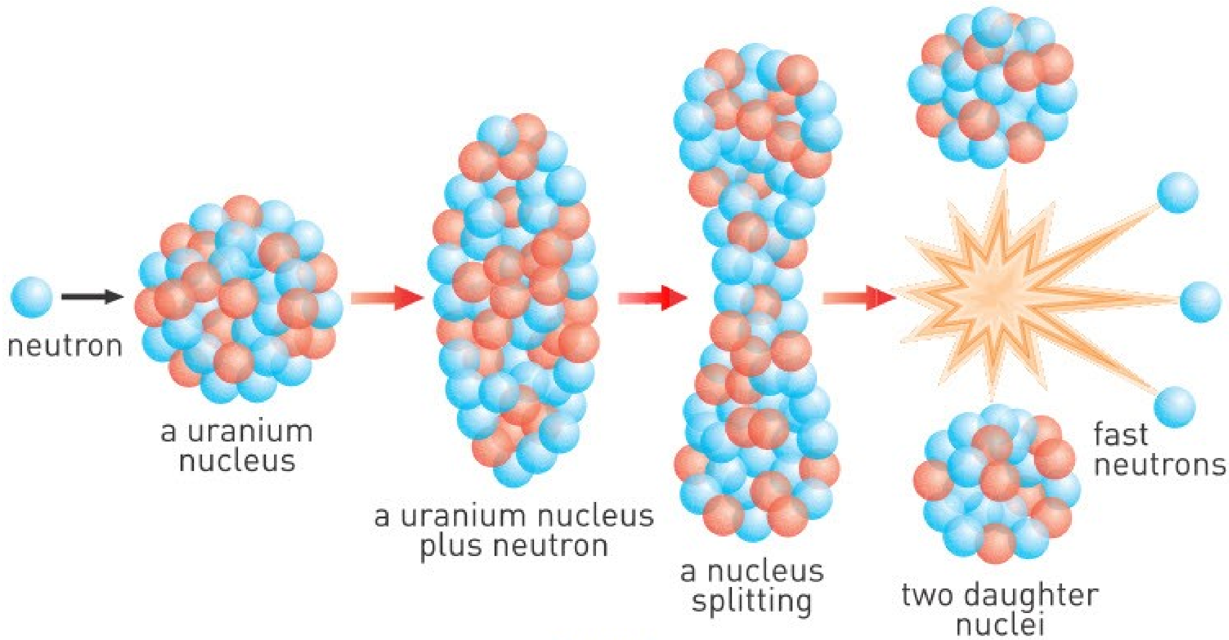


Figure 1

A nuclear fission reaction of Uranium-235 may proceed by one of the following paths:

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{94}_{38}Sr + ^{140}_{54}Xe + 2^{1}_{0}n$$

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{92}_{36}Kr + ^{140}_{56}Ba + 4^{1}_{0}n$$

$$^{235}_{92}U + ^{1}_{0}n \rightarrow ^{150}_{60}Nd + ^{81}_{32}Sre + 5^{1}_{0}n$$

The element uranium is used in almost all of the fission processes, Figure 1. It has two natural isotopes. One of them is 238 U which constitutes 99.3% of natural uranium ore and ^{235}U which constitutes 0.7% of natural uranium ore. Fissionable nuclei such as ^{235}U and ^{239}Pu are called fissile nuclei.

Energy that could be taken from 1 kg ^{235}U is equal to the energy of 3000 tons of coal (or the energy of 20000 tons of dynamite).

Number of neutrons produced during fission is greater than the number of neutrons that are used for bombardment. The neutrons generated during the nuclear reaction also bombard other ^{235}U isotopes and cause new fissions. These new nuclear fission reactions also produce neutrons and the process carries on. This continuous process is called a nuclear chain reaction, Figure 2. It is the basic principle of the atomic bomb and the nuclear reactor.

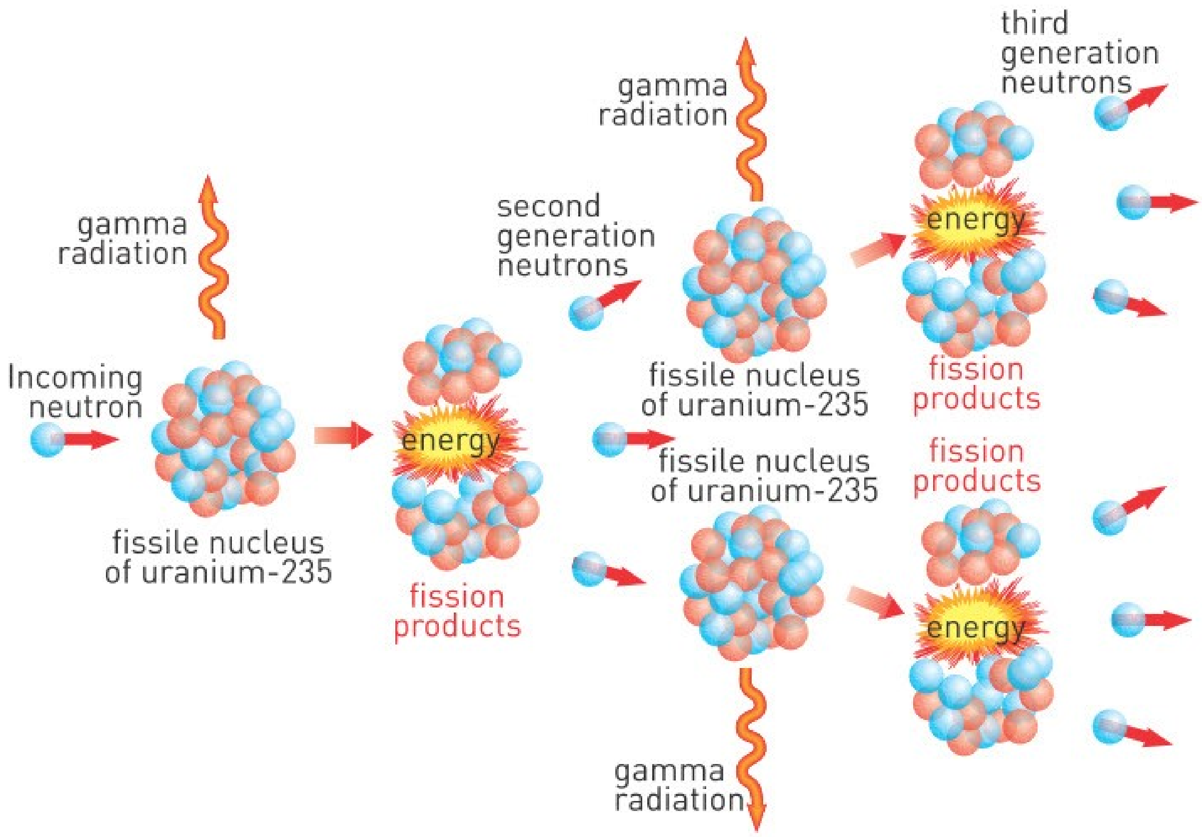


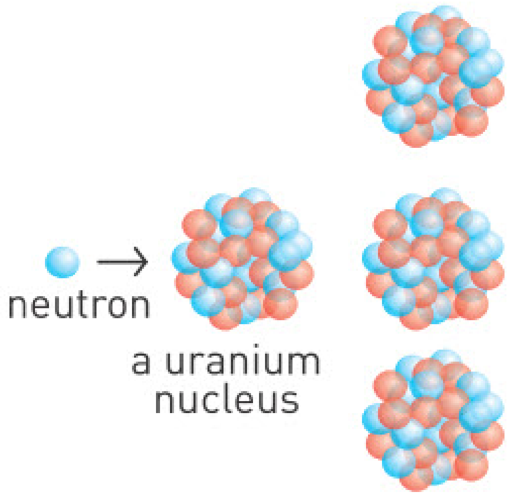
Figure 2 Nuclear Chain Reaction

The minimum mass necessary to sustain a nuclear chain reaction is called the critical mass. In nuclear fission bomb several subcritical radioactive samples are forced into each other. Then they form one sample of supercritical mass. Total number of fissions increases rapidly (exponentially) with time.

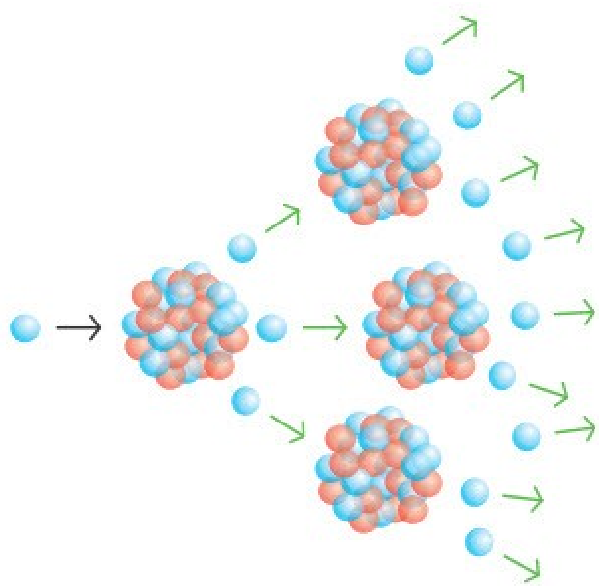
In a fission reactor, the number of subsequent fissions for each fission must be exactly one. If the rate is slower, the chain reaction will stop. If rate is faster, it will grow exponentially and explosion will happen.

Example

Neutron is sent to nucleus as shown in the figure. What is the maximum number of third generation neutrons if each fission produces 3 neutrons?



Solution:



After every reaction Uranium nucleus produces 3 neutrons. So, after second reaction 9 third generation neutrons can be produced.

Fact

Kazakhstan is TOP-3 country in uranium mining.

Research time

Research the locations of uranium ore in Kazakhstan and methods of mining of uranium.

Activity

Play Phet Nuclear fission. Why does only Uranium - 235 split into particles? phet.colorado.edu

Art time

Make “domino show” that shows nuclear chain reaction.

Terminology

nuclear chain reaction - тізбекті ядролық реакция / цепная ядерная реакция
nuclear power plants - атом электр станциясы / атомная электростанция
to bombard - атқылау / обстреливать
fission - ыдырау, бөліну / расщепление
uranium ore - уран кені / урановая руда
fissionable, fissile - бөлшектенілетін / расщепляемый
subcritical - критикалық массадан аз / меньше критической массы
supercritical - критикалық массадан көп / больше критической массы
exponentially - өте тез / очень быстро
explosion - жарылыс / взрыв

subsequent - кейінгі / последующий
mining - кен өндіру / добыча руды

Literacy

1. Why do we need to slow down neutrons in chain reaction?
2. Why can’t we use Uranium-238 for chain reaction?
3. Why don’t we use alpha-particles to split Uranium-235?
4. Why do we use neutrons to split Uranium-235?
5. Imagine and tell (or write) history of XX century if there was no nuclear chain reaction.

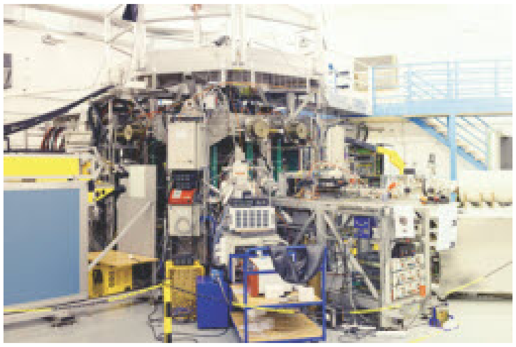
7.5 NUCLEAR FUSION

You will

- compare nuclear fission and nuclear fusion;
- tell examples of use of radioactive isotopes;
- apply conservation of mass and charge to solve problems of nuclear reactions;

Question

Tokamak is device for producing nuclear fusion. How many tokamaks are there in Kazakhstan? How does tokamak work? (http://www.nnc.kz/)

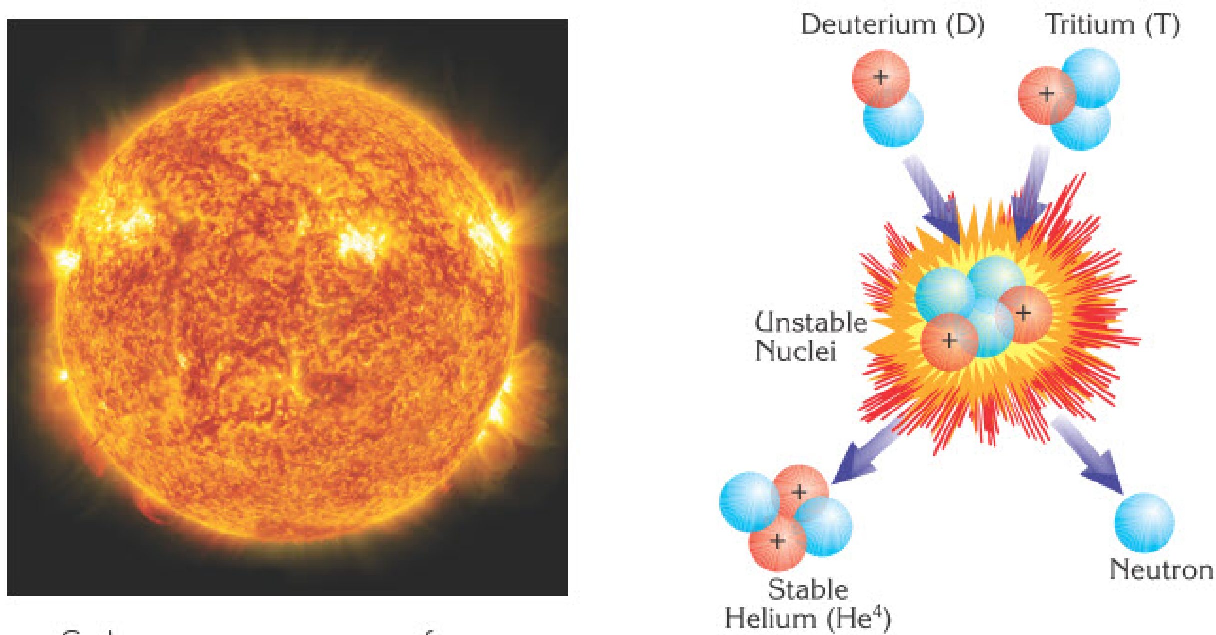


The combination of several lighter nuclei to form a heavier nucleus is called nuclear fusion.

Nuclear fusion occurs in the stars. Hydrogen nuclei are converted into helium nuclei in the stars. That is why stars become hot and emit light, Figure 1a .

The amount of energy released in fusion reactions is greater than the energy released during fission reactions. However, a huge amount of activation energy is required to start nuclear fusion reactions. The simplest nuclear fusion reaction is the combination of the isotopes of hydrogen (deuterium and tritium). Result of this fusion reaction is heavier nucleus of helium, Figure 1b .

$$^{2}_{1}H + {}^{3}_{1}H \rightarrow {}^{4}_{2}He + {}^{1}_{0}n + \text{Energy}$$



Solar energy comes from nuclear fusion reactions.

a

A Fusion Reaction

b

Figure 1

Deuterium and tritium must get very close to start a nuclear fusion reaction. Atomic nuclei repel each other due to their positive charge. So nuclei must have very high energies to overcome the electrostatic repulsive forces. This is only possible at temperatures above 10-15 millions degrees of Celsius. Above this temperature atoms are separated into their components (nuclei and electrons). Hence, substances are in the form of positively charged nuclei floating around in electron clouds. This state is called plasma. In this state the combination of nuclei is possible.

The advantage of fusion, compared to fission, is in the abundance of hydrogen. Fission uses uranium, which is rare and expensive. Fusion uses hydrogen, which is abundant and cheap.

Example

Complete the following fusion reaction:

$$^{2}_{1}H \quad + \quad ^{2}_{1}H \rightarrow \quad ^{A}_{Z}Y \quad + \quad \text{Energy}$$

Solution:

On the left side sum of mass number gives 2 + 2 = 4. It means that right side is also equal to A = 4. The same for left side atomic number 1+1 = 2. Right side is Z = 2. So it is

$^{4}_{2}He$ helium nucleus.

Activity

Research this website www.iter.org. What will happen in future if this project becomes successful?

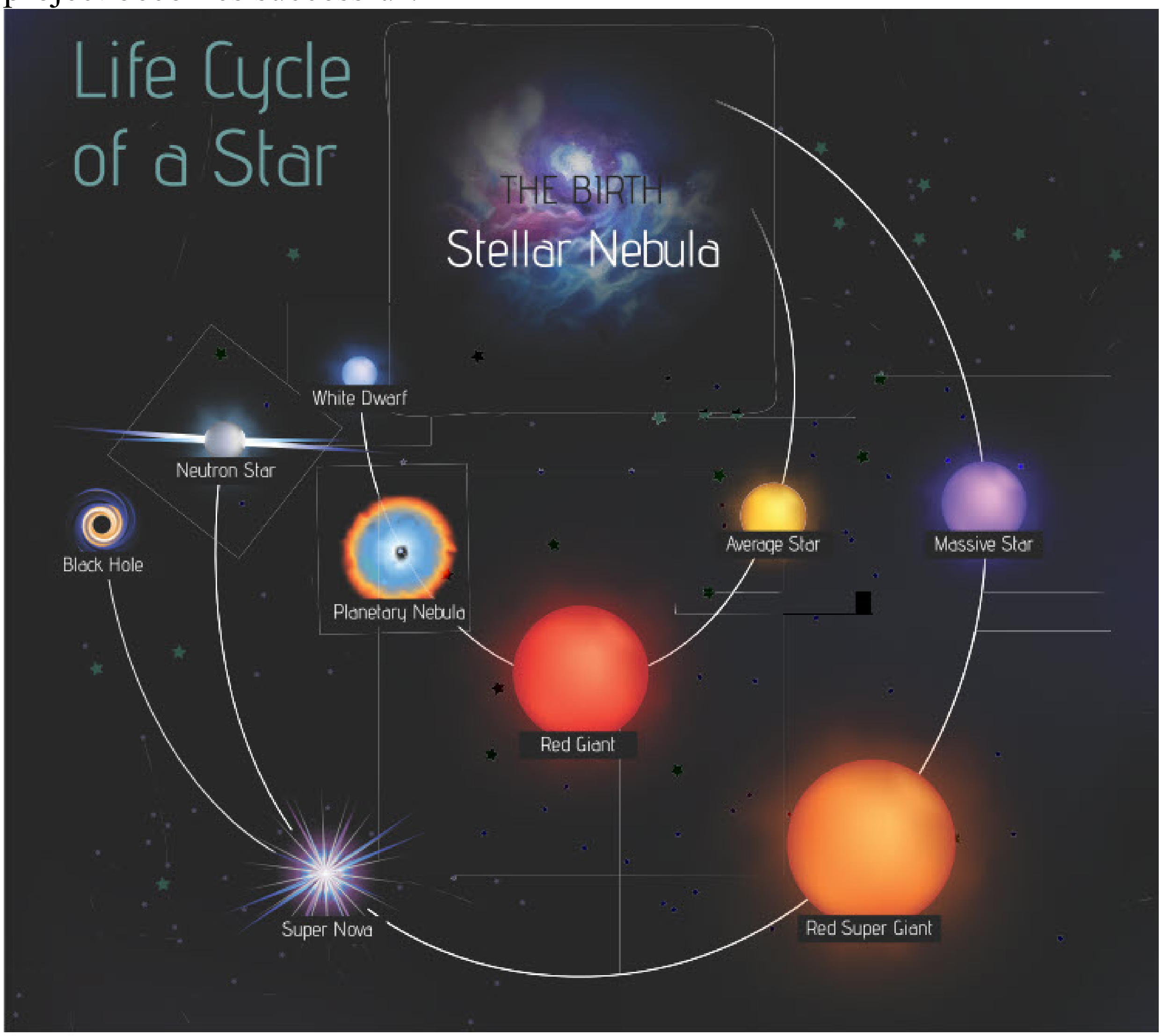


Figure 2

Literacy

1. Where do iron, gold, silver, copper and other metals come from, Figure 2?
2. Why does Sun emit light? Where does it take energy from?
3. Why do we build “thermonuclear bombs (hydrogen bombs)”?
4. Why don’t we use nuclear fusion to produce electricity?
5. Why don’t we use nuclear fusion to launch space rockets?

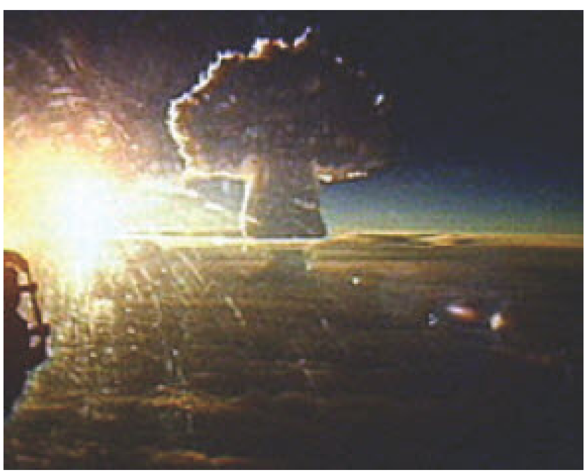
Art time

Use plasticine to show nuclear fusion reactions that take place inside of the Sun.

Research time

Why does nuclear fusion occur in the centre of the star? Why this type of reaction does not occur on Earth?

Fact



Tsar Bomba or "King of bombs" was the Western nickname for the Soviet RDS-220 hydrogen bomb (thermonuclear bomb). Its test on 30 October 1961 remains the most powerful man-made explosion in history.

Terminology

nuclear fusion - термоядролық синтез / термоядерный синтез
solar - күнмен байланысты / солнечный
repulsive - итеруші / отталкивающий
abundance - молшылық / избыток
to occur - пайда болу / происходить

7.6 NUCLEAR REACTOR

You will

describe working principles of nuclear reactor;

Question

Why do we use two nuclear reactors in Kurchatov (East Kazakhstan)?

Nuclear reactor is a device that starts and sustains nuclear chain reaction. Nuclear reactors are used for electricity production, ship propulsion and scientific research.

There three main parts of a nuclear reactor:

Fuel: Usually pellets of uranium oxide (UO_2) arranged in tubes to form fuel rods.

Moderator: This is material which slows down the neutrons released from fission. Slow neutrons cause more fission. Moderator is usually water, but may be heavy water or graphite.

Control rods: These are made with neutron-absorbing material such as cadmium, hafnium or boron. Control rods are used to control the rate of reaction, or to halt it, Figure 1.

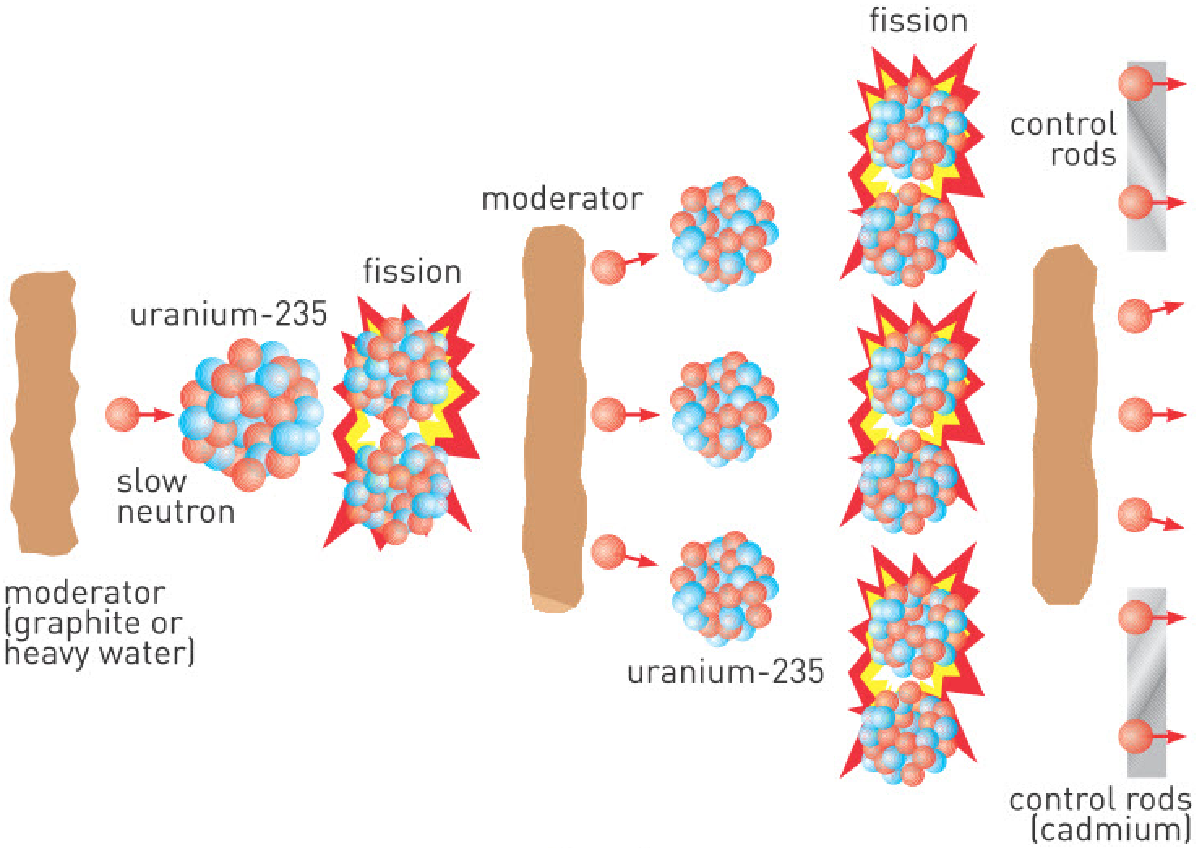


Figure 1

Heat from nuclear chain reaction is used to boil water and make high pressure steam. This steam passes through steam turbine and rotates it. Steam turbine turns electrical generator and as result electricity is produced, Figure 2.

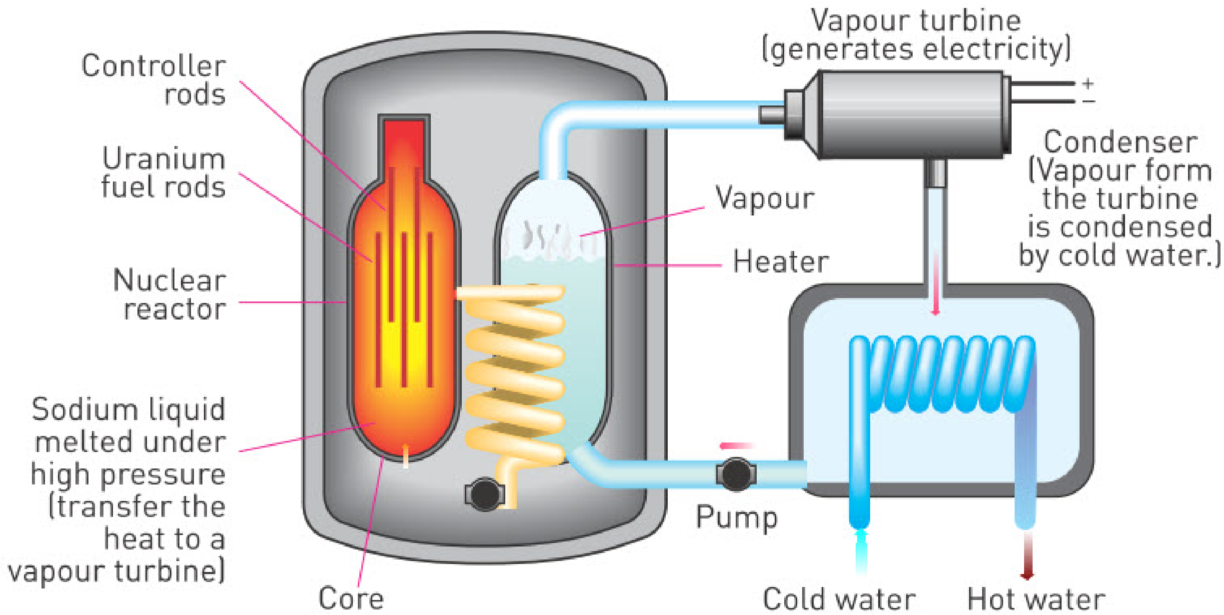


Figure 2

Example

In 1986 there was a nuclear disaster in Chernobyl. It is considered as the worst nuclear accident in the world. One of the reasons of the accident is that the nuclear reactions went out of control. What controls the rate of reaction in nuclear reactor?

Solution:

The rate of nuclear reaction are controlled by control rods, which can absorb neutrons.

Activity

What are advantages and disadvantages of using nuclear energy? Make a discussion.

Literacy

1. Why do we build nuclear reactors?
2. Why did Chernobyl and Fukushima nuclear disasters happen?
3. Why do we use “steam turbines” in nuclear reactors?
4. How do we produce steam in nuclear reactors?
5. Why do we use “heavy water” in nuclear reactors?
6. Why don’t we see “natural” nuclear reactors?

Fact

Many firefighters and soldiers from Kazakhstan took part in fire extinguishing and clean up after accident at the Chernobyl nuclear power plant in 1986.

Research time

Why do nuclear disasters happen? What should we do to avoid them?

Fukushima nuclear disaster

Fact

National Nuclear Center is in Kurchatov (East Kazakhstan). There are two nuclear reactors and one tokamak.

Terminology

nuclear reactor - ядролық реактор / ядерный реактор
ship propulsion - кеме қозғалысы / корабельное движение
pellet - түйіршік / гранула
fuel rod - жылу бөлгіш элемент / тепловыделяющий элемент (твэл)
heavy water - ауыр су / тяжелая вода
control rod - апаттық таяқша / регулирующий стержень
steam turbine - бу турбинасы / паровая турбина

Art time

Make paper model (or origami) of nuclear reactor.

7.7 ELEMENTARY PARTICLES

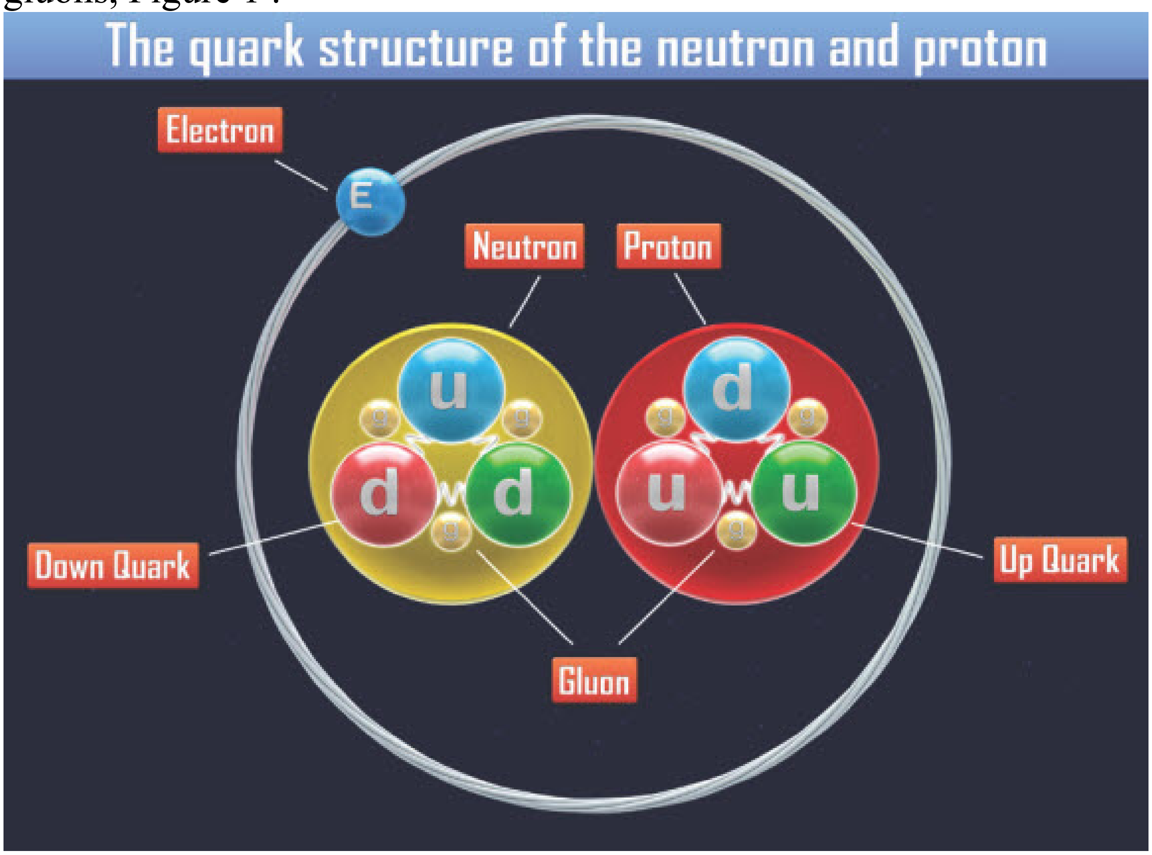
You will

classify elementary particles;

Question

Are nucleons (proton and neutron) the smallest particles?

Atom is composed of protons, neutrons and electrons. Protons and neutrons are composed of quarks. Quarks are "glued" to each other by gluons, Figure 1 .



We can classify elementary particles by structure as hadrons and leptons, and by spin number as fermions and bosons, Figure 2.

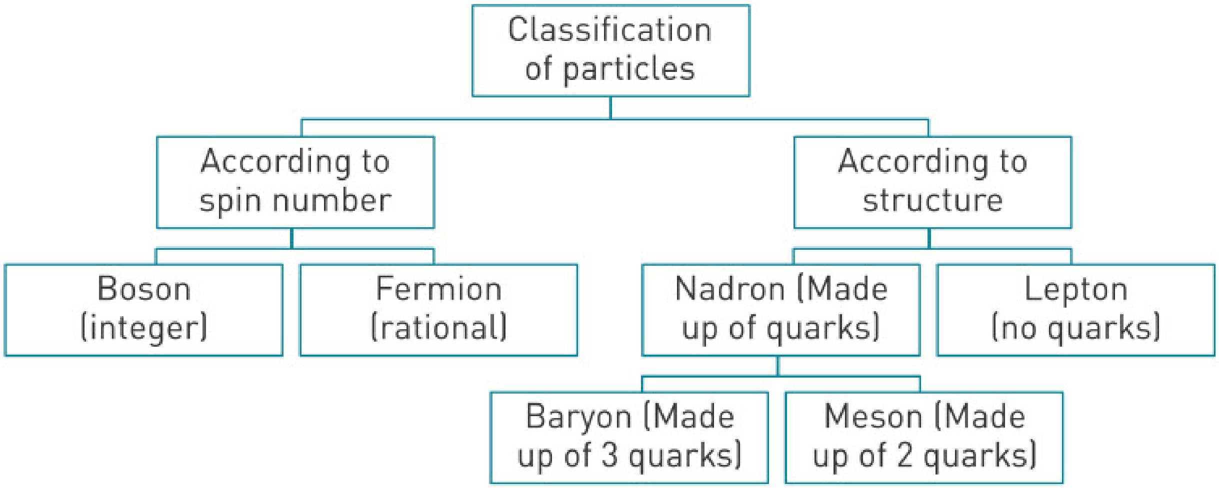


Figure 2

Proton and neutron are composed of quarks. That is why proton and neutron are called hadrons. Other hadrons are baryons, mesons, pions, kaons, etc.

There are six types of quarks and six types of anti-quarks. Their symbols and charges are given in Table 1.

Name	Symbol	Charge (e)
Up	u	+2/3
Down	d	–1/3
Strange	s	–1/3
Charmed	c	+2/3
Top	t	+2/3
Bottom	b	–1/3

Table 1. The six types of quarks

Electron is not composed of quarks. That's why electron is called lepton. Other leptons are muons, tauons, neutrinos, etc, Table 2.

Name	Symbol	Charge (e)
Electron	e	–1
Muon	μ	–1
Tau	τ	–
Electron neutrino	v_e	0
Muon neutrino	v_m	0
Tau neutrino	v_t	0

Table 2. Types of leptons

Protons and neutrons are baryons. Let's look at their structure.

Proton (uud):

(+2/3)+(+2/3)+(–1/3)=+1 Charge of proton

Neutron (udd):

(+2/3)+(–1/3)+(–1/3)=0 Charge of neutron

The most familiar lepton is the electron. It is the only lepton that naturally exists in the atom and is nearly two thousand times smaller than the proton.

Another type of lepton is neutrino. Mass of neutrino is very small. Neutrinos travel at nearly the speed of light. They are produced in nuclear reactions. All objects are transparent to neutrinos. Billions of neutrinos are produced by the Sun. These neutrinos pass directly through the human body and the Earth each second. Then, they continue travelling in space at the speed of light.

Particles that have non-integer spin are called fermions. Quarks (protons, neutrons) and leptons (electrons) are fermions. That means fermions are matter. Fermions cannot occupy same space at same time. That is why two billiard balls can hit each other.

Particles that have integer spin are called bosons. Gluons and photons are bosons. Bosons are forces that connect matter. Bosons can occupy same space at same time. That is why two laser rays (photons) cannot hit each other like billiard balls.

Particles and antiparticles have same mass but opposite charges. For example positron (anti-electron) has same mass as electron. However, electron has negative charge and positron has positive charge.

Research time

Read book “QED: The Strange Theory of Light and Matter” by Richard Feynman. QED is quantum electrodynamics. QED describes how light and matter interact.

Example

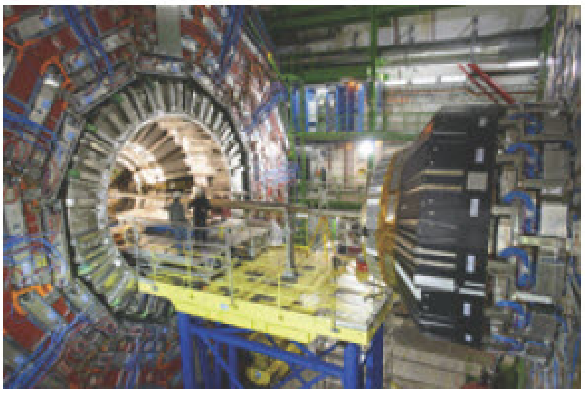
Which particle is both a fermion and a lepton?
Solution:
The most familiar example of a fermion and a lepton is an electron.

Literacy

1. Why do quarks have “colour charges”?
2. Why do quarks have “flavours”?
3. Why do quarks have “spin”?
4. Why don’t we see “antiprotons, antineutrons, antiquarks” on the Earth or in space?
5. What does happen if there are no “gluons”?
6. Why did scientists build “Large Hadron Collider”?

Fact

In Geneva, Switzerland there is a detector that is used to find out new elementary particles. It is called Large Hadron Collider (LHC). Particles inside it are accelerated to more than 99.9999 percent of the speed of light.



Terminology

elementary particle - элементар (бөлінбейтін) бөлшек / элементарная (неделимая) частица
antimatter - антизат / антивещество

Art time

Use plasticine to make “quark models” of proton, neutron, electron, antiproton, antineutron, positron, photon, gluon and Higgs boson.

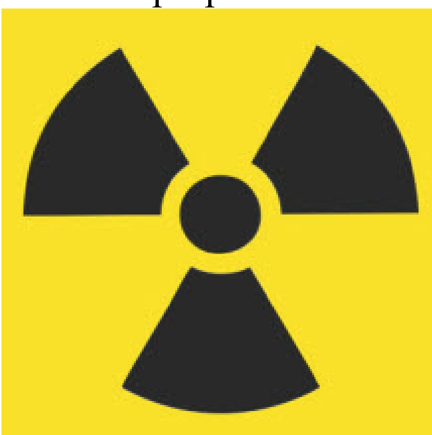
7.8 RADIATION PROTECTION

You will

tell and classify methods of protection from radiation;

Question

For what purpose do we use this symbol? Why is it important?



Radioisotope is unstable atom that undergoes radioactive decay. We can use radioisotopes in such areas as medical treatment, electricity production, scientific research, transportation, etc.

Radioisotopes can be very dangerous if they are used incorrectly. Radiation from radioisotopes does not produce sensation of heat or pressure. That means we cannot feel, see, hear or smell radiation. Radiation damages living cells by ionising molecules of cells. It affects bone marrow, spleen, blood and reproductive cells more quickly. Why? Because these tissues grow faster than others. Damage from radiation can be transferred to new cells. This can result in tumours and cancer. Radiation can damage chromosomes. As a result mutation of cell happens. If mutation occurs in reproductive cells, the illnesses are transferred to children.

On the Figure 1 you can see five types of radiation and materials that can stop radiation.

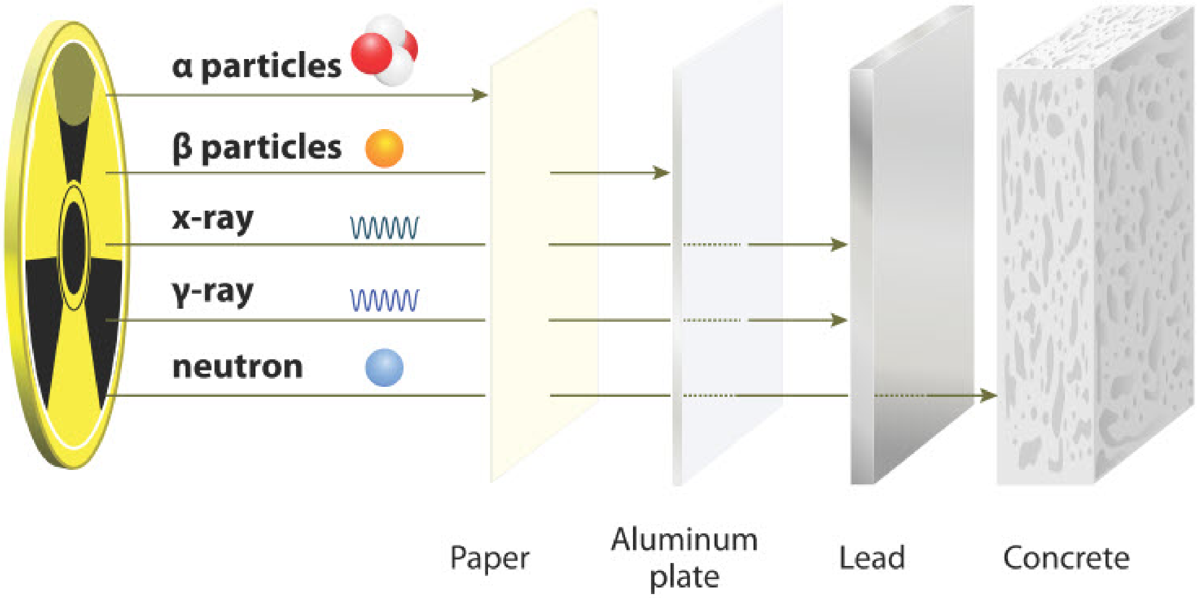


Figure 1. Types of radiation and penetration power

Medical personnel and patients that use X-rays often wear “lead aprons”. On the Figure 2 you can see nurse wearing red lead apron.

Figure 2

Military personnel wear “nuclear suits” called Nuclear Biological Chemical suits (NBC suits) to protect themselves from radiation. On the Figure 3 you can see example of NBC suit.

Figure 3

Example

In a place with high radiation which one of the following is the best place to hide?
a) Near tree
b) In a car
c) In a building

Answer:
c) in a building , because thick concrete walls of a building can protect better from radiation than other answers.

Activity

Nuclear plants use radioactive fuel. Storage of used nuclear fuel is big problem. How can you store it? How can you reprocess used nuclear fuel?

Literacy

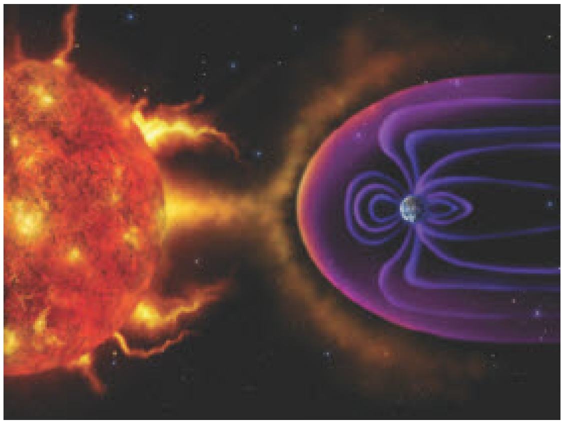
1. Why you cannot feel taste, sound, colour, smell, pressure or heat of radiation?
2. What type of devices can detect radiation?
3. Why do nuclear power plants have thick concrete walls?
4. Why do we wear “lead apron” during X-ray scan?
5. How many people did receive damage from “Semipalatinsk Test Site”? What types of damage did they receive?

Fact

There were 456 nuclear explosions on Semipalatinsk Test Site (Polygon). Radiation of these explosions damaged health of about 200000 local residents.

Research time

Sun regularly emits very harmful "cosmic rays" that travel to Earth. Why “cosmic rays” do not kill all living organisms on the Earth?



Fact

Tsutomu Yamaguchi is the only person to have been officially recognized by the government of Japan as surviving both explosions of Hiroshima and Nagasaki.

Terminology

bone marrow - сүйек кемігі / костный мозг
spleen - көкбауыр / селезенка
tumour - ісік / опухоль

lead apron - қорғасын алжапқыш / свинцовый фартук
nuclear suit - жалпы әскери қорғаныс киімі / общевойсковой защитный комплект
cosmic rays - ғарыш сәулелері / космические лучи

Art time

Write poem or short story about “Hibakusha”.

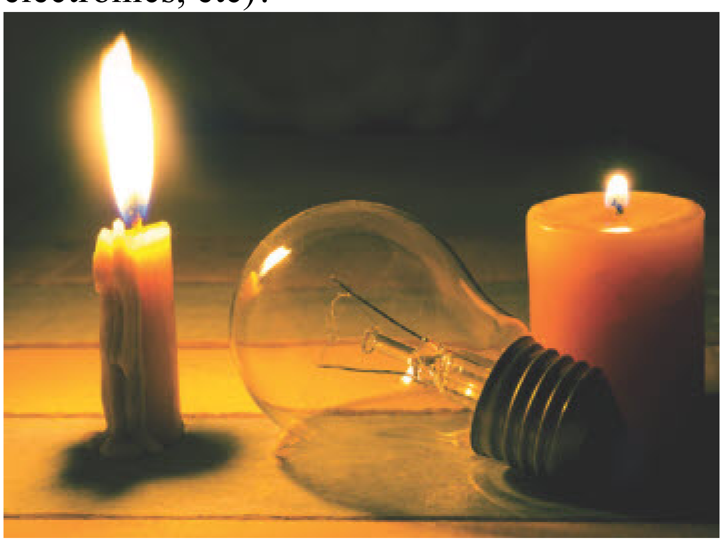
7.9 PHYSICS AS PART OF CULTURE. ECOLOGY OF WORLD

You will

- explain influence of physics and astronomy on worldview of mankind;
- estimate benefits and calculate risks of effect of new technologies on environment;

Question

Can you imagine your life without electricity (without TV, Internet, electronics, etc)?



Science and knowledge always had and will have big influence on lives of people. In history of mankind there were three big epochs:
1. Agricultural Age
2. Industrial Age
3. Information Age

During Agricultural Age people were working in fields. People were growing crops and domestic animals. Most people were living in villages. People were not travelling much. The most important science was science of irrigation.

During Industrial Age people were working in factories. Most people were living in cities. People started to travel more, new continents were discovered. The most important sciences were physics (transportation, manufacturing, communication, energy production, etc), chemistry (new materials), biology (medicine), Figure 1.

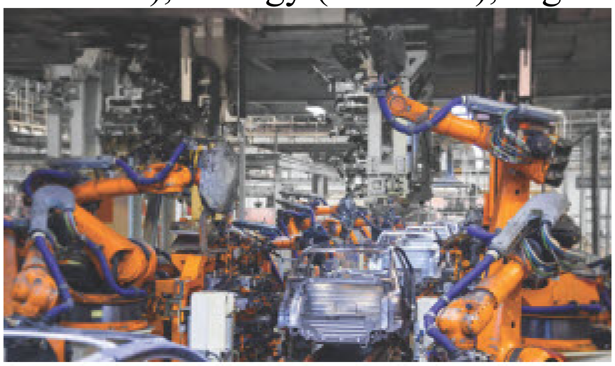


Figure 1

Now we live in Information Age, Figure 2. During Information Age people are working in Internet. Nowadays the place where people are living is not important. Why? Because everybody and everything are connected by Internet. Trade, work, relationships - almost everything is done by Internet now. People are travelling frequently. The most important sciences now are Computer Science, Artificial Intelligence, Nanotechnology, Virtual Reality (Figure 3), Robotics (Figure 4), Biotechnology, etc.

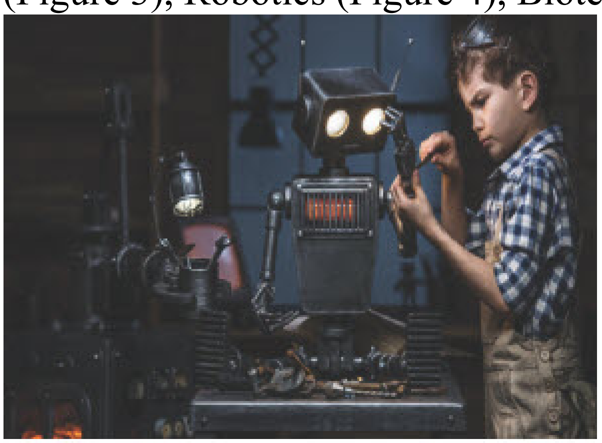


Figure 2

Figure 3

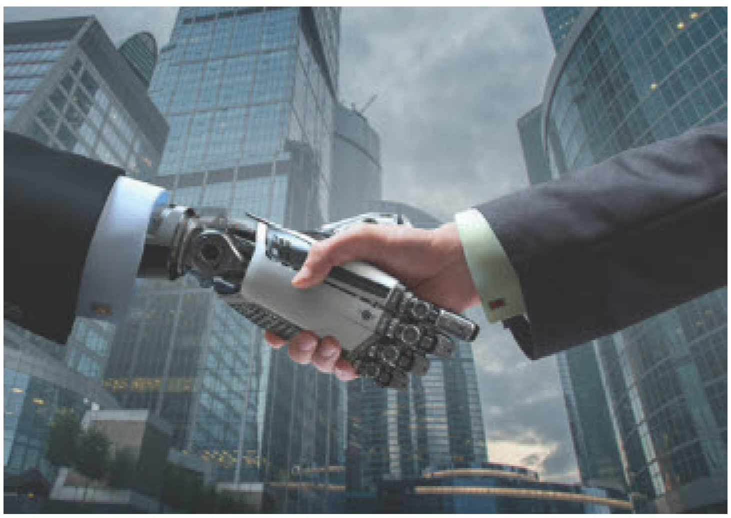


Figure 4

After Information Age, there will be Imagination Age. During Imagination Age all sciences will be important. Why? Because sciences will merge and new branches of science will emerge. During Imagination Age the imagination, creativity and innovation will be the most valuable traits among people.

Physics was very important during Industrial Age. Transportation (planes, cars, trains, etc), energy production (fossil fuel power plants, nuclear power plants, hydropower, solar power, wind turbines, etc), communication (telephone, TV, radio, Internet, etc) are results of advancements in physics. Physics had a great impact on philosophy and psychology. We can list seven most important key advancements in physics that changed the way people think about the world and about themselves:

1. Copernican heliocentrism
2. Newtonian mechanics

3. Relativity of Einstein
4. Hiroshima and Nagasaki atomic bombs
5. Launch of “Sputnik”
6. Spaceflight of Yuri Gagarin
7. Neil Armstrong’s landing on Moon.

These seven advancements showed that nature has very delicate equilibrium. However, this equilibrium of nature can be destroyed. Examples are nuclear disasters, global warming, air-water-soil pollution, etc. In order to make sustainable development we must not disturb ecological balance. Otherwise, natural or social calamities can bring end to human civilisation.

Example

When did the key events below occur?
1. Copernican heliocentrism
2. Newtonian mechanics
3. Einstein’s theory of relativity
4. Hiroshima and Nagasaki atomic bombs
5. Launch of “Sputnik”
6. Spaceflight of Yuri Gagarin
7. Neil Armstrong’s landing on Moon

Answer
1. XVI century
2. XVII century
3. XX century
4. XX century
5. XX century
6. XX century
7. XX century

Activity

Make list of the most profitable jobs for each epoch: Agricultural Age, Industrial Age, Information Age, Imagination Age.

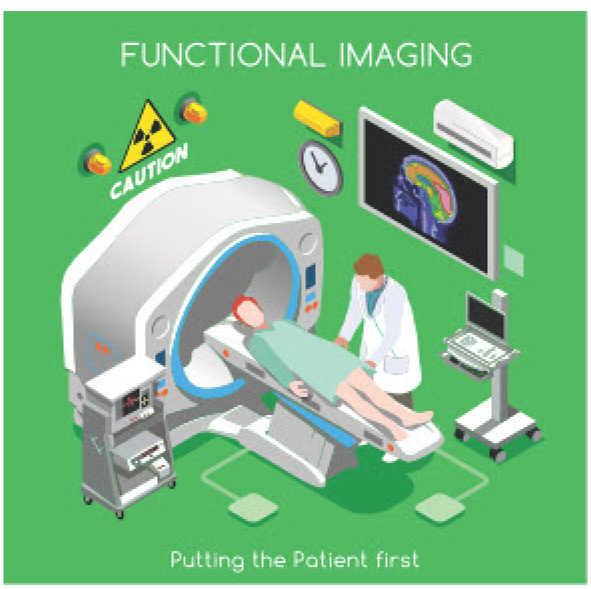
Literacy

1. Why does “global warming” happen?
2. What does happen if average temperature of Earth increases by several degrees?
3. Why do we use so much energy (electric energy, fossil fuel energy, nuclear energy, etc)?
4. What will we do after fossil fuel reserves are finished?
5. Why do we pollute water, air, soil?

Research time

Research how seven key advancements in physics changed philosophy and psychology of people.
1. Copernican heliocentrism
2. Newtonian mechanics
3. Relativity of Einstein
4. Hiroshima and Nagasaki atomic bombs
5. Launch of “Sputnik”
6. Spaceflight of Yuri Gagarin
7. Neil Armstrong’s landing on Moon

Fact



Discovery of radioactivity had very big influence on development of medicine in XXth century.

Terminology

crop - дән / агрокультура
irrigation - суару / орошение почвы
artificial intelligence - жасанды интеллект / искусственный интеллект
virtual reality - виртуалды шындық / виртуальная реальность
to merge - бірігу / соединяться
to emerge - пайда болу / возникать

Art time

Make theatre play that shows and explains dialogue between Human and Nature.

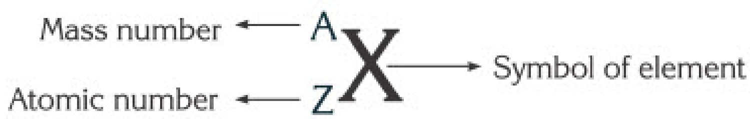
SUMMARY

7.1. Nucleus of an atom is composed of protons (p) and neutrons (n). They are called nucleons.

1 atomic mass unit (u)= 1.6606×10^{-27} kg

The number of protons in an atom is called the atomic number, Z.

The total number of protons and neutrons in the atom is the atomic mass number, A.



A=Z+N

The nuclear force is much stronger than the electrostatic and gravitational forces.

7.2. Mass converted into energy is called the mass defect.

Mass defect between nucleons and nucleus of any atom can be calculated by

$$\Delta m = (Z\times m_p + N \times m_n) - A$$

The energy of this 'lost mass' is the same energy preventing the nucleus from breaking up.It is called nuclear binding energy and represented by E_b

$$E_b = \Delta m \times c^2$$

$$\text{Average binding energy per nucleon} = \frac{\text{total binding energy}}{\text{nucleon number (mass number)}} = \frac{E_b}{A} \quad \frac{\text{MeV}}{\text{nucleon}}$$

If average binding energy per nucleon is high, then stability of nucleus is also high.

7.3. In a large nucleus the electrostatic force acting on a proton could be more than strong nuclear force.So nuclei become unstable. Such elements are called radioactive elements.

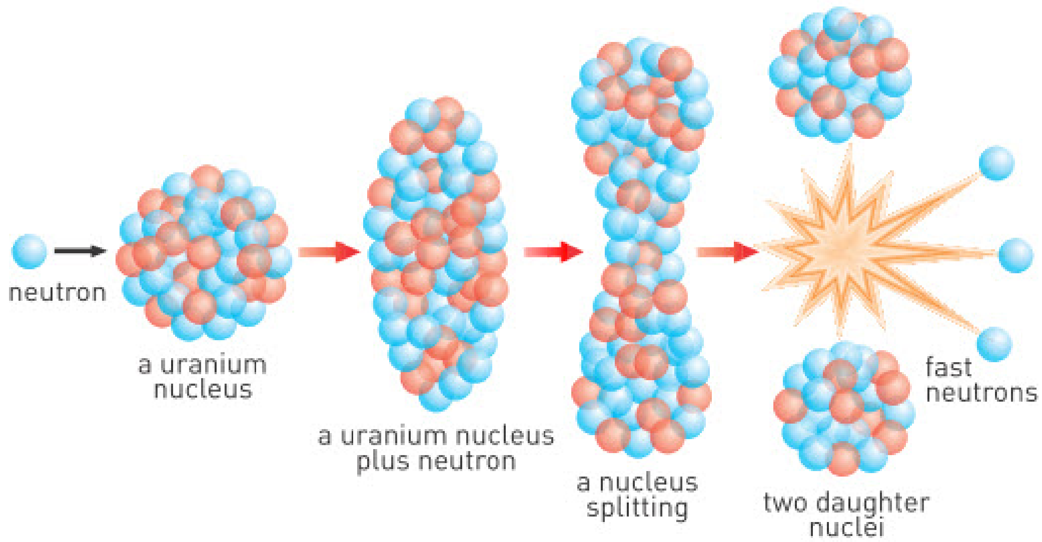
During nuclear decay processes

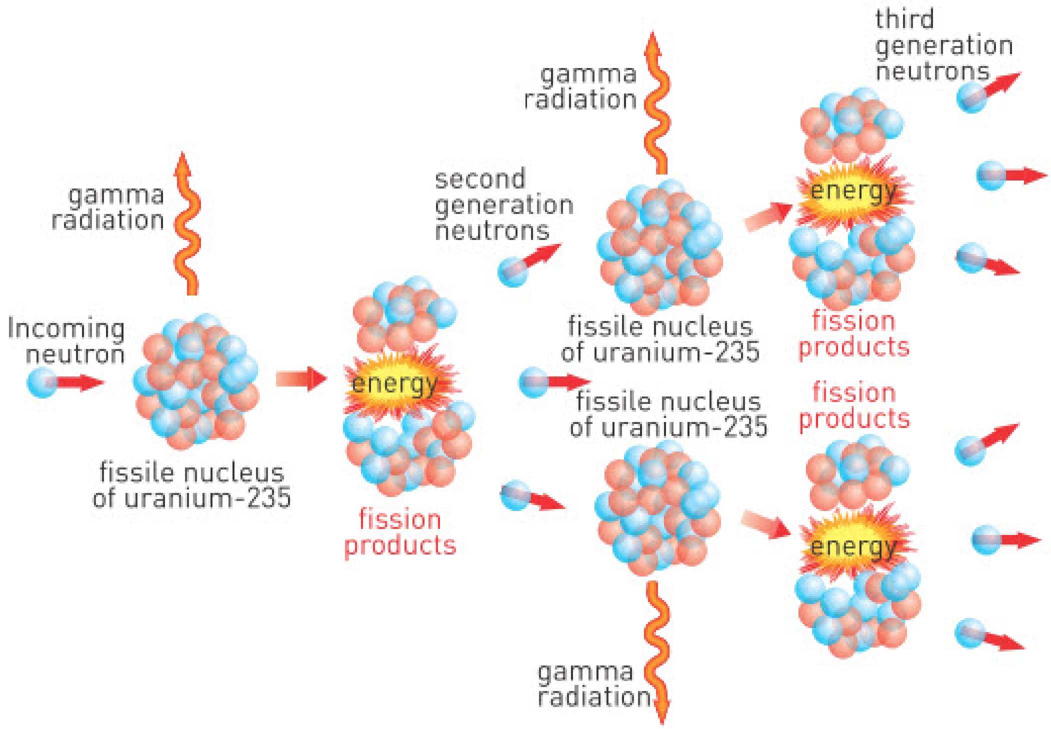
1. The number of nucleons is conserved
2. Charge is conserved
3. Energy is conserved

The most common types of radiation are α-alpha, β-beta and γ-gamma radiations.
Half-life is the period of time over which the number of radioactive nuclei decreases by half.

If $\frac{N}{N_0} = \frac{1}{2}$ $(T_{1/2}$: half-life$)$

7.4. Nuclear reactions take place inside the nucleus of an atom. There are two types of nuclear reaction:
1) Fission (division, splitting)
2) Fusion (combining)
The disintegration of a heavier nucleus into a lighter nucleus via neutron bombardment is called nuclear fission (nuclear division).

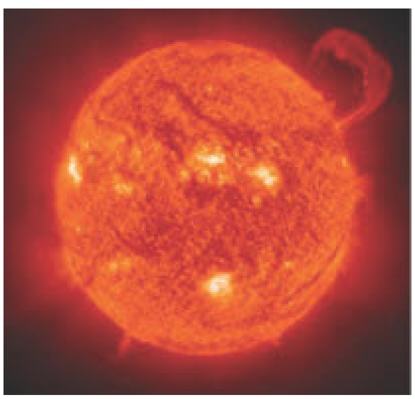




Nuclear Chain Reaction

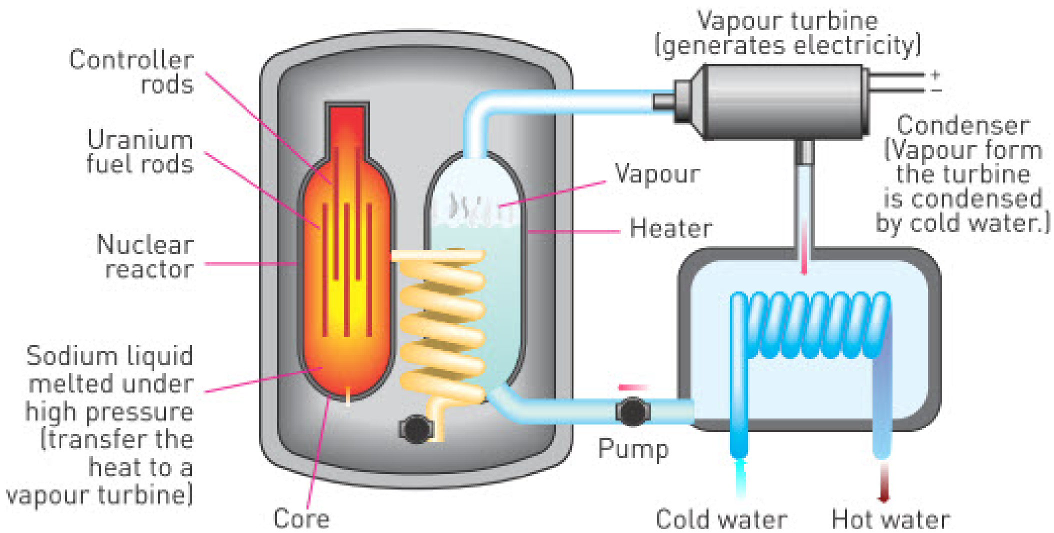
7.5. The combination of several lighter nuclei to form a heavier nucleus is called nuclear fusion. The amount of energy released in fusion reactions is greater than energy released during fission reactions.

However, a huge amount of activation energy is required to initiate nuclear fusion reactions.



Solar energy comes from nuclear fusion reactions.

7.6. Nuclear reactor is a device that starts and sustains nuclear chain reaction. Nuclear reactors are used for electricity production, ship propulsion and research.



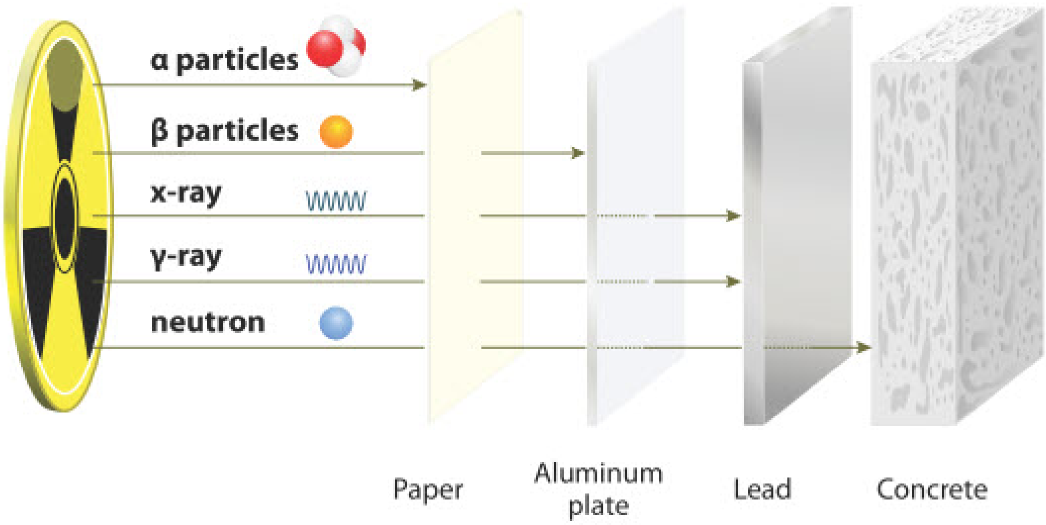
7.7. Atom is composed of protons, neutrons and electrons. Protons and neutrons are composed of quarks. Quarks are "glued" to each other by gluons.

Particles and anti-particles have same mass but opposite charges.

We can classify elementary particles by structure as hadrons and leptons.

There is another parameter that is called spin number. Particles that have non-integer spin are called fermions. Quarks (protons, neutrons) and leptons (electrons) are fermions. That means fermions are matter. Fermions cannot occupy same space at same time.

7.8. Types of radiation and penetration power.



7.9. In history of mankind there were three big epochs:

1. Agricultural Age
2. Industrial Age
3. Information Age

After Information Age, there will be Imagination Age. During Imagination Age all sciences will be important. Why? Because sciences will merge and new branches of science will emerge. During Imagination Age the imagination, creativity and innovation will be the most valuable traits among people.

PROBLEMS

Nucleus and Nuclear Force

1. There are 92 electrons and 143 neutrons in the neutral ^{235}U uranium atom

a) How many protons are there?

b) How many nucleons are there?

2. What are the components of the nuclei of the elements given below?

^{13}C, ^{31}P, ^{57}Fe, ^{107}Ag, ^{208}Pb

Mass Defect and Nuclear Binding Energy

3. What is the binding energy of the hydrogen

$^{1}_{1}H$ atom?

4. What is the minimum energy needed to divide a ^{138}Ba barium nucleus into its component protons and neutrons? What is the mass equivalent of this energy?

5. What is the average binding energy per nucleon of the

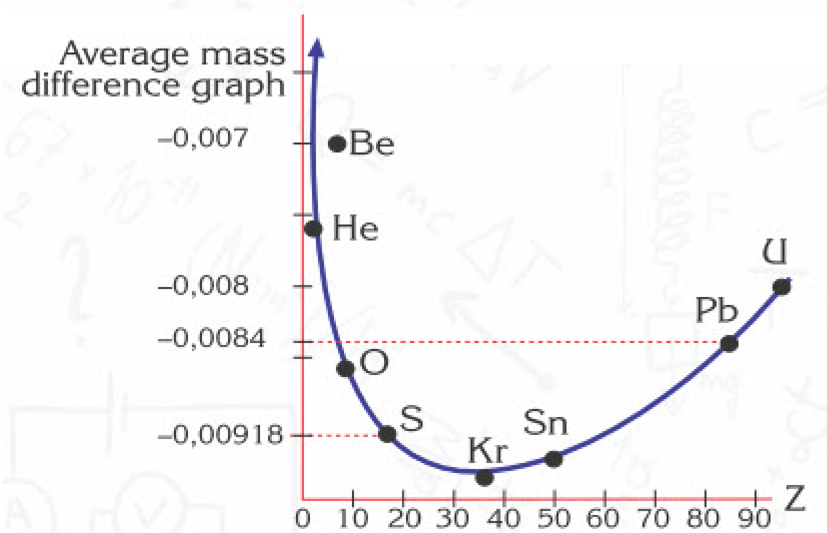
$^{209}_{83}Be$

atom in MeV?

6. Using the graph calculate the mass loss of

$^{208}_{82}Pb$

(Lead) when it is decomposed to free protons and neutrons



7. By leaving out one proton of the

$^{28}_{14}Si$

nucleus, what is the minimum energy,
in MeV, needed to turn it into a

$^{27}_{13}Al$

nucleus?

8. Is energy given out (exothermic) or absorbed (endothermic) during the following nuclear reactions:

a) $^{14}_{7}N + ^{4}_{2}He \longrightarrow ^{17}_{8}O + ^{1}_{1}H$

b) $^{6}_{3}Li + ^{1}_{1}H \longrightarrow ^{4}_{2}O + ^{3}_{2}He$

9. What energy is given out in the nuclear reaction:

$^{6}_{3}Li + ^{1}_{1}H \longrightarrow ^{4}_{2}O + ^{3}_{2}He$

Radioactive Decay

10. What is the name of the process in which the nuclei of unstable atoms become more stable by emitting particles and/or electromagnetic radiation?

12. In which type of decay does an element turn into another element with an atomic number two less than its parent and a mass number four less than its parent?

13. Where does an a–particle have a greater mean free path: Near to the surface of Earth or in the top layers of the atmosphere?

14. What is the name of an electron released by a radioactive nucleus that causes a neutron to change into a proton?
15. As a result of which radioactive decay
does sodium
$^{22}_{11}Na$
turn into magnesium
$^{22}_{12}Mg$?
16. What is the name of the type of high energy electromagnetic radiation released by a radioactive nucleus?
17. Why do we use thick-walled lead containers to store radioactive materials?
18. The frequency of electromagnetic waves broadcast from a radio station is 2×10^6 Hz, and the frequency of Gamma radiation emitted from a radioactive material is 2×10^{20} Hz. Compare the
energies of the photons of the radio waves and the Gamma- radiation?
19. Which isotope is formed from uranium
$^{239}_{92}U$
after two b- decays and one a-decay?
20. As a result of which radioactive decay does plutonium
$^{239}_{94}Pu$
turn into uranium
$^{235}_{92}U$?
21. Which type of radiation can be stopped with a piece of paper.
22. Which type of radiation can travel at the speed of light?
23. What are the instruments used to detect radiation?
24. What is the advantage of using a scintillation counter over a Geiger counter?
26. What is half-life?

Half Life

27. A small quantity of the element radium is sealed in a tube. When the tube is opened later, it is observed that an amount of gas has been produced inside it. What can this gas be?

28. The iron (^{56}Fe) nucleus is more stable than the chloride (^{35}Cl) nucleus. What can be said about their halflives?
29. Is it possible to alter the half-life of a given isotope by heat, pressure, or some other physical means?
30. The half-life of Zn-71 is 2.4 minutes. If one has 100.0 g at the beginning, how many grams would be left after 7.2 minutes had elapsed?
31. Pd-100 has a half-life of 3.6 days. If one had 6.02×10^{23} atoms at the start, how many atoms would be present after 20.0 days?
32. Os-182 has a half-life of 21.5 hours. How many grams of a 10.0 gram sample would have decayed after exactly three half-lives?
33. How long will it take a 40.0 gram sample of I-131 (halflife=8.040 days) to decay to 1/100 of its original mass?
34. 100.0 grams of an isotope with a half-life of 36.0 hours is present at time zero. How much time will elapse before 5.0 grams remains?
35. Rn-222 has a half-life of 3.82 days. How long before only 1/16 of the original sample remains?
36. The activity of a radioactive element has decreased 4 times in 8 days. Find its half-life?

The Discovery of Protons and Neutrons

37. Who produced the first artificial isotope, when and how?
38. What was the dream of alchemists?
39. Arrange in order the main particles inside the atom according to their dates of discovery?
40. Why did Rutherford think that there had to be neutral, massive particles in the nucleus besides protons?
41. Why was the discovery of the neutron more difficult than that of the proton?

Nuclear Chain Reaction and Nuclear Fusion

42. What is a nuclear fission reaction?
43. Why is a huge amount of energy released in a fission reaction?
44. What is the harmful effect of fission reactions on the human body?
45. What is the main application of nuclear chain reactions?
46. What is the difference between nuclear fission and nuclear fusion reactions?
47. Why are nuclear fusion reactions more difficult to achieve?
48. What are the main components of a nuclear reactor?

49. What is the name for the change of an atom into another atom during radioactive decay?
50. What is the most stable element?
51. Write a nuclear reaction describing the bombardment of an aluminum

$^{27}_{13}Al$

nucleus by an a – particle, which results in the separation of a proton from the nucleus.
52. Find the missing particle in the following nuclear reactions:

$$^{27}_{13}Al + ^{1}_{0}n \longrightarrow ? + ^{4}_{2}\alpha$$

$$^{27}_{13}Al + \gamma \longrightarrow ^{26}_{12}Mg + ?$$

$$^{55}_{25}Mn + ? \longrightarrow ^{55}_{26}Fe + ^{1}_{0}n$$

53. If nucleus

$^{7}_{3}Li$

captures a proton, it breaks up into two a- particles. Find the total kinetic energy of these particles. (Initial kinetic energy of the proton is neglected.)
54. What is the minimum energy needed by an a – particle in order to realise the following nuclear reaction:

$$^{7}_{3}Li + ^{4}_{2}\alpha \longrightarrow ^{10}_{5}B + ^{1}_{0}n$$

55. The ^{235}U uranium undergoes a fission reaction by losing 0.1% of its mass.
a) If 1 kg of U-235 undergoes a fission reaction, how much energy is released?
b) A ton of TNT explosive releases approximately 4 GJ of energy when it explodes. A bomb made with 1 kg of U-235 explodes. How many tons of TNT would be required to release the same amount of energy? (1 GJ=10^9 J)

Radiation Protection

56. Where do we use radiation in medicine?
57. What are the harmful effects of radiation on living tissue?

Elementary Particles

58. What methods are used to classify the elementary particles?

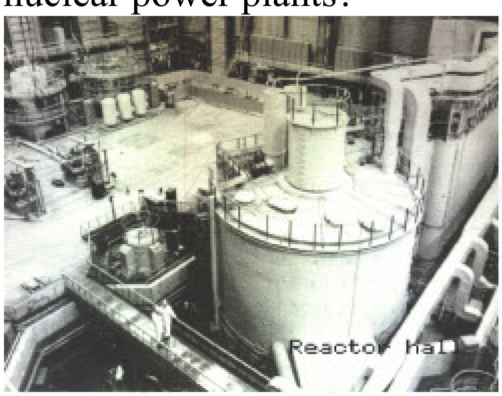
59. What are the differences between bosons and fermions?
60. According to the classification of sub-atomic particles by structure, which classes of particles are there?
61. Write down some examples of hadrons and leptons.
62. Which particle is both a fermion and a lepton?
63. What is an anti-particle?

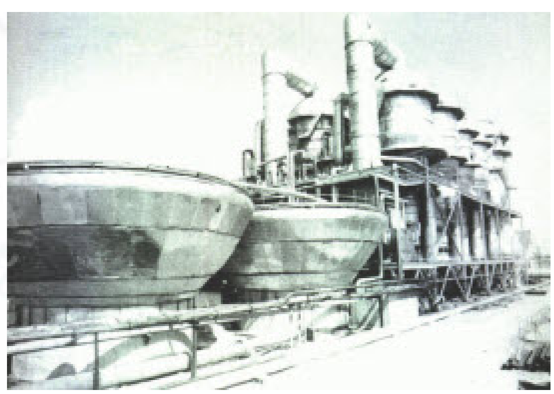
PHYSICS IN LIFE

1. Americium-241 is used in smoke detectors. Why?

2. Sometimes food products receive small dose of radiation. Why?

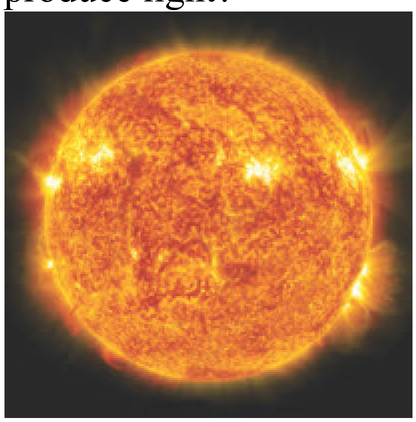
3. Aktau Nuclear Power Plant worked from 1973 to 1999. Why do we build nuclear power plants?



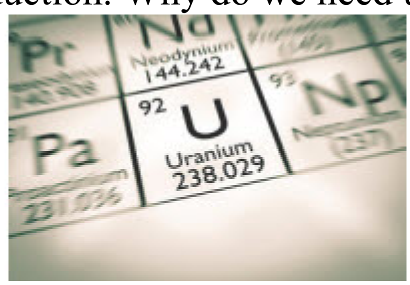


4. Radiation is dangerous, but sometimes doctors apply small dose of radiation to people. Why?

5. Sun produces light that heats and illuminates Earth. Why does the Sun produce light?

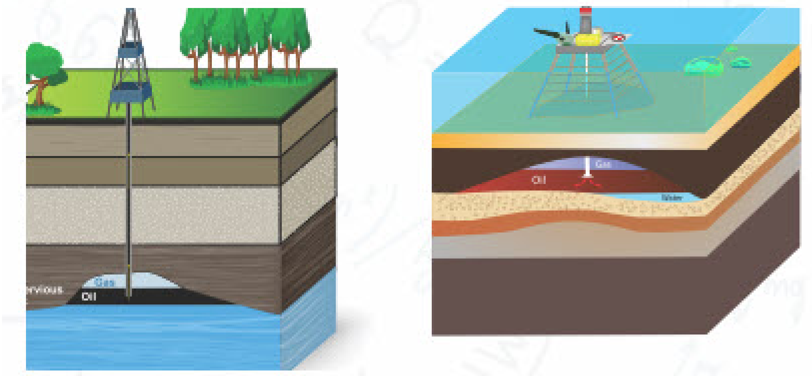


6. Kazakhstan is leader in uranium production. Why do we need uranium?



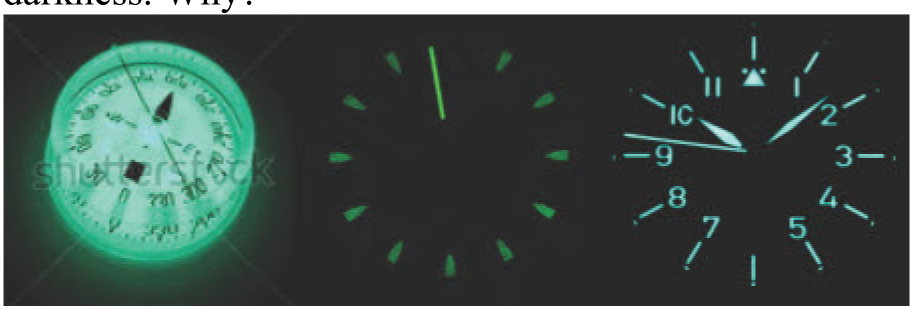
7. The red device on photo produces radiation. Why do we use such device?

8. We put device that measures radioactivity in drill holes during search of petroleum and gas. Why?

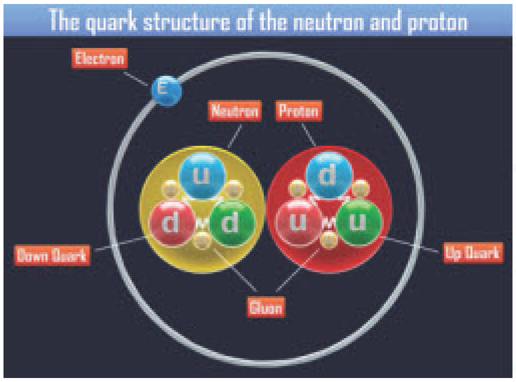


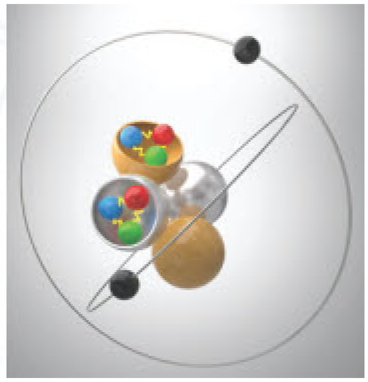
9. Person on the photo wears protective clothes and holds many devices. Why does he need these clothes and devices?

10. Some compasses and watches use radioactive materials to glow in darkness. Why?



11. Neutron and proton consist of three quarks. Are there particles smaller than quarks and electrons?

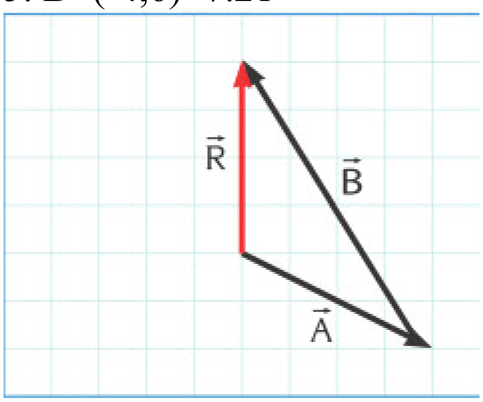

The quark structure of the neutron and proton
Electron
E
Neutron
Proton
u
d
d
d
u
u
Down Quark
Up Quark
Gluon



ANSWERS

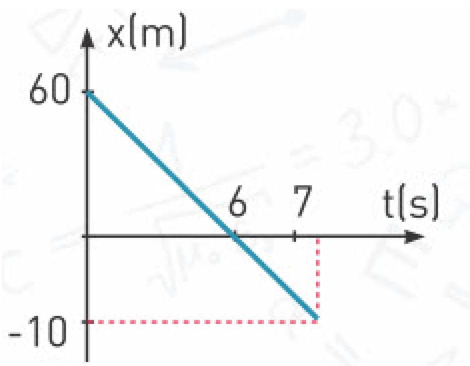
Chapter 1.
Kinematics

1. a) Vector
   b) Scalar
   c) Scalar
   d) Scalar
   e) Vector
2. R_{max}=18, R_{min} =2
3. 500 N, 53° north of west
4. R=10, α=36.87° to the North-East
5. B=(-4,6)=7.21

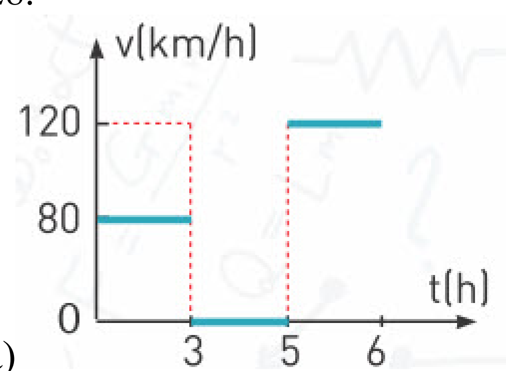


6. a) R=8 upward b) R=-4 to the left
7. R=2.24, α=26.57° to the South-East
8. 0
9. If 3 vectors from equilateral triangle
10. R=2
11. magnitudes of components are equal
12. vertical: 12.50 m/s
    horizontal: 21.65 m/s
13. a) A=9.43, α=-57.99° b) B=8.54 α=110.56°
14. 0
15. R=8.66 α=9.74°
16. M=7.07

17. C=(4,1)
18. R=8.66 α=30°
19. 19. 376.20 km 25.02 0
23. a)20 m/s
b) 0.27 m/s
c) 54 km/h
24. Velocity
25. 6 m/s
26. a) Positive
b) Positive
c) Negative
d) Does not move
27.



28.

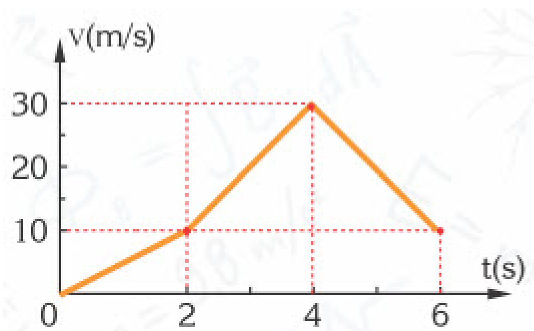


a)
b) 240 km
29. a) 9.46 . 10 12 km
b) 4.23 years
c) 18068.26 years
30. A and B have same speed because their slopes are equal
31. 2000 sec
32. 30 sec

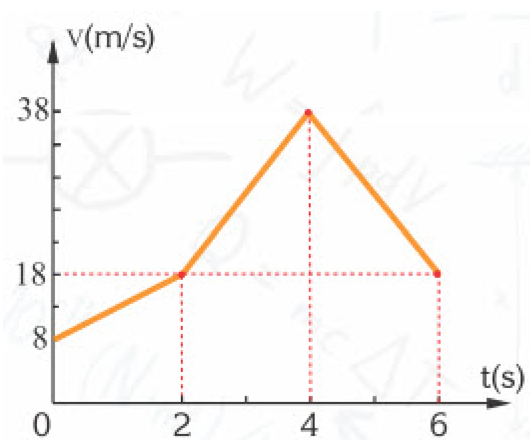
33. 1.5 min, 3500 m
34. 80 km/h
35. 32 sec
36. x = 3 + 2t
37. a) 20 m/s, -30 m/s
b) 600 m, 1400 m
c) 920 m, 16 sec
38. 25 km
39. Uniform motion
40. a) 3.125 m/s, 3.125 m/s
b) 3 m/s, 2 m/s
c) 2.5 m/s, 0 m/s
41. 0 m/s
42. 15 m/s
43. a) 10.14 m/s
b) 6.41 s
44. a) 40 m/s
b) 15 m/s
c) -30 m/s
d) -45 m/s
e) 10 m/s
45. a) 4.8 m/s
b) 0 m/s
46. a) 40 m/s
b) -60 m/s
c) 0 m/s
d) 60 m/s
47. 55 sec
48. a) Body moving in space without influence of any force.
b) Body thrown upwards at the uppermost point of its trajectory
49. Car is slowing down.
50. $a=5\ m/s^2$
51. $a=-4\ m/s^2$
52. $\upsilon=15$ m/s
S=75 m
53. a) 50 s

b) 375 m
54. a) 2.4 m/s
S=14.4 m
b) t=75 s
55. a) 40 m/s, 325 m
b) 10 m/s, 175 m
56. 36m
57. 17.5 m
58. a) -6.25 m/s^2
b) 4s
59. a) -2.4 m/s^2
b) positive direction
60. a) a_1= 3 m/s^2, a_2= 0 m/s^2, a_3 = 0.67 m/s^2
61.

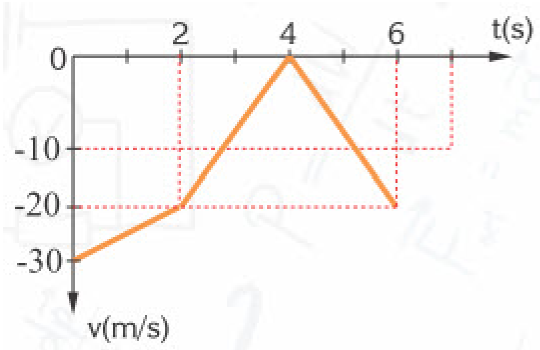
a)



b)



c)



62. a = 457175.90 m/s^2, t = $1.35.10^{-3}$

63. a=2.5m/s^2

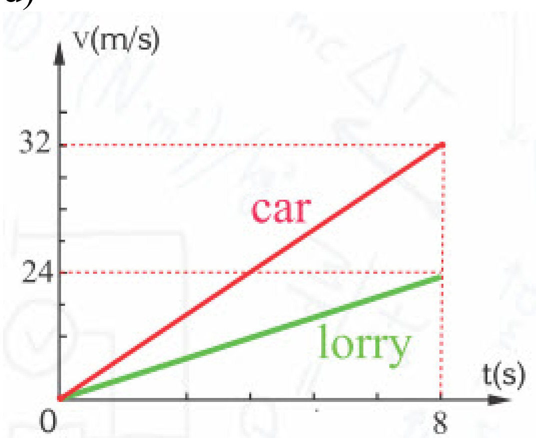
64. a) 3 times b) 1.73 times

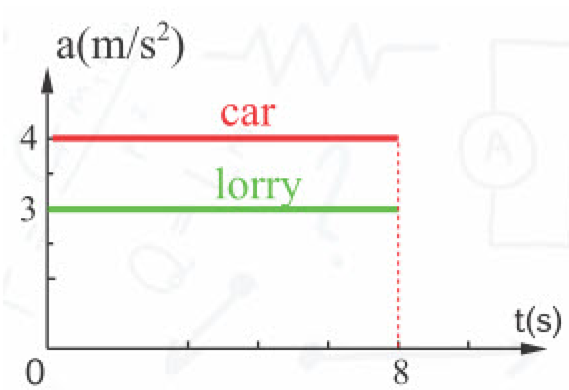
65. a) 8 s

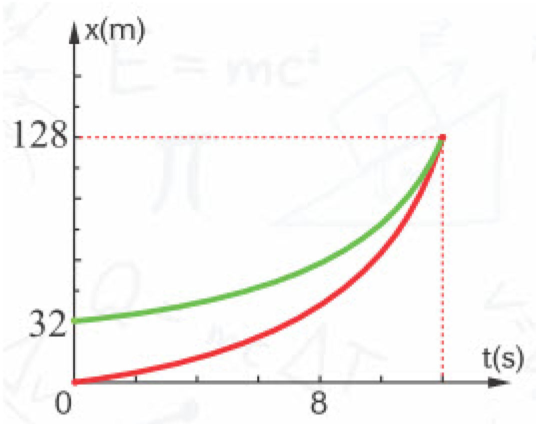
b) 32 m

c) 32 m/s, 24 m/s

d)







66. 10 m/s
67. a_{min} =0.11m/s^2
68. No
5m, 15m, 25m, 35m
69. Raindrops would strike as bullets and possibly kill us. 154.92 m/s
70. a) 4s
b) 40 m/s
c) 20 m/s, 60 m
71. a) 44.72 m/s
b) 8.94 s
c) 55 m
72. 120 m
74. 140 m
75. 0.18 s
76. a) 240 m
b) 70 m/s
73. a) 6 sec
b) 40 m/s
c) 75 m
78. 1.5 s
79. 480 s
80. a) 6 s
b) 0.17 Hz
c) 1 rad/s
d) 0.5 m/s
81. a) 0.017 s
b) 60 Hz

c) 360 rad/s
82. -Hour hand
43200 s, $2.31.10^{-5}$ Hz
- Minute hand
3600 s, 2.77.9 -4 Hz
- Second hand
60 s, 0.017 Hz
83. a) 12.5 Hz
0.08 s
b) 15 m/s
c) 45 m/s
84. a) 0.075 sec
b) 13.33 Hz
c) 80 rad/s
d) 24 m/s
85. a) 0.05 s
b) 300 m/s
86. 976.80 m/s
87. a) 54.77 ms
b) 1095.45 m/s
88. 9×10^{6} m

Chapter 2

Astronomy

1. 385957 km
2. 389
3. 252103 km
4. 0.01"
11. 1 hour 47 minutes 0.73 sec.
12. 30° 30' 30"
13. 1^{st} law: All planets revolve in elliptical orbits around the Sun which is at one of the foci of the elliptical orbit.

2^{nd} law: $\upsilon_1\times r_1 = \upsilon_2\times r_2$

3^{rd} law: a^3/P^2=const

Chapter 3

Dynamics

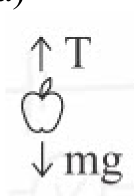
1. Force is any kind of push or pull, it causes motion.
2. Net force is vector sum of all forces acting on a body.
3. a) $F_{NET}=0$

b) $F_{NET}=5.66$ N

c) $F_{NET}=4$ N

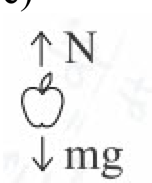
4. $F_{NET}=0$, $a=0$, $\upsilon=const$
5. No, but net force is zero.
6. Yes, it moves with constant velocity.
7. Acceleration depends on net force acting on an object and mass of that object.
8. Newton=kg.m/s^2
9. No
10. No, but net force is zero.
11. No
12. No
13.

a)



b)

c)



14.

$$\frac{F}{m}=a$$

15. a=3 m/s^2
16. a=5 m/s^2
17. a) 0 m/s^2
b) 2.83 m/s^2
c) 2 m/s^2
18. a=10 m/s^2
19. F_2 =6 N
20. 4000 N
21. 1000 m/s^2
22. 25 N
23. 18 m
24. 1000 N
25. 2080 N
26. a) a=2 m/s^2
b) T=12 N
27. a) a=3 m/s^2
b) F_2 =9 N
28. a) F=200 N, T=100 N
b) F=220 N, T=110 N
29. a) a=2.5 m/s^2
b) T=7.5 N
30. a=6 m/s^2
31. a) a=2 m/s^2
b) T=40 N
32. 50 N
33. a) 2 m/s^2
b) 24 N
34. a) 5 m/s^2
b) 30 N
35. 2.5 m/s^2
36. T_1/T_2=2 1
37. a) a=2 m/s^2

b) T=4 N

38. a) $a=2\ m/s^2$

b) T=16 N

39. a) 1 s

b) $2.5\ m/s^2$

c) 2.45 s

40. 312 N

41. a) $a_1=12\ m/s^2$, $a_2=6\ m/s^2$

b) $T_1=12$ N, $T_2=24$ N

42. Because gravitational force of the Earth attracts it back.

43. 0 N

44. Attraction between the masses depend upon the masses and the distance between the centers of masses.

45. Same

46. Because distance between the pole and center of the Earth is less than distance between the equator and center of the Earth.

47. Yes. Because it is rotating around the Earth.

48. 1.90×10^{20} N

49. 4 N

50. 5.34×10^{-8} N

51. 4

52. $g_{Jupiter}=25.86\ m/s^2$

$g_{Mars}=3.69\ m/s^2$

53. $54R_E$ from the Earth

54. 259358.4 km

Chapter 4

Conservation Laws

1. Daily life: work is anything we do to receive payment.

Physics: work is movement of object under the effect of force.

2. No. To do work force must move the object.

3. Normal contact force and centripetal force.

4. 100 J

5. 15.97 J

6. $W_1=W_2=W_3$

7. a) 200 J
b) -80 J
c) 120 J
8. a) W_1 =159.73 J
W 2 =0 J
W 3 =-120 J
b) W_{NET} =39.73 J
9. a) 0 J
b) 200 J
10. a) 75 J
b) 60 J
c) No
11. a) 200 J
b) 0 J
c) -200 J
12. a) 12 J
b) 6 J
c) -24 J
d) -6 J
13. 75 J
14. a) 1000 J
b) 10^7 J
15. Kinetic energy depends on mass and speed of an object.
Joule=$kg \cdot m^2/s^2$
16. Train carriage has more kinetic energy because it has bigger mass than the car.
17. a) 8 J
b) 50 J
18. Red lorry has twice more kinetic energy than blue lorry.
19. 400 J
20. 2 m/s
21. a) 250 J
b) 5 m/s
c) 10 s
22. a) 144 J
b) 8 m/s

c) 6.93 m/s
23. a) -10 J
b) 6 m/s
24. a) W=mg=20 N
b) 1600 J
c) 1600 J
d) 40 m/s
25. 25 J
26. a) 44 J
b) 44 J
27. 4 J
28. a) E_A =3 J, E_B =10 J
b) 20 J
29. a) m_1 =0.1 kg, m_2 =0.05 kg
b) E_1 =20 J, E_2 =10 J
30. 10 m/s
31. 5 m
32. a) 400 J
b) 10 m/s
33. 40 m
34. 30 m/s
35. 2.83 m/s
36. 25 N
37. a) 10 m/s
b) 40 J
c) 60 J
d) 100 J
38. a) 4 J
b) 16 J
39. E_K =80 J, E_L =40 J
40. a) 10^5 N/m
b) 6.4 N
c) 3.2 N
41. 0.2 m
42. a) 0.5 m
b) 0.58 m

43. 0.95 m
44. 0.2 m
45. a) 500 N/m
b) 90 J
46. 0.4 m
47. a) 2 m/s
b) 0.2 m
48. 6 m/s
49. Momentum depends on mass and velocity.
50. 4.5 kg·m/s
51. 1.82×10^{-25} kg.m/s
52. 20 m/s
53. a) 0 kg·m/s
b) 2.83 kg·m/s
54. 48000 kg·m/s
55. I=F·t
56. 5 kg·m/s
57. a) 0.8 kg·m/s
b) 4 m/s
58. 1800 N
59. 100 kg·m/s
60. a) 7.07 kg·m/s
b) 35.36 N

61. a) 16000 kg·m/s
b) 1200 kg·m/s
c) 1600 N
62. 14.14 kg·m/s
63. 20 kg·m/s
64. a) 10 kg·m/s
b) 100 N
65. 10 kg·m/s
66. 50 kg·m/s
67. 5 m/s to the East
68. a) 6 kg·m/s
b) 0.2 m/s from friend
69. 3 m/s east

70. -16 m/s
71. a) 1.6 m/s
b) 24 N
72. 11 m/s
73. a) 4 m/s
b) 0.25 m/s
74. a) 2.5 m/s
b) E_1 =50 J, E_2=25 J
c) 75 J
75. 8 m/s
76. 3 m/s
77. a) 0 m/s
b) 2 m/s
78. 200 m/s
79. 2.4 m/s
80. 2 m/s
81. 0.67
82. 200 m/s
83. a) 10 m/s
b) 5m
c) 5 kg·m/s
84. -5 m/s
85. a) 1 m/s
b) 10 cm
86. 20 cm
87. -3 m/s, 2m/s
88. -2 m/s, 4 m/s
89. -13 m/s, 2 m/s
90. 5 m/s, 8 m/s
91. -17 m/s, -7 m/s
92. 25 kg
93. 4.67 m/s
94. 40 m/s
95. 600 m/s
96. 200 m/s

Chapter 5

Oscillations

1. a) No
b) No
c) No
d) Yes
e) No
2. a) Yes
b) No
c) Yes
3. a) 0.33 s
b) 3 Hz
4. a) 6 s
b) $v_{BB'}$ =0.105 m/s
$a_{BB'}$ =0 m/s^2
c) $v_{BB'}$ =0 m/s
$a_{BB'}$ =0.027 m/s^2
5. a) T= 12 s
b) υ_{max} = 0.0209 m/s
c) a_{max} = 0.011 m/s^2
d) F_k = 0.011 N
6. a) 0.25 s
b) 3.14 m/s
c) 19.72 m/s^2
d) x= 0.5 cos(2πt)
7. a) 1.97 m/s^2
b) 0.6 m/s
8. a) 1.97 N
b) -0.27 m/s
c) 0.986 N
9. a) 16.67 ms
b) 50 ms
10. a) 0.628 sec, 1.59 Hz
b) 0.3 m

c) 30 m/s^2
12. a) 4 sec
b) 0.25 Hz
13. a) 1.256 sec, 0.796 Hz
b) 0.8 kg
c) 4 N
14. a) SHM
b) 160 N/m, 0.314 sec
15. 1
16. 3 sec
17. 5 sec
18. 0.6 sec
19. a) 1.25 sec
b) 0.8 Hz
20. 1.01 m
21. a) 1.256 sec
b) 3.14 sec
22. 0.125 m
23. a) between O and L
b) at point O
24. 4.90 sec
25. 8 sec
26. 16
27. a) $T\sqrt{2}/2$
b) $T\sqrt{2}$
c) $T\ g^{\infty}$
28. T=0.25 s f=4 Hz
29. a) $F_{NET}=0$
b) $\upsilon=0$
30. 0.8 m
31. a) f=1Hz
b) A=0.1m
32. There is NO relation between the amplitude of oscillation and the period of oscillation in Simple Harmonic Motion.
33. a) 20 J
b) 20J

34. a) E_P =24 J E_K =0 J
b) E_P =0 J E_K =24 J
35. a_{max} = 200m/s^2
υ_{max} = 4.47 m/s
36. υ_{max}=ωA is doubled
37. E_1/E_2=1
38. a) υ_o =0, a_o=25m/s^2
b) υ=2.24 m/s, a=0
39. A_1/A_2=1/2
40. a) υ=-1.6 m/s a=-24m/s^2
b) υ=-1.6 m/s a= 24m/s^2
41. υ=-8 m/s a=-120m/s^2
42.

$$\frac{k}{m}=\frac{N/m}{kg}=\frac{N}{m}\cdot\frac{1}{kg}=$$
$$=\frac{kg\cdot m}{m\cdot s^2\cdot kg}=\frac{1}{s^2}$$

43.υ=-0.6 m/s
44. a) A=0.1m
b) υ=0.8m/s
45. 0.14 m
46. A mechanical wave is the propagation of an oscillation in an elastic medium.
Wave motion does not involve matter transfer.
47. The wavelength of a wave is the distance between two successive points oscillating in phase. Frequency is the number of complete oscillations of a particle in the medium.
48. 10 wavelengths
49. A wave pulse is a wave of short duration.
A periodic wave is continuous wave.
50. T=0.2 s, f=5 Hz

51. λ_I =4, λ_{II}=4, λ_{III}=4
52. to the right
53. In transverse wave direction of oscillation of a particle is perpendicular to the direction of propagation of wave.
In longitudinal wave direction of oscillation of a particle is parallel to the direction of propagation of wave.
55. Because

$$v = \sqrt{\frac{F}{\mu}}.$$

At the upper portions of rope tension is bigger because it supports bigger weight.
56. λ=4 m
57. T=0.067 s, f=15 Hz
58. v=1.8 m/s
59.
λ=0.24 m
60. f=1 MHz
61. 3 m/s
62. 0.1 m
63. frequency increases, speed does not change, wavelenth decreases
64. v=1.1 m/s,
λ=0.37 m
65. All sounds have same speed in air
66. 5 Hz
67. λ_{max}=4.25 m, λ_{min}=0.25 m
68. Energy is dissipated into the medium via resistive forces.
69. a) Electric charge ALWAYS produces electric field.
b) Moving electric charge (current) produces magnetic field.
c) Accelerating electric charge produces electromagnetic waves.
70. Electromagnetic waves are emitted by accelerating charges.
71. λ= 200 m
72. λ= 3.10^8 m
73. 3 MHz - 30 MHz
74. d. Radio waves
a. Radar waves

e. Infrared waves
g. Visible waves
b. Ultraviolet waves
f. X-rays
c. Gamma rays
75. 15000 m
76. 3923.33 s

Chapter 6
Atomic Physics

7. T_2 =747.67 K
8. 5.57 times
9. a) 36,000 J
   b) P=905.9 W
   c) t= 39.74 s
   d) T= 149.29°C
10. 1.1
11. 4.7 eV
12. 2.34eV=$3.75.10^{-19}$ J
16. 0.9945 eV
17. 5.64 eV
18. 2755.5 Å
19. a) 2.14 eV
b) 5.16×10^{14} Hz
c) 5794 Å
20. a) 1.6 eV
b) 7750 Å
c) 3.86×10^{14} Hz
21. 3×10^{-25} Ns
24. 1216 Å
25. 2.43eV

Chapter 7

Nuclear Physics

1. a) 92

b) 235

2.

	C	P	Fe	Ag	Pb
Protons	6	15	26	47	82
Neutrons	7	16	31	60	126

3. 0

4. 1669 MeV, 1.79 u

5. 7.65 MeV

6. 1.747 u

7. 7.42 MeV

8. a) Endothermic

b) Exothermic

9. 4.02 MeV

10. Radioactivity

11. Alpha decay

12. Top layers of the atmosphere

13. Beta particle

14. Beta decay

15. Gamma decay

16. Because other materials than the lead are highly penetrable for radiation of radioactive materials

17. $E_{gamma} = 10^{14} E_{radio}$

18.

$^{235}_{92}U$

19. Alpha decay

20. Alpha decay

21. Gamma decay

22. a) Geiger counter

b) Scintillation counter

c) Cloud chamber

d) Bubble chamber

23. Scintillation counter counts particles at faster rate than Geiger counter. It also provides information about the energy of particle.

24. Half-life is the period of time over which the number of radioactive nuclei decreases by half.
25. Radon gas
26. Iron has half-life longer than half-life of chloride.
27. No.
28. 12.5 g
29. 1.28×10^{22}
30. 8.75 g
31. 53.16 days
32. 155.62 days
33. 15.28 days
34. 4 days
35. In 1919 Ernest Rutherford bombarded nitrogen with alpha particles and obtained first artificial isotope of oxygen.
36. Alchemists wanted to obtain gold from less valuable metals.
37. Electron was discovered first in 1897.
Proton was discovered second in 1919.
Neutron was discovered last in 1932.
38. Because there was difference between element's atomic number and atomic mass.
39. Because neutron has no charge.
40. Disintegration of a heavier nucleus into two or more lighter nuclei due to neutron bombardment.
41. Because mass of heavy nucleus is not equal to resulating light nuclei.
The difference of the masses is relased as energy by Einstein's $E=mc^2$ formula.
42. Products of nuclear fission are chemically harmful for human body. Also high energy electromagnetic radiation and high kinetic energy particles are emitted during reaction which are also very harmful as they cause cancer.
43. Atomic bomb and nuclear reactor.
44. Fusion is combination, fission is disintegration.
45. Fusion requires huge amount of activation energy (Very big temperature and pressure).
46. Fuel, moderator, control rods.
47. Nuclear transmutation.

48. Iron

49.

$$^{27}_{13}Al + ^{4}_{2}He \rightarrow ^{30}_{14}Si + ^{1}_{1}p$$

50.

$$^{27}_{13}Al + ^{1}_{0}n \rightarrow ^{24}_{11}Na + ^{4}_{2}He$$

$$^{27}_{13}Al + ^{0}_{0}\gamma \rightarrow ^{26}_{12}Mg + ^{1}_{1}p$$

$$^{55}_{25}Mn + ^{1}_{1}p \rightarrow ^{55}_{26}Fe + ^{1}_{0}n$$

51. 11.46 MeV

52. 8.16 MeV

53. a) 9×10^{13} J

b) 22.5×10^{3} tons

54. To destroy cancer cells

55. Cells damaged by radiation cannot function properly.

56. Spin and structure

57. Bosons have integer spin,while fermions have half-integer spin

58. Hadron, Lepton, Baryon, Meson

59. Proton and neutron

60. Electron

61. A particle with the same mass, but opposite charge

GLOSSARY

A

Absorption - the removal of energy or particles from a beam by the medium through which the beam propagates

Acceleration - the time rate of change of velocity with respect to magnitude or direction

Alpha decay - the spontaneous emission of a helium nucleus

Alpha particle - a helium nucleus emitted from a radioactive element

Amplitude - the magnitude of displacement of an oscillating particle or wave relative to its rest position

Angstrom - a unit of length equal to 0.1 nanometer

Angular frequency - a measure of the frequency of an object varying sinusoidally equal to 2π times the frequency in cycles per second

Angular speed - number of radians passed in unit time

Apparent weight - a property of objects that corresponds to how heavy an object is

Artificial radioactivity - radioactivity introduced into a nonradioactive substance by bombarding the substance with charged particles

Astronomical unit - the mean distance between the Sun and the Earth. It is equal to 149 597 870 km

Astronomy - the study of the universe beyond the Earth's atmosphere

Atom - the smallest part of an element that can exist

Atomic energy - same as nuclear energy

Atomic mass unit - a unit of mass, equal to 1/12 the mass of the carbon-12 atom and used to express the mass of atomic and subatomic particles

Atomic number - the number of protons in the nucleus of an atom

Autumnal equinox - the time when the sun crosses the plane of the earth's equator, making night and day of approximately equal length all over the earth and occurring about September 22

Average binding energy per nucleon - the energy equivalent to the mass defect when nucleons bind together to form an atomic nucleus divided by nucleon number

Average speed - the total distance traveled divided by the total time elapsed

B

Baryon - a proton, neutron, or any elementary particle that decays into a set of particles that includes a proton

Beta decay - the spontaneous emission of an electron from the nucleus of a radioactive atom

Beta particle - high-energy and high-speed electrons emitted from the nucleus of a radioactive atom

Boson - any particle that obeys Bose-Einstein statistics

C

Celestial sphere - the imaginary spherical shell formed by the sky, usually represented as an infinite sphere, the center of which is a given observer's position

Centripetal acceleration - the acceleration on a mass that is moving in a circular path at a constant speed

Chemical reaction - a process that leads to the transformation of one set of chemical substances to another

Cluster - a group of neighboring stars, held together by mutual gravitation, that have essentially the same age and composition and thus supposedly a common origin

Components of a vector - ordered pair that describes the changes in the x- and y-values

Compression - the reduction in volume

Conservation of energy - for an isolated system, the total energy may change forms but remains constant during the interactions within the system

Constant - not changing or varying; uniform; regular; invariable

Control rod - a neutron-absorbing material, as boron or cadmium, in the shape of a rod or other configuration, that can be moved into or out of the core of a nuclear reactor to regulate the rate of fission

Crest - the head or top of anything

Cut-off frequency - the minimum frequency of an electromagnetic wave necessary to strike the surface of a piece of metal and cause the ejection of electrons as per the photoelectric effect

Cycle - any complete round or series of occurrences that repeats or is repeated

D

Damped oscillation - oscillation which decreases in amplitude

Deceleration - reduction in speed or rate

Declination - the angular distance of a heavenly body from the celestial equator, measured on the great circle passing through the celestial pole and the body

Deuterium - an isotope of hydrogen consisting of 1 proton and 1 neutron in its nucleus

Displacement - the change in position of an object from a beginning point to an ending point

Distance - the extent or amount of space between two things, points, lines, etc

Dynamics - the branch of mechanics that deals with the motion and equilibrium of systems under the action of forces

E

Echo - a repetition of sound produced by the reflection of sound waves from a wall, mountain, or other obstructing surface

Efficiency - the ratio of work output to work input.

Elastic collision - a collision in which the total kinetic energy of the colliding bodies or particles is the same after the collision as it was before

Elastic potential energy - the stored energy of a spring

Electric field - a region in space that exerts a force on a charged particle

Electromagnetic spectrum - the range of electromagnetic waves that all travel at the speed of light

Electromagnetic wave - a wave produced by the acceleration of an electric charge and propagated by the periodic variation of intensities of, usually, perpendicular electric and magnetic fields

Electron - a subatomic particle with a negative elementary electric charge which orbits the nucleus of an atom

Electron volt - the amount of energy necessary to move 1 unit of elementary electric charge through a potential difference of 1 volt

Elementary particle - any lepton, hadron, photon, or graviton, the particles once thought to be the indivisible components of all matter or radiation

Energy - the property of an object, or a system, that allows it to do work

Energy level - each atom has discrete levels of energy at which an electron may be found outside of the nucleus

Equilibrium - occurs when the sum of all external force vectors acting on an object is zero

Escape velocity - the minimum initial velocity necessary so that an object will not return to the planet from which it was launched.

F

Fermion - any particle that obeys the exclusion principle and Fermi-Dirac statistics

Fission - the splitting of large atomic nuclei into smaller atomic nuclei

Force - a push or a pull caused by an interaction that accelerates an object

Forced oscillation - an oscillation imposed upon a body or system by and with the frequency of some external vibrator of sensibly different frequency

Free fall - motion of a body where gravity is the only force acting upon it

Free oscillation - oscillation that occur due to the initial energy given to the oscillating object

Frequency - the number of oscillations per second

Fuel - an energy source for engines, power plants, or reactors

Fusion - the combining of smaller nuclei into larger atoms

G

Galaxy - a large system of stars held together by mutual gravitation and isolated from similar systems by vast regions of space

Gamma decay - type of radioactivity in which an unstable atomic nucleus dissipates energy by gamma emission, producing gamma rays

Gamma ray - high-energy photons emitted by naturally decayingradioisotopes and by fission reactions

Geocentic - having or representing the Earth as a center

Gravitational acceleraton - the acceleration on an object caused by the force of gravitation

Gravitational field - gravitational force per unit mass at a point in space

Gravity - the force of attraction by which terrestrial bodies tend to fall toward the center of the earth

H

Hadron - any elementary particle that is subject to the strong interaction. Hadrons are subdivided into baryons and mesons

Halflife - the amount of time required for half of the radioactive isotopes of an element to decay

Harmful - causing or capable of causing harm; injurious

Heliocentric - having or representing the sun as a center

Hertz - the unit for frequency

Hooke's law - the distance of extension or compression of a spring is directly proportional to the applied force

I

Impulse - the change in momentum; the product of force and the time interval of the force acting on a mass

Inelastic collision - a collision in which the total kinetic energy of the colliding bodies or particles is not the same after the collision as it was before

Inertia - tendency of an object to resist any change in its state of motion

Infrared wave - the part of the invisible spectrum that is contiguous to the red end of the visible spectrum and that comprises electromagnetic radiation of wavelengths from 800 nm to 1 mm

Initial - beginning; first

Instantaneous speed - the speed of an object at a specific instant of time

Intensity - magnitude, as of energy or a force per unit of area, volume, time, etc

Isotope - an atom with the same atomic number but a different atomic mass number

J

Joule - the SI unit of work and of all other forms of energy

K

Kepler's first law - the orbital paths of all planets are elliptical with the Sun at one focus

Kepler's second law - an imaginary line from the Sun to a planet will sweep out an equal area in an equal amount of time during the orbit of the planet about the Sun.

Kepler's third law - a ratio of the square of the period of an orbit to the cube of the radius of that orbit is constant for any planet orbiting the Sun

Kinematics - the branch of mechanics that deals with pure motion, without reference to the masses or forces involved in it

Kinetic energy - the amount of energy based on the mass of an object and its velocity

L

Laser - an acronym standing for Light Amplification by the Stimulated Emission of Radiation. A beam of intense, coherent (all in the same phase), monochromatic (all having the same frequency) light

Longitudinal wave - a wave in which the vibration of oscillating particles is in a direction parallel to the direction of wave propagation

Loudness - the physiological perception of sound intensity

M

Magnetic field - a region surrounding a permanent magnet, a moving charged particle, or an electric current that induces a force in magnetic materials or moving charged particles

Mass - the property of matter that quantifies the amount of inertia inherent in that matter

Mass defect - the total amount of mass at the end of the reaction is slightly less than the total amount of mass before the reaction

Mass difference - see "mass defect"

Mass loss - see "mass defect"

Mass number - the total number of protons plus neutrons for an atom

Medium - an intervening substance through which a force acts or an effect is produced

Meson - any hadron, or strongly interacting particle, other than a baryon

Microwave - an electromagnetic wave of extremely high frequency, 1 GHz or more, and having wavelengths of from 1 mm to 30 cm.

Milky Way - the spiral galaxy containing our solar system

Moderator - a substance, as graphite or heavy water, used to slow neutrons to speeds at which they are more efficient in causing fission

Momentum - a quantity expressing the motion of a body or system, equal to the product of the mass of a body and its velocity

Muon - a lepton similar in most respects to the electron except that it is unstable

N

Net force - the vector sum of all forces acting on a mass

Neutrino - any of the massless or nearly massless electrically neutral leptons

Neutron - an electrically neutral nucleon that has a mass of 1 atomic mass unit (amu) and works with protons to produce the strong nuclear force to keep the nucleus of an atom intact

Newton - the SI unit for force

Newton's first law of motion - a statement of inertia. An object in motion will stay in motion unless acted upon by an applied force. An object at rest will remain at rest unless acted upon by an applied force.

Newton's second law of motion - the acceleration, a , produced by a net force, F , on an object is directly proportional to the magnitude and direction of that net force and is inversely proportional to the mass, m , of the object. It is summarized by the equation a = F /m , most often expressed as F = ma .

Newton's third law of motion - for every action of a force by one object upon another, there is an equal force in the opposite direction.

Normal force - the force on an object due to contact with a surface

Nuclear binding energy - the energy equivalent to the mass defect when nucleons bind together to form an atomic nucleus

Nuclear energy - energy released by reactions within atomic nuclei, as in nuclear fission or fusion

Nuclear force - see "strong nuclear force"

Nuclear physics - the physics of atomic nuclei and their interactions

Nuclear power - electric power or motive power generated by a nuclear reactor

Nuclear reaction - a process in which the structure and energy content of an atomic nucleus are changed by interaction with another nucleus or particle

Nuclear reactor - a device used to initiate and control a sustained nuclear chain reaction

Nucleon - the name given to either a proton or a neutron when it resides in the nucleus of an atom

Nucleus - the positively charged mass within an atom, composed of neutrons and protons, and possessing most of the mass but occupying only a small fraction of the volume of the atom

O

Oscillation - an effect expressible as a quantity that repeatedly and regularly fluctuates above and below some mean value

P

Period - the number of seconds per oscillation

Phase - a stage in a process of change

Photoelectric effect - the process by which electrons in the surface of a piece of metal can be ejected above a certain minimum (threshold) frequency of electromagnetic radiation (light) that is incident upon the surface of the metal

Photon - a quantum particle of electromagnetic energy that travels at the speed of light and has a discrete frequency

Pitch - the frequency of a sound wave

Planet - a celestial body moving in the sky, as distinguished from a fixed star

Potential energy - the energy associated with an object's position

Power - the rate at which work is done or energy is transformed

Propagate - to travel through space or a physical medium

Proton - a positively charged nucleon that has a mass of 1 atomic mass unit

Pulse - a sudden fluctuation in a medium causing a wave of energy to propagate

Q

Quantum - see "photon"

Quark - any of the hypothetical particles with spin 1/2, baryon number 1/3, and electric charge 1/3 or −2/3 that, together with their antiparticles, are believed to constitute all the elementary particles classed as baryons and mesons

R

Radar wave - see "microwave"

Radian - the measure of a central angle subtending an arc equal in length to the radius : equal to 57.2958°

Radiation - the process in which energy is emitted as particles or waves

Radio wave - an electromagnetic wave having a wavelength between 1 millimeter and 30,000 meters, or a frequency between 10 kilohertz and 300,000 megahertz

Radioactive decay - the spontaneous change of a radioactive nucleus into other atomic particles including alpha particles, beta particles, and gamma radiation, and/or the transmutation to other atom

Radioactivity - the phenomenon, exhibited by and being a property of certain elements, of spontaneously emitting radiation resulting from changes in the nuclei of atoms of the element

Ray - a thin beam of light

Reference frame - a system of geometric axes in relation to which measurements of size, position, or motion can be made.

Resonance - a dramatic increase in the amplitude of a vibrating object when the frequency of forced vibrations matches the natural frequency of the object

Resultant force - see "net force"

Resultant vector - vector sum of two or more vectors

Revolution - the motion of an object turning around another object

Right ascension - the arc of the celestial equator measured eastward from the vernal equinox to the foot of the great circle passing through the celestial poles and a given point on the celestial sphere, expressed in degrees or hours

Rotation - the spinning motion of an object about its own axis

S

Satellite - a natural body that revolves around a planet; a device designed to be launched into orbit around the earth, another planet, the sun, etc

Scalar quantity - a quantity possessing only magnitude

Semi-major axis - one half the major axis of the ellipse that one celestial body describes around another equivalent to the mean distance between the two bodies

Simple harmonic motion - vibratory motion in a system in which the restoring force is proportional to the displacement from equilibrium

Simple pendulum - a hypothetical apparatus consisting of a point mass suspended from a weightless, frictionless thread whose length is constant, the motion of the body about the string being periodic and, if the angle of deviation from the original equilibrium position is small, representing simple harmonic motion

Sinusoidal wave - a mathematical curve that describes a smooth repetitive oscillation

Sound - mechanical vibrations transmitted through an elastic medium

Source - any thing or place from which something comes, arises, or is obtained; origin

Spectrum - the spreading out of electromagnetic radiation by frequency through a prism, diffraction grating, or spectroscope

Speed - the distance an object moves in a specific amount of time

Spring constant - the force needed to stretch or compress a spring by a specific length

Standing wave - a stationary wave pattern that appears to be moving

Steady motion - motion in which the linear velocity is constant

Strong nuclear force - the force responsible for holding neutrons and protons together in the nucleus of an atom and overcoming the electrostatic repulsive force among protons

Summer solstice - the solstice on or about June 21st that marks the beginning of summer in the Northern Hemisphere

T

Tangential speed - linear speed

Telescope - an optical instrument for making distant objects appear larger and therefore nearer

Tension - the longitudinal deformation of an elastic body that results in its elongation

Threshold frequency - the minimum frequency of an electromagnetic wave necessary to strike the surface of a piece of metal and cause the ejection of electrons as per the photoelectric effect

Timbre - the characteristic quality of a sound, independent of pitch and loudness, from which its source or manner of production can be inferred

Total mechanical energy - the sum of kinetic and potential energies in a mechanical system

Transverse wave - a wave with oscillations that are at right angles to the direction of propagation

Trough - any long depression or hollow, as between two ridges or waves

Twinkle - to shine with a flickering gleam of light, as a star or distant light

U

Ultraviolet wave - electromagnetic radiation having wavelengths between that of violet light and long X-rays, i.e. between 400 and 4 nm

Unaided eye - without astronomical equipment

Uniform circular motion - an object in circular motion that has a constant speed

Uniform motion - straight line motion at a constant speed

Universal law of gravitation - the gravitational force between any two masses is directly proportional to the product of their masses and is inversely proportional to the square of the distance that separates them.

V

Vacuum - an enclosed space from which matter has been removed

Vector quantity - a physical quantity that has magnitude and a specific direction

Velocity - the speed of an object in a specific direction

Vernal equinox - the time when the sun crosses the plane of the earth's equator, making night and day of approximately equal length all over the earth and occurring about March 21

Vibration - the oscillating, reciprocating, or other periodic motion of a rigid or elastic body or medium forced from a position or state of equilibrium

Visible light - the range of the electromagnetic spectrum that can be perceived by the human eye as colors

W

Watt - the SI unit of power

Wave - a periodic disturbance in a medium or in space

Wavelength - the distance between two successive points in phase along a wave

Weak nuclear force - along with gravity, electromagnetism, and the strong nuclear force, it is one of the fundamental forces in nature. The weak nuclear force is responsible for the radioactive decay of subatomic particles in processes such as beta decay.

Weight - the force of gravity on an object in a gravitational field

Weightlessness - being without apparent weight

Winter solstice - the solstice on or about December 21st that marks the beginning of winter in the Northern Hemisphere

Work - a measure of the amount of change in mechanical energy

Work function - minimum amount of energy needed to eject an electron from the surface of a piece of metal as per the photoelectric effec

X-ray - a form of electromagnetic radiation capable of penetrating solids and of ionizing gases having wavelengths in the range of approximately 0.1–10 nm.

INFOGRAPHICS

APPENDIX 1 Physical Constants and Data

Speed of light	$c=2.997925\times10^{8}$ m/s	Mass of earth	5.98×10^{24} kg
Gravitational constant	$G=6.67\times10^{-11}$ N·M²/kg²	Average density of earth	5.570 kg/m³
Electron charge	$e=1.60218\times10^{-19}$ C	Average earth-moon distance	3.84×10^{8} m
Magnetic permeability constant	$m_0=4p\times10^{-7}$ N/A²	Average earth-sun distance	1.496×10^{11} m
Standard gravitational acceleration	$g=9.80665$ m/s² $=32.17$ ft/s²	Mass of electron	$9.11.10^{-31}$ kg

APPENDIX 2 Trigonometric Table

θ (Deg.)	θ (Rad.)	sin θ	cos θ	tan θ	θ (Deg.)	θ (Rad.)	sin θ	cos θ	tan θ
0°	0.000	0.000	1.000	0.000					
1°	0.017	0.017	1.000	0.017	46°	0.803	0.719	0.695	1.036
2°	0.035	0.035	0.999	0.035	47°	0.820	0.731	0.682	1.072
3°	0.052	0.052	0.999	0.052	48°	0.838	0.743	0.669	1.111
4°	0.070	0.070	0.998	0.070	49°	0.855	0.755	0.656	1.15
5°	0.087	0.087	0.996	0.087	50°	0.873	0.766	0.643	1.192
6°	0.105	0.105	0.995	0.105	51°	0.890	0.777	0.629	1.235
7°	0.122	0.122	0.993	0.123	52°	0.908	0.788	0.616	1.28
8°	0.140	0.139	0.990	0.141	53°	0.925	0.799	0.602	1.327
9°	0.157	0.156	0.988	0.158	54°	0.942	0.809	0.588	1.376
10°	0.175	0.174	0.985	0.176	55°	0.960	0.819	0.574	1.428
11°	0.192	0.191	0.982	0.194	56°	0.977	0.829	0.559	1.483
12°	0.209	0.208	0.978	0.213	57°	0.995	0.839	0.545	1.540
13°	0.227	0.225	0.974	0.231	58°	1.012	0.848	0.530	1.600
14°	0.244	0.242	0.970	0.249	59°	1.030	0.857	0.515	1.664
15°	0.262	0.259	0.966	0.268	60°	1.047	0.866	0.500	1.732
16°	0.279	0.276	0.961	0.287	61°	1.065	0.875	0.485	1.804
17°	0.297	0.292	0.956	0.306	62°	1.082	0.883	0.469	1.881
18°	0.314	0.309	0.951	0.325	63°	1.100	0.891	0.454	1.963
19°	0.332	0.326	0.946	0.344	64°	1.117	0.899	0.438	2.050
20°	0.349	0.342	0.940	0.364	65°	1.134	0.906	0.423	2.145
21°	0.367	0.358	0.934	0.384	66°	1.152	0.914	0.407	2.246
22°	0.384	0.375	0.927	0.404	67°	1.169	0.921	0.391	2.356
23°	0.401	0.391	0.921	0.424	68°	1.187	0.927	0.375	2.475
24°	0.419	0.407	0.914	0.445	69°	1.204	0.934	0.358	2.605
25°	0.436	0.423	0.906	0.466	70°	1.222	0.940	0.342	2.747
26°	0.454	0.438	0.899	0.488	71°	1.239	0.946	0.326	2.904
27°	0.471	0.454	0.891	0.510	72°	1.257	0.951	0.309	3.078
28°	0.489	0.469	0.883	0.532	73°	1.274	0.956	0.292	3.271
29°	0.506	0.485	0.875	0.554	74°	1.292	0.961	0.276	3.487
30°	0.524	0.500	0.866	0.577	75°	1.309	0.966	0.259	3.732
31°	0.541	0.515	0.857	0.601	76°	1.326	0.970	0.242	4.011
32°	0.559	0.530	0.848	0.625	77°	1.344	0.974	0.225	4.331
33°	0.576	0.545	0.839	0.649	78°	1.361	0.978	0.208	4.705
34°	0.593	0.559	0.829	0.675	79°	1.379	0.982	0.191	5.145
35°	0.611	0.574	0.819	0.700	80°	1.396	0.985	0.174	5.671
36°	0.628	0.588	0.809	0.727	81°	1.414	0.988	0.156	6.314
37°	0.646	0.602	0.799	0.754	82°	1.431	0.990	0.139	7.115
38°	0.663	0.616	0.788	0.781	83°	1.449	0.993	0.122	8.144
39°	0.681	0.629	0.777	0.810	84°	1.466	0.995	0.105	9.514
40°	0.698	0.643	0.766	0.839	85°	1.484	0.996	0.087	11.43
41°	0.716	0.656	0.755	0.869	86°	1.501	0.998	0.070	14.301
42°	0.733	0.669	0.743	0.900	87°	1.518	0.999	0.052	19.081
43°	0.750	0.682	0.731	0.933	88°	1.536	0.999	0.035	28.636
44°	0.768	0.695	0.719	0.966	89°	1.553	1.000	0.017	57.290
45°	0.785	0.707	0.707	1.000	90°	1.571	1.000	0.000	∞

In a right triangle ABC, where the sides a and b are perpendicular each other, c is hypotenuse and is an acute angle;
a) Sine of the angle q is equal to the ratio of the opposite side of this angle (side a) to the hypotenuse (side c).

$$\sin\theta = \frac{a}{c}$$

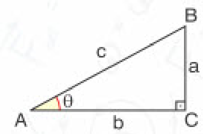
b) Cosine of the angle q is equal to the ratio of the adjacent side of this angle (side b) to the hypotenuse (side c).

$$\cos\theta = \frac{b}{c}$$

Pythagorean theorem:

In a right triangle ABC, where a and b are perpendicular sides and c is the hypotenuse, "the square of hypotenuse is equal to the sum of the squares of perpendicular sides". Hence the Pythagorean theorem can be expressed as follows:

$$c^2 = a^2 + b^2$$



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PHYSICS

Grade 9

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