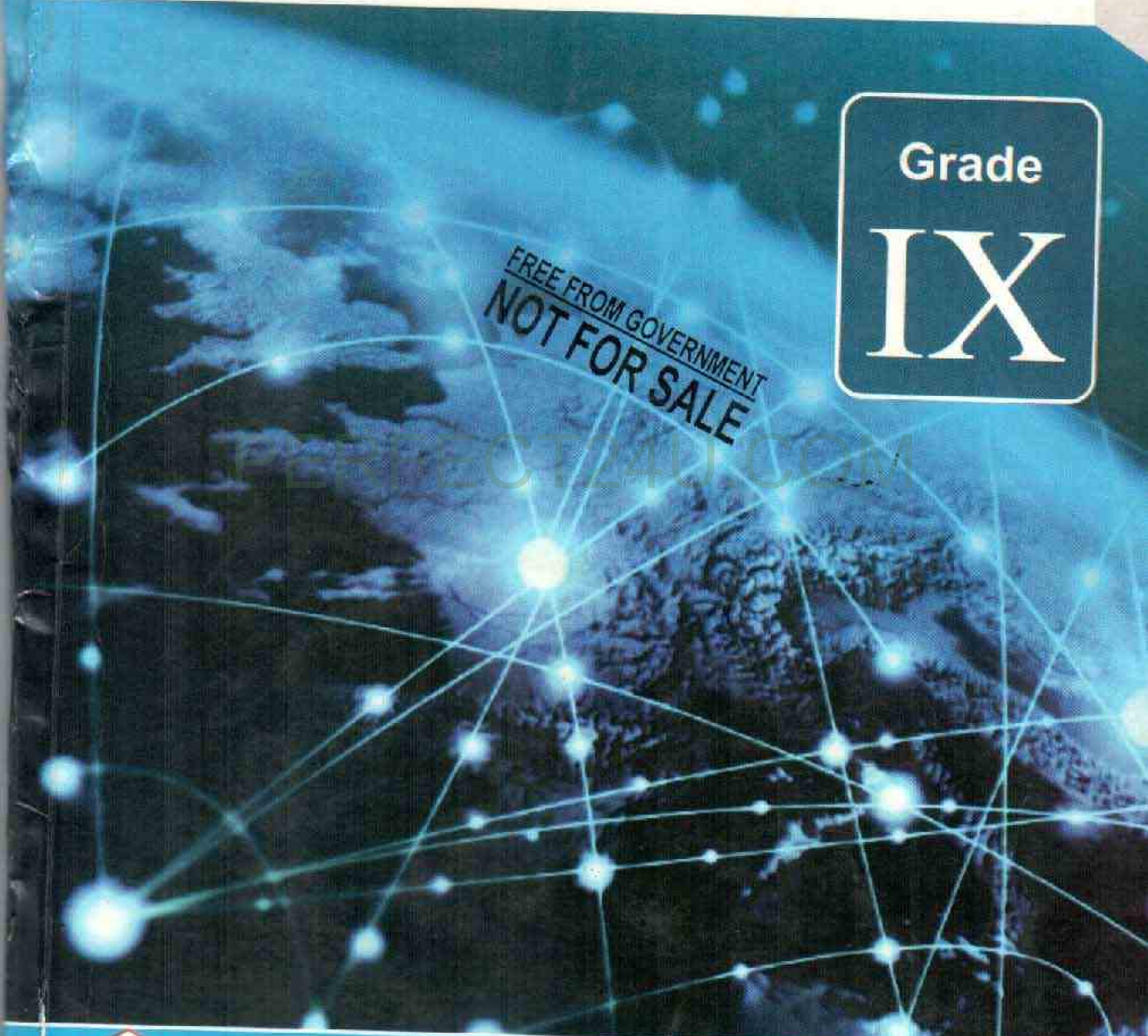
A Textbook of

PHYSICS

Grade IX



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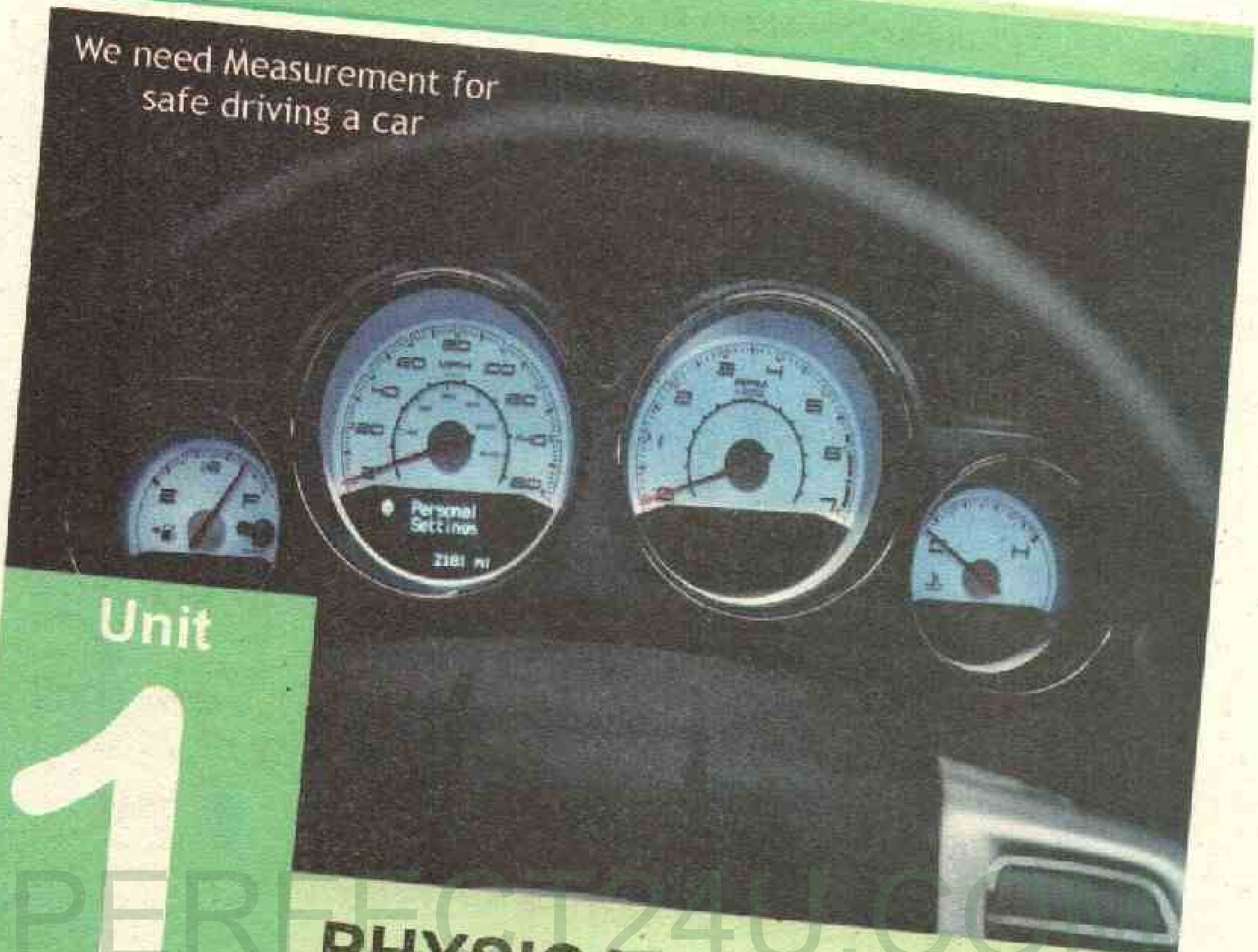


Unit 1

PHYSICAL QUANTITIES AND MEASUREMENT

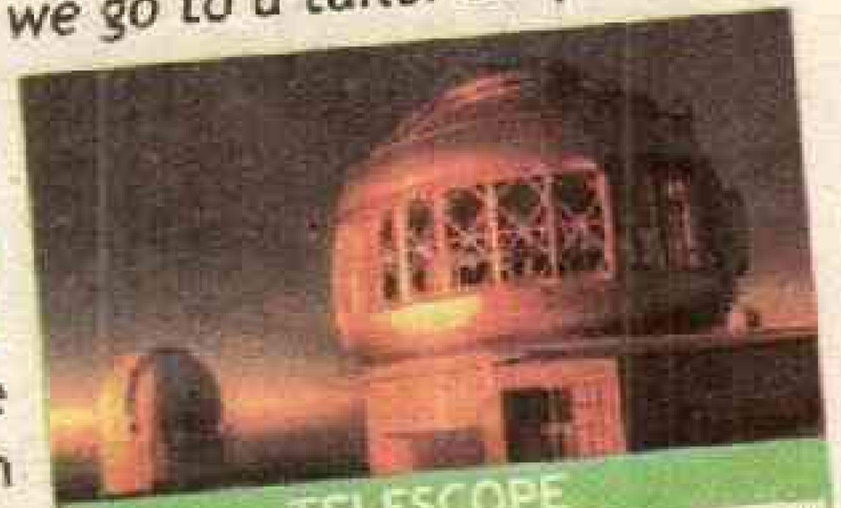
CHECK LIST

After studying this unit you should be able to:

- ✓ Describe the crucial role of Physics in Science, Technology and Society.
- ✓ Explain with examples that Science is based on physical quantities which consist of numerical magnitude and a unit.
- ✓ Differentiate between base and derived physical quantities.
- ✓ List the seven units of System International (SI) along with their symbols and physical quantities
- ✓ Interconvert the prefixes and their symbols to indicate multiples and sub-multiples for both base and derived units.
- ✓ Write the answer in scientific notation in measurements and calculations.
- ✓ Describe the working of vernier callipers and screw gauge for measuring len
- ✓ Identify and explain the limitation of measuring instruments such as m vernier callipers and screw gauge.
- ✓ Describe the need for using significant figures for recording and st the laboratory.

All the quantities we deal in physics require measurements. This chapter is built on Unit 8: Measurement of physical quantities of general science for grade 8.

Measurement is not only a key concern in physics; in our daily life we are always making measurements. For example when we go to a tailor shop before sewing our cloths he takes the required measurements.



TELESCOPE

The telescope in the foreground is Gemini North, one of a pair of twin 8.1-m telescopes located on Mauna Kea in Hawaii. Together, these two telescopes are used to see the visible universe.

1.1 INTRODUCTION TO PHYSICS

Man has always been curious to know the 'how' and 'why' behind the working and function of things. He asks the fundamental questions like how did the universe begin? How does it change? What rules govern its behaviour? Why do things fall to the ground? Why does the moon seem to change shape during the month? What goes inside the sun to make it hot? Physics is all about trying to answer questions like these. All of these phenomena in the universe involve the study of matter and energy.

Physics is the branch of science that involves the study of physical universe: energy, matter, and how they are related.

The study of physics is to understand the world around us, the world inside us and the world beyond us. Physics covers a wide range of phenomena, from the smallest sub-atomic particles to the largest galaxies and universe.

Physicists investigate the motions of electrons and rockets, the energy in sound waves and electric circuits, the structure of the proton and of the universe.

MILKY WAY GALAXY

Our solar system is located in a large spiral-shaped galaxy called the Milky Way and the Sun is just one of at least 100 billion stars in this galaxy.

Mathematics-The Language of Physics: Physics and human conditions improved when mathematics was incorporated in physics some 400 years ago. When the ideas of physics are expressed ... mathematical terms, they are clearer. They ...'t have multiple meanings that so often confuse ...iscussion of ideas expressed in common ... equations of physics provide compact ...f relationships between concepts. ...ngs in nature are expressed mathematically, they are easier to ...e by experiment.

Physics and Science:

Physics is at the root of every field of science. Most of the major developments in Chemistry, Biology, Geology, Agricultural, Environmental science, Astronomy, Engineering and even in medicine have been made by physicists.

Recall GENERAL SCIENCE for GRADE 7, CHAPTER 11, CIRCUITS AND ELECTRIC CURRENT:

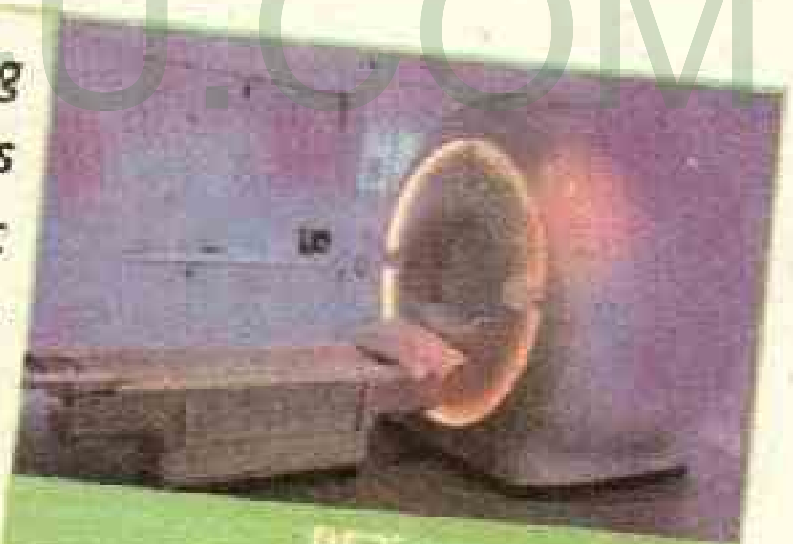
You have already used mathematics in physics when you defined electric current 'I', as time rate of flow of electric charge 'Q' through a given cross-section of a conductor as

$$I = \frac{Q}{t}$$ where I = current, Q = charge, t = time

Physics, Technology and its Impact on our Society:

Physics and technology are closely related however they are also different from each other. Physics is concerned with gathering knowledge and organizing it. Technology lets humans use that knowledge for practical purposes. Physical phenomenon is there behind every technology and therefore physics has a key role in the progress of humankind and in the improvement of quality of living.

Physics provide basic understanding for developing new instrumentation for medical applications such as Computed Tomography (CT Scan), Magnetic Resonance Imaging (MRI), and laser surgeries. The image shown an advance medical imaging device called Positron Emission Tomography (PET).



PET

The use of physics in information technology has improved the standard of communication. Mobile cell phones are commonly used even by illiterates. Hologram technology is a three-dimensional image, created with photographic projection. The hologram technology is also incorporated in cell phones.

HOLOGRAM

QURAAN AND PHYSICS

It is generally accepted that there are more than 700 A'yahat in the Quraan dealing with the natural phenomena. Many A'yahat of Quraan ask mankind to study nature, few are described

لَا الشَّمْسُ يَنْۢبَغِيْ لَهَآ اَنْ تُدْرِكَ الْقَمَرَ وَلَا الَّيْلُ سَابِقُ النَّهَارِ ۭ وَكُلٌّ فِيْ فَلَكٍ يَّسْبَحُوْنَ ۝ (سورہ یٰسٓ - 40)

نہ تو سورج ہی سے ہو سکتا ہے کہ چاند کو جا پکڑے اور نہ رات ہی دن سے پہلے آ سکتی ہے اور سب اپنے اپنے دائرے میں تیر رہے ہیں۔

The sun is not to overtake the moon, nor is the night to outpace the day. Each floats in an orbit.

يٰمَعْشَرَ الْجِنِّ وَالْاِنْسِ اِنِ اسْتَطَعْتُمْ اَنْ تَنْفُذُوْا مِنْ اَقْطَارِ السَّمٰوٰتِ وَالْاَرْضِ فَانْفُذُوْا ۭ لَا تَنْفُذُوْنَ اِلَّا بِسُلْطٰنٍ ۝ (سورہ رحمٰن - 33)

اے گروہ جن وانس اگر تمہیں قدرت ہو کہ آسمان اور زمین کے کناروں سے نکل جاؤ تو نکل جاؤ اور زور کے سوا تو تم نکل سکتے ہی نہیں۔

O company of Jinn and men, if you can (and want) to cross the limits sky and earth, then cross, you will not cross except by the authority (from Allah).

الَّذِيْ خَلَقَ سَبْعَ سَمٰوٰتٍ طِبَاقًا ۭ مَا تَرٰى فِيْ خَلْقِ الرَّحْمٰنِ مِنْ تَفٰوُتٍ ۭ فَارْجِعِ الْبَصَرَ ۙ هَلْ تَرٰى مِنْ فُطُوْرٍ ۝ (سورہ ملک - 3)

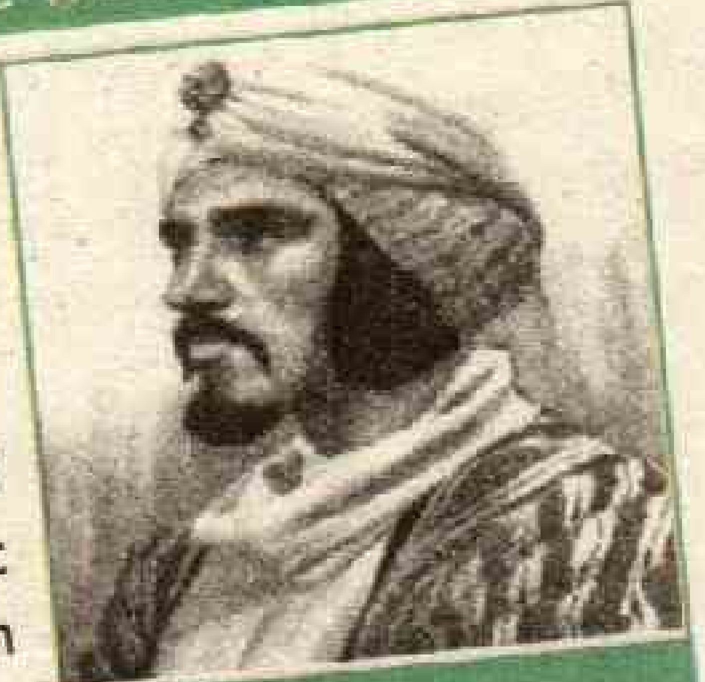
اس نے سات آسمان اوپر تلے بنائے (اے دیکھنے والے) کیا تو (اللہ) رحمٰن کی آفرینش میں کوئی نقص دیکھتا ہے؟ ذرا آنکھ اٹھا کر دیکھ تجھ کو (آسمان میں) کوئی شگاف نظر آتا ہے۔

He who created seven heavens in layers. You see no discrepancy in the creation of the compassionate. Look again can you see any fault?

اَفَلَا يَنْظُرُوْنَ	اَفَلَا يَتَدَبَّرُوْنَ	اَفَلَا يَتَفَكَّرُوْنَ
آیا یہ لوگ نہیں دیکھتے۔	بھلا یہ لوگ غور نہیں کرتے۔	بھلا یہ لوگ غور و فکر نہیں۔
Do they (people) not look?	Do they not contemplate?	Do they not think?

CONTRIBUTION TO PHYSICAL SCIENCE BY ISLAMIC WORLD

Scientists of the Islamic world contributed in the development of physics. Few of the notable scientists are:



YAQUB KINDI

Yaqub Kindi (800 - 873):

He was born in Busra, Iraq. He produced extensive research monographs on metrology, specific gravity and tides. His most important work was done in the field of optics, especially on reflection of light.

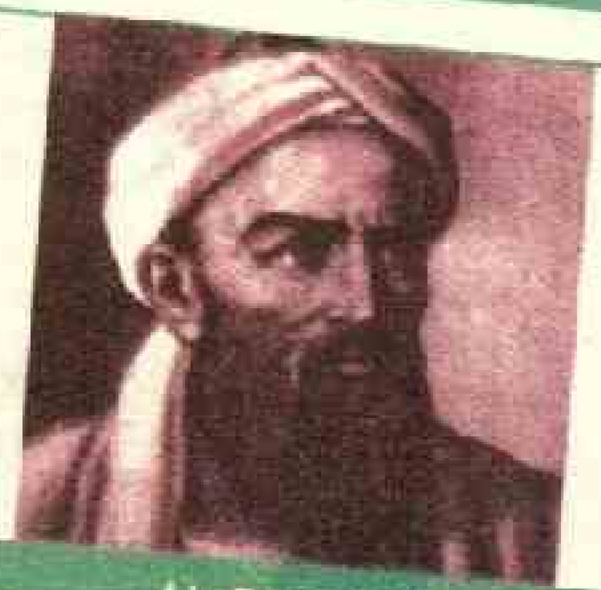
Ibnal Haitham (965 - 1039):

He was born in Busra, Iraq. He was great scholar of his time. His greatest work is the book on optics named KITAB UL MANAZIR. He is also considered as the inventor of the pin-hole camera.

IBNAL HAITHAM

Al Beruni (973-1048):

He is afghan scholar and wrote about 150 books on physics, cosmology, geography, culture, archeology and medicine. Al Beruni discussed the shape of earth the movement of sun, moon and phases of moon.



AL BERUNI

FAMOUS PAKISTANI PHYSICISTS

Mohammad Abdus Salam:

(29 January 1926 – 21 November 1996), was a Pakistani theoretical physicist. A major figure in 20th century theoretical physics, he shared the 1979 Nobel Prize in Physics with Sheldon Glashow and Steven Weinberg for his contribution to the electroweak unification theory. He was the first Pakistani to receive a Nobel Prize in science.

Abdul Qadeer Khan:

Abdul Qadeer Khan known as A. Q. Khan (born in 27 April 1936) is a Pakistani nuclear physicist and a metallurgical engineer, who founded the uranium enrichment program for Pakistan's atomic bomb project. He founded and established Kahuta Research Laboratories (KRL) in 1976, and served as both its Senior Scientist and Director-General until he retired in 2001.

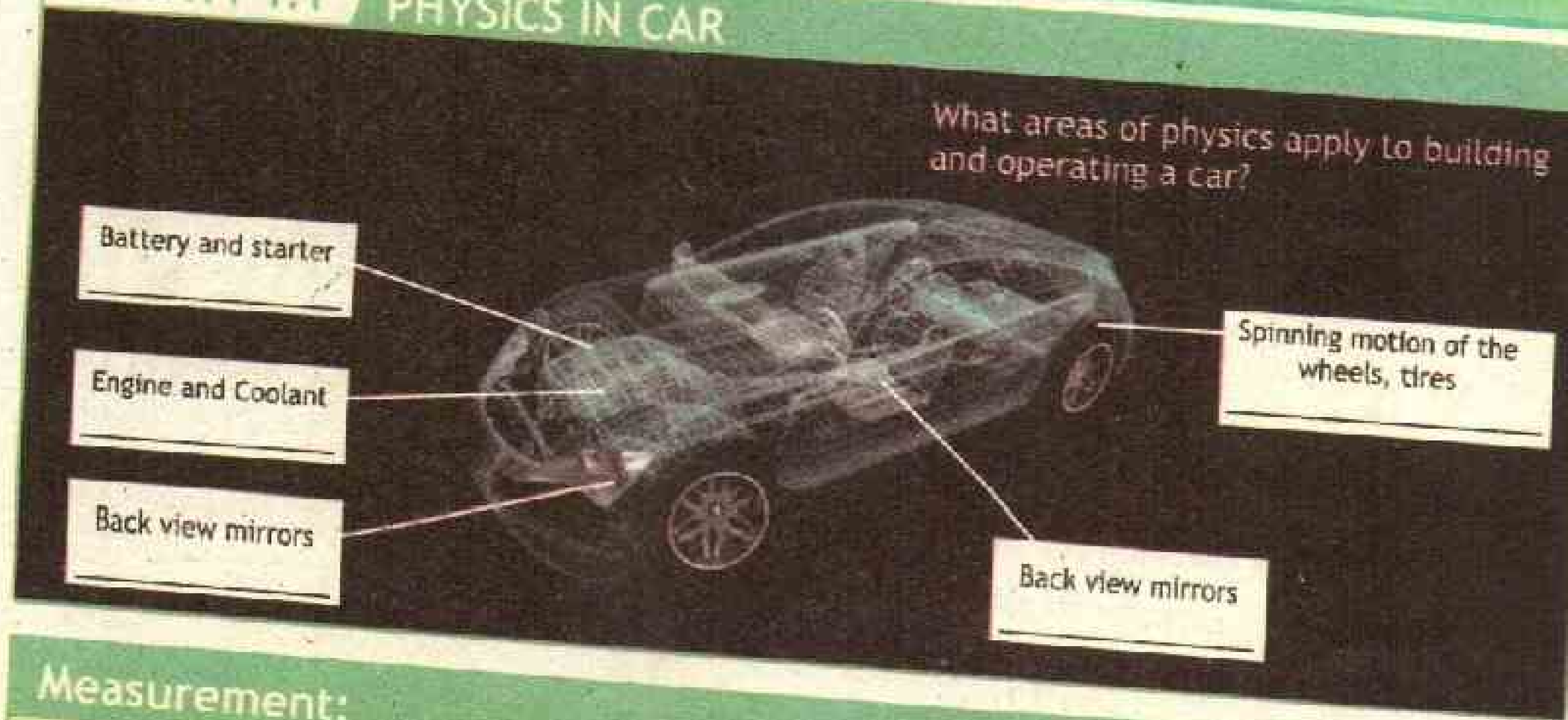
BRANCHES OF PHYSICS

Due to vast scope and research in physics it is usually divided into a number of branches some of them given below.

TABLE 1.1 BRANCHES OF PHYSICS

Area within physics	Description	Examples
Mechanics	Motion of objects and how it relates to forces	falling objects, friction, weight, spinning objects
Heat and Therodynamics	Heat and temperature and their relation to energy.	melting and freezing processes, engines, refrigerators
Oscillations and Waves	to and fro motion	Springs, Water waves, Sound
Optics	Light and the instrument created to use or detect it	Mirrors, Lenses, telescopes, Eye
Electricity and Magnetism	Static as well as moving charges and associated physical phenomena	electrical charge, circuitry, magnets, electromagnets
Atomic and Nuclear Physics	Structure and properties of individual atoms and nuclei of an atom.	X-rays, LASERS, Nuclear Reactor, MRI, CT Scan, PET Scan
Relativity	Moving Object (including very high speed) and gravitation	Particle accelerators, Nuclear Energy
Quantum Physics	Discrete, indivisible units of energy called quanta	the atom and its parts
Particle Physics	nature of the particles that constitute matter and radiation	Quarks, Leptons, Photons, Bosons
Cosmology and astrophysics	the origin, evolution, and eventual fate of the universe	Stars, galaxies and black holes
Biophysics and Medical Physics	physical interactions of biological processes and Application of physics health processes such as prevention, diagnosis, and treatment.	MRI, CT Scan, Radiotracers and conduction in living cells.

ACTIVITY 1.1 PHYSICS IN CAR



Measurement:

Recall

Measurement is a comparison between an unknown quantity *(measurable quantities like mass, length etc)* ***and standard*** *to see how many times as big it is.*

Unit is standard with which things are compared. Before a measurement can be made, a standard or unit must be chosen. The size of the quantity to be measured is then found with an instrument having a scale marked in the unit.

1.2 PHYSICAL QUANTITIES

All the quantities that can be measured are called physical quantities.

In physics we study only those quantities which can be defined and measured. Quantities like length, mass, time, density, temperature can be measured therefore they are called physical quantities.

For example the length of the book can be measured, the duration of our stay at school is measurable, hence these are physical quantities. Physical quantities are classified into two categories:

> **CAN YOU TELL?**
>
> Are there quantities which we can not measure?

A. Base quantities:

Minimum Number of physical quantities selected and their units are defined and standardized such that in terms of these all other physical quantities can be expressed are called base quantities. The corresponding units for these quantities are called base units.

B. Derived quantities:

The physical quantities defined in terms of base quantities are called derived quantities. The corresponding units for these quantities are called derived units.

1.3 INTERNATIONAL SYSTEM OF UNITS

'A complete set of units for all physical quantities is called system of units'. The international system of unite's is abbreviated as SI units. Actually, SI units is a short form of the French name 'System International (d' Units') which means 'International System of Units'. The international system of units is based on seven base units (or seven basic units) from which all other units are derived. The seven basic physical quantities, their SI base units and symbols are given in the table 1.2.

INFORMATION

Aeroplane pilot require large number of measuring and information instruments for safe flight.

TABLE 1.2 BASE UNITS FOR INTERNATIONAL SYSTEM OF UNITS

Base Quantity		SI Base Unit	
Name	Symbol	Name	Symbol
length	l, x, r (e.t.c)	meter	m
mass	m	kilogram	kg
time, duration	t	second	s
electric current	I or *i*	ampere	A
thermodynamic temperature	T	kelvin	K
amount of substance	n	mole	mol
luminous intensity	I	candela	cd

A. SI Base Units:

In SI *SEVEN* physical quantities are chosen as base and their units are defined, standardized and are called base units. Each SI unit is defined carefully so that it is unique and upon which accurate and reproducible measurements can be made.

TID-BIT : WHY SI?

Before SI units were standardized, Isaac Newton in his book while specifying the length of the pendulum reported not only as '37 whole 7/8 inches long' but '37 whole 7/8 London inches long'. The inch (unit of length) in different cities of England was defined to have different length.
Similarly before SI, we had to deal with odd conversion factors like 16 ounces in a pound or 12 inches in a foot or 5280 feet in a mile. SI came up with decimal notation like 1000 metres was termed as 1 kilometre and 100 centimetres as 1 metre.

In physics we deal with numbers that are either very small or very large, it becomes difficult to write these numbers. For example, the mass of moon is approximately 70,000,000,000,000,000,000,000 kilograms. If we use this number often, we would surely like to have a more compact notation for it. This is exactly what standard form or scientific notation is. It represents a number as the product of a number greater than 1 and less than 10 (called the mantissa) and a power of 10 (termed as exponent):

$$\text{number (N)} = \text{mantissa (M)} \times 10^{\text{exponent (n)}}$$

The mass of moon can thus be written compactly as 7×10^{22} kg, where 7 is the mantissa and 22 is the exponent. Similarly, the diameter of atomic nucleus is about 0.00000000000001 m, which in standard form or scientific notation is 1×10^{-14} m.

STEPS FOR CONVERTING NUMBER TO STANDARD FORM

1. In a given number N, move the decimal point and place it after first non-zero digit which will make it mantissa (M).
2. If the decimal is moved towards left from its given initial position then the power of 10 will be positive and whatever is the number of digits through which the decimal point has been moved that will be the value of exponent (power of 10).
3. Similarly, if the decimal point is moved towards right from its given position then the power of 10 will be negative and whatever is the number of digits through which the decimal point has been moved that will be the value of exponent (power of 10).

Example 1.1 AVERAGE DISTANCE BETWEEN EARTH AND MOON

Average distance between earth and moon is 384,400,000 m. Write this number in Standard form / scientific notation.

SOLUTION

For Standard form / scientific notation we can write the term as

$$\text{distance} = 384400000.0 \times 10^{0}\,m$$

For Standard form / scientific notation in order to get mantissa (M) in which the 1st digit before the decimal is non-zero, we have to move the decimal 8 digits towards left. Therefore, the power of 10 will be positive 8, that is

$$\text{distance} = 3.84400000 \times 10^{8}\,m$$ — Answer

EXTENSION EXERCISE 1.1

Why we used the word average in problem statement.

B. Derived Units:

Units derived from multiplying and dividing base units are termed as derived units. In SI units for all other physical quantities can be derived from the seven base units. The units for velocity and acceleration are 'm/s' and 'm/s^2', respectively. Some derived units were used so often that it became convenient to give them their own names and symbols. For example force has derived units of '$kgms^{-2}$' which is given special name as 'newton' and represented as 'N'. Some derived quantities with derived units in terms of base units are given in table 1.3.

POINT TO PONDER

Viruses (about 10^{7} m long) attacking a cell. How such small lengths can be measured?

TABLE 1.3 DERIVED UNITS FOR 'INTERNATIONAL SYSTEM OF UNITS'

Derived Quantity		Derived Unit	
Name	Symbol	Name	Symbol
area	A	square meter	m^2
volume	V	cubic meter	m^3
speed, velocity	v	meter per second	ms^{-1}
acceleration	a	meter per second squared	ms^{-2}
density	ρ	kilogram per cubic meter	kgm^{-3}
force	F	newton	$N = kgms^{-2}$
pressure	P	pascal	$Pa = kgm^{-1}s^{-2}$
energy	E, U	joule	$J = kgm^2s^{-2}$
capacitance	C	farad	$F = kg^{-1}m^{-2}s^4A^2$
resistance	R	ohm	$\Omega = kgm^2s^{-3}A^{-2}$

1.4 Standard Form / SCIENTIFIC NOTATION

Scientific notation is a way of writing numbers that are too big or too small to be easily written in decimal form. Standard form or scientific notation has a number of useful properties and is commonly used by scientists, mathematicians and engineers.

Which is the average distance between earth and moon in standard form or scientific notation.

Assignment 1.1 MASS OF EARTH

The mass of Earth is 5,980,000,000,000,000,000,000,000 kg, write this number in Standard form / scientific notation.

Example 1.2 NUMBER OF SECONDS IN AN YEAR

Find the number of seconds in a year and write the answer in Standard form or scientific notation.

SOLUTION

We know that there are 365 days in a year (y), 24 hours in a day (d), 60 minutes in an hour (h), and 60 seconds (s) in a minute (min). These four relationships are conversion factors. Starting with 1 y and multiplying by these conversion factors, we obtain

$$1y = 1y \times \frac{365d}{1y} \times \frac{24h}{1d} \times \frac{60m}{1h} \times \frac{60s}{1m}$$

or $1y = 1 \times 365 \times 24 \times 60 \times 60\,s$

or $1y = 31536000\,s$

For Standard form / scientific notation we can write the term as

$$1y = 31536000.0 \times 10^0 s$$

In order to get mantissa (M) in which the 1st digit before the decimal is non-zero, we have to move the decimal 7 digits towards left. Therefore, the power of 10 will be positive 7, that is

$$1y = 3.1536000 \times 10^7 s$$ — **Answer**

EXTENSION EXERCISE 1.2

Is this value exact? After each 4 years we have a leap year in which we have 366 days, how would we account for that?

Assignment 1.2 SECONDS IN A WEEK

Calculate the number of seconds in a week. Express The number in power of 10 notation.

Example 1.3 SMALLEST MOLECULE

The smallest molecule is the diatomic hydrogen (H_2), with a bond length of 0.000,000,000,074 m. Write the answer in Standard form.

SOLUTION

In Standard form / scientific notation we can write the term as

$$\text{Bondlength} = 0.000000000074 \times 10^{0} m$$

For Standard form / scientific notation in order to get mantissa (M) in which the 1st digit before the decimal is non-zero, we have to move the decimal 11 digits to the right. Therefore, the power of 10 will be negative 11, that is

$$\text{Bondlength} = 7.4 \times 10^{-11} m$$ — Answer

Which is the bond length for diatomic hydrogen in standard form / scientific notation.

Assignment 1.3 AVERAGE MASS OF HOUSE FLY

Adult housefly (Musca domestica) is having a mass of only about 0.000,021,4 kg. Express this number in standard form / scientific notation.

1.5 PREFIXES TO POWER OF TEN

A mechanism through which a very small or very large number is expressed in terms of power of ten by giving a proper name to it is called prefix to the power of ten.

Prefixes makes standard form to be written even more easily. Large numbers are simply written in more convenient prefix with units.

The thickness of a paper can be written conveniently in smaller units of millimetre instead of metre. Similarly the long distance between two cities may be expressed better in a bigger unit of distance, i.e., kilometre. A useful set of prefixes in SI to replace powers of 10 are given in table 1.5.

CAN YOU TELL?

Name the convenient unit you will use to measure.

a) width of a book
b) length of a room
c) diameter of a wire
d) mass of candy
e) mass of cricket ball.

TABLE 1.5 PREFIXES

Prefix	Decimal Multiplier	Symbol	Prefix	Decimal Multiplier	Symbol
Exa	10^{18}	E	deci	10^{-1}	d
Peta	10^{15}	P	centi	10^{-2}	c
Tera	10^{12}	T	milli	10^{-3}	m
giga	10^{9}	G	micro	10^{-6}	μ
Mega	10^{6}	M	nano	10^{-9}	n
kilo	10^{3}	k	pico	10^{-12}	p
hecto	10^{2}	h	femto	10^{-15}	f
deca	10^{1}	da	atto	10^{-18}	a

ACTIVITY 1.2 ABOUT US

Calculate your height in centimeters and meters and your mass (notice that we do not say weight) in kilograms.

INFORMATION

The mass of this mosquito can be expressed several different ways: 1×10^{-5} kg, 0.0 1 g, or 10 mg.

CAN YOU TELL?

Choose the base physical quantities and derived physical quantities from the following.

Temperature, Volume, Time, Area, Density, Length

Example 1.4 SIZE OF BACTERIUM

A typical bacterium has a mass of 2.0 fg. Express this measurement in terms of kg.

SOLUTION

Given mass m = 2.0 fg

We know that femtogram $1fg = 1\times10^{-15}\,g$

kilogram $1kg = 1\times10^{3}\,g$

$m = 2fg$

$m = 2\,fg = 2\times10^{-15}\,g \times \frac{1\,kg}{1\times10^{3}\,g}$

therefore $m = 2\,fg = 2\times10^{-18}\,kg$ — **Answer**

*Tuberculosis is a respiratory disease (infectious) caused by a bacteria known as **Mycobacterium tuberculosis.***

Assignment 1.4 SMALLEST BIRD

The smallest bird is the bee hummingbird. Males measure only 0.057 m, Convert this number to standard form and write this number in millimetre.

Example 1.5 PESHAWAR TO LAHORE VIA MOTORWAY

The distance from Peshawar to Lahore through motorway is 489 km, convert this number to megametre (Mm).

SOLUTION

Given Distance d = 489 km

We know that kilometre $1km = 1\times10^3\,m$

and megametre $1Mm = 1\times10^6\,m$

$$d = 489\,km = 489\times10^3\,m\times\frac{1\,Mm}{1\times10^6\,m} \quad \text{or} \quad 489\,km = 489\times10^{-3}\,Mm$$

$$d = 489\,km = 0.489\times10^0\,Mm$$

therefore $489\,km = 0.489\,Mm$ — **Answer**

EXTENSION EXERCISE 1.3

If we go to Lahore by aeroplane, the distance shortens to 376 km, why?

Assignment 1.5 *mm* **TO LAHORE**

Calculate the distance from Peshawar to Lahore in millimetres.

1.6 MEASURING INSTRUMENTS

'Measuring instruments are devices to measure physical quantities'.

Physicists use large number of measuring instruments. These range from simple objects such as rulers and stopwatches to Atomic Force Microscope (AFM) and Scanning Tunneling Electron Microscope (STEM). All measuring instruments have some measuring limitations.

Least count is the minimum value that can be measured on the scale of measuring instrument.

While using a measuring instrument, it is therefore important to take certain precautions in order to obtain an accurate reading.

1.6.1 METRE RULE

This instrument is used to measure the lengths of objects or the distance between two points.

Rulers are made from different materials (wood, plastic, metal) and in a wide range of sizes. Metre rules are one metre long as compared to the standard metre. Metre Rulers usually have 1000 small divisions on them called millimetres. Such metre rulers have least count of 1 mm.

POINT TO PONDER

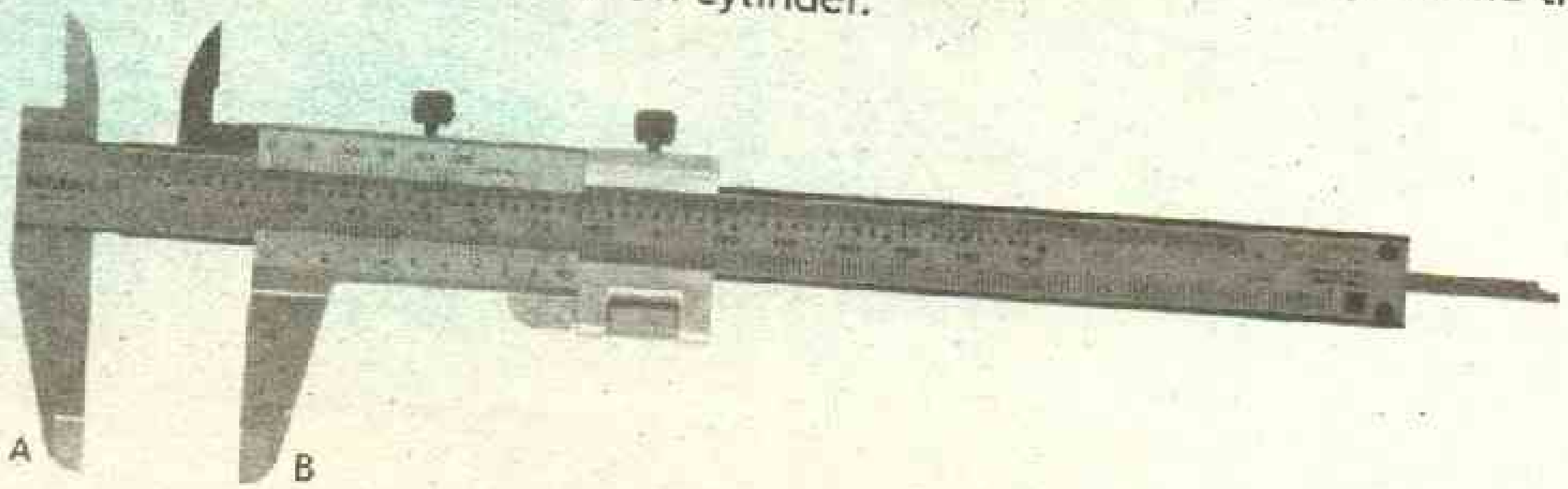
INCHES ON METRE RULE:

Why are inches and feet marked on metre rule? Show the relationship between foot and inch to metre, centimetre and millimetre.

1.6.2 VERNIER CALIPER

'A device used to measure a fraction of smallest scale division by sliding another scale over it is called vernier caliper'. It is a device used to measure small length accurately upto 0.1mm or 0.01cm.

It can be used to measure the thickness, diameter or width of an object and the internal, external diameter of hollow cylinder.



There are two scales on vernier callipers.

Main (fixed) Scale:

A main scale which has markings of usually of 1 mm each and it contains jaw A on its left end.

Vernier (sliding) Scale:

A vernier (sliding) scale which has markings of some multiple of the marking on the main scale. The vernier scale usually has length of 9 mm and is divided equally into 10 divisions (thus separation between two lines on vernier scale is 9/10 mm = 0.9 mm).

Vernier Constant (Least Count of Vernier Callipers):

Minimum length which can be measured accurately with the help of a vernier callipers is called vernier constant or least count of vernier callipers.

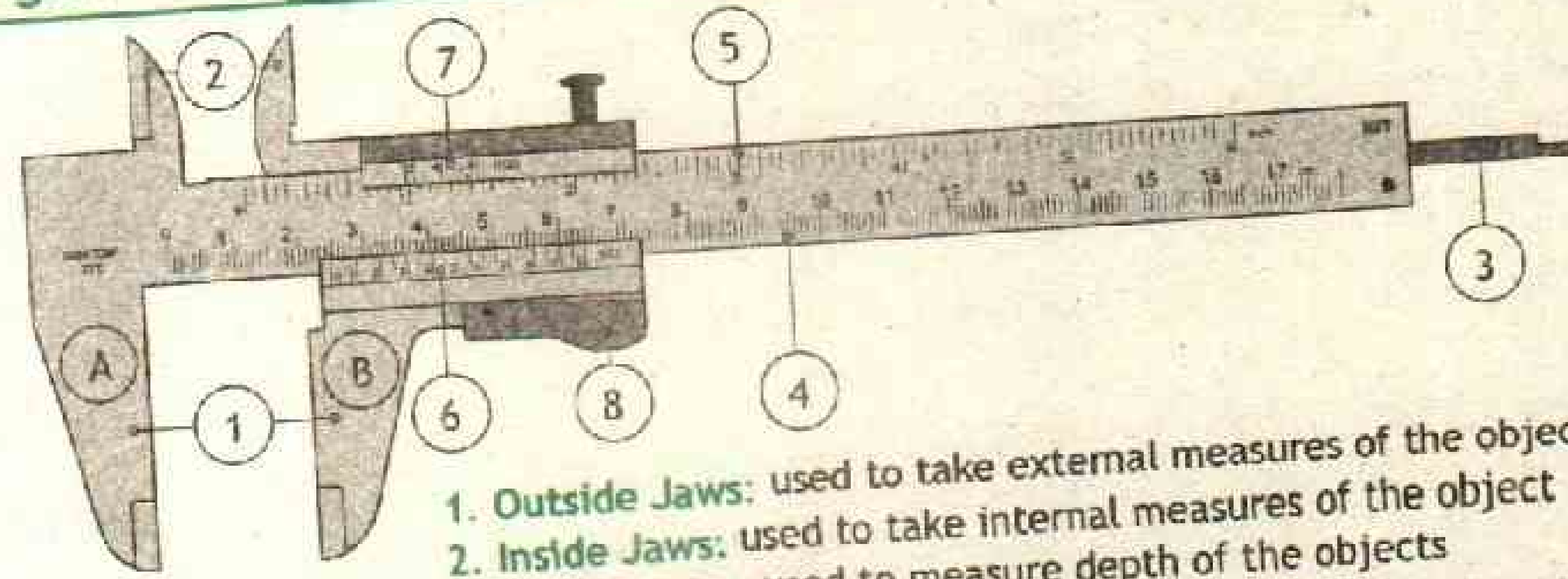
Least count is calculated by two methods:

Method 1:

The difference between the value of one main scale division and the value of one vernier scale division i.e.

Least Count = One Main Scale Division – One Vernier Scale Division

Figure 1.1 Vernier Caliper



1. **Outside Jaws:** used to take external measures of the object
2. **Inside Jaws:** used to take internal measures of the object
3. **Depth Probe:** used to measure depth of the objects
4. **Main Scale:** Used in centimetre or millimetre measurements
5. **Main Scale:** Used in inches measurements
6. **Vernier Scale:** Used in centimetre or millimetre measurements
7. **Vernier Scale:** Used in inches measurements
8. **Retainer:** Used to block movable parts

If one main scale division is 1 mm one vernier scale division is 0.9 mm, the least count is 0.1mm.

Method 2:

Mathematically, least count can also be obtained from dividing the value of smallest division on main scale by total number of divisions on vernier scale.

$$\text{Least Count} = \frac{\text{Smallest division on main scale}}{\text{Total number of divisions on vernier scale}}$$

If the smallest main scale division is 1 mm and vernier scale division has 10 division on it then the least count is

$$\text{Least Count} = \frac{1mm}{10} = 0.1mm$$

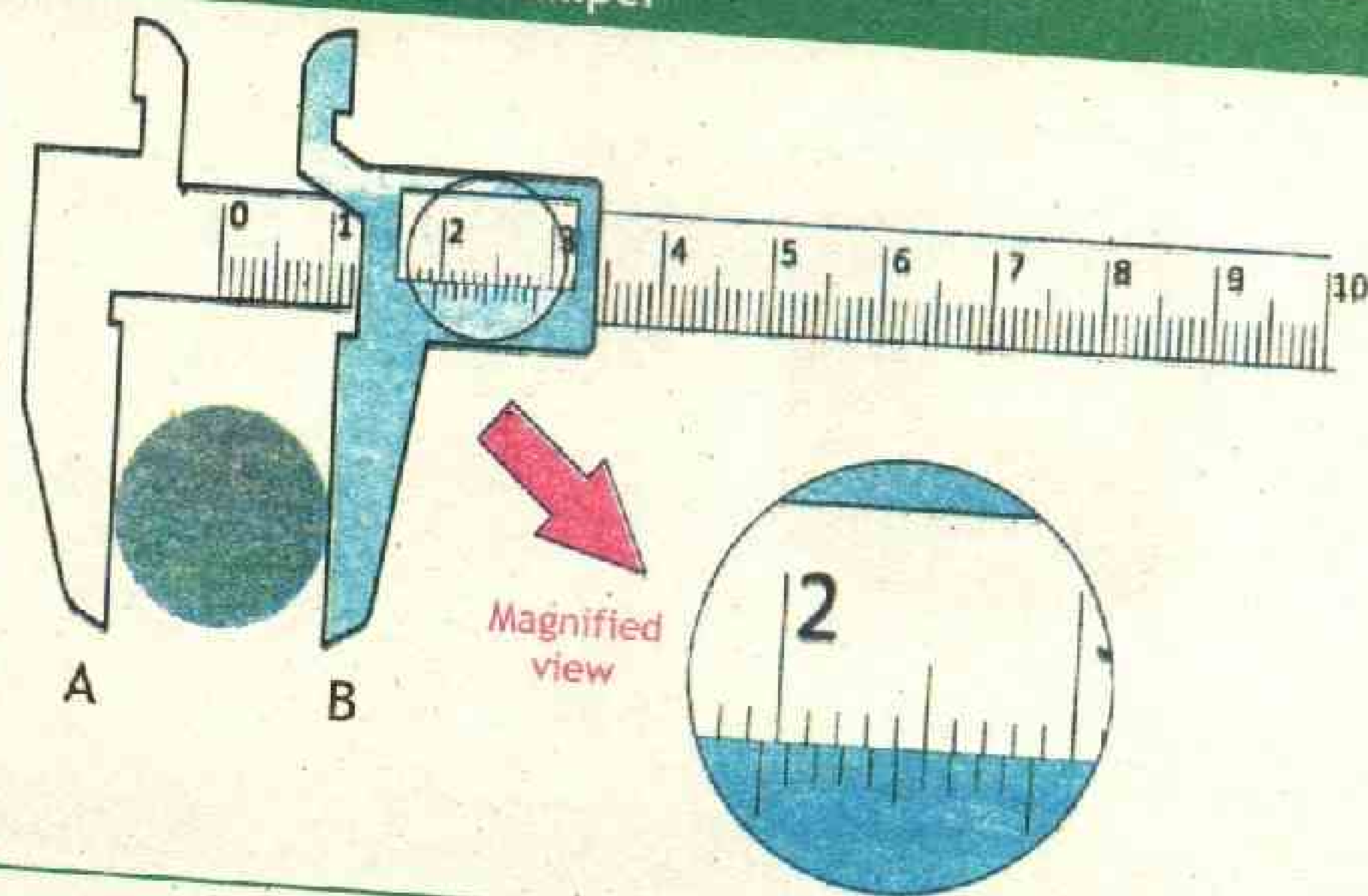
ZERO ERROR IN VERNIER CALIPER

On closing the jaws of the calipers, the zero of the Vernier Scale may or may not coincide with the zero of the main Scale. If their zeros does not coincide, there is zero error in the instrument. The zero error and its correction will be discussed in laboratory work.

Suppose we want to measure the diameter of a small solid cylinder with vernier caliper we will use the following method.

1. Note the least count of the vernier, (it is usually written on vernier caliper, otherwise we can find it out by method described previously) which in our case is 0.01 cm (0.1 mm).

Figure 1.2 Vernier Caliper



2. Close the jaws fully with no object between the jaws. If the zero line of the vernier scale coincides with the zero line of the main scale then there is no zero error.
3. Now fix the solid cylinder in between the two jaws and tighten the vernier with the help of screw 'S' suppose the zero of the vernier scale is to the right of 1.9 cm the mark and to the left of the 2.0 cm (20 mm) mark as shown in figure 1.2. Thus the required length is somewhat greater than 1.9 cm (19 mm).
4. To find the fraction to be added. We see that division of the vernier scale which coincides (in line) with any division of the main scale. As the 6th division of the vernier scale coincides with one of the main scale divisions as in figure 1.2.
5. Multiply the least count 0.01 cm (0.1 mm) by 6 which gives 0.06 cm (0.6 mm) and add to 1.9 cm (19 mm). The measured length is 1.9 cm + 0.06 cm = 1.96 cm or 19 mm + 0.6 mm = 19.6 mm

Hence the diameter of solid cylinder is 1.96 cm (19.6 mm).

LAB WORK

- To measure the area of cross section by measuring diameter of a solid cylinder with vernier callipers.
- To measure the volume of a solid cylinder by measuring length and diameter of a solid cylinder with vernier callipers.

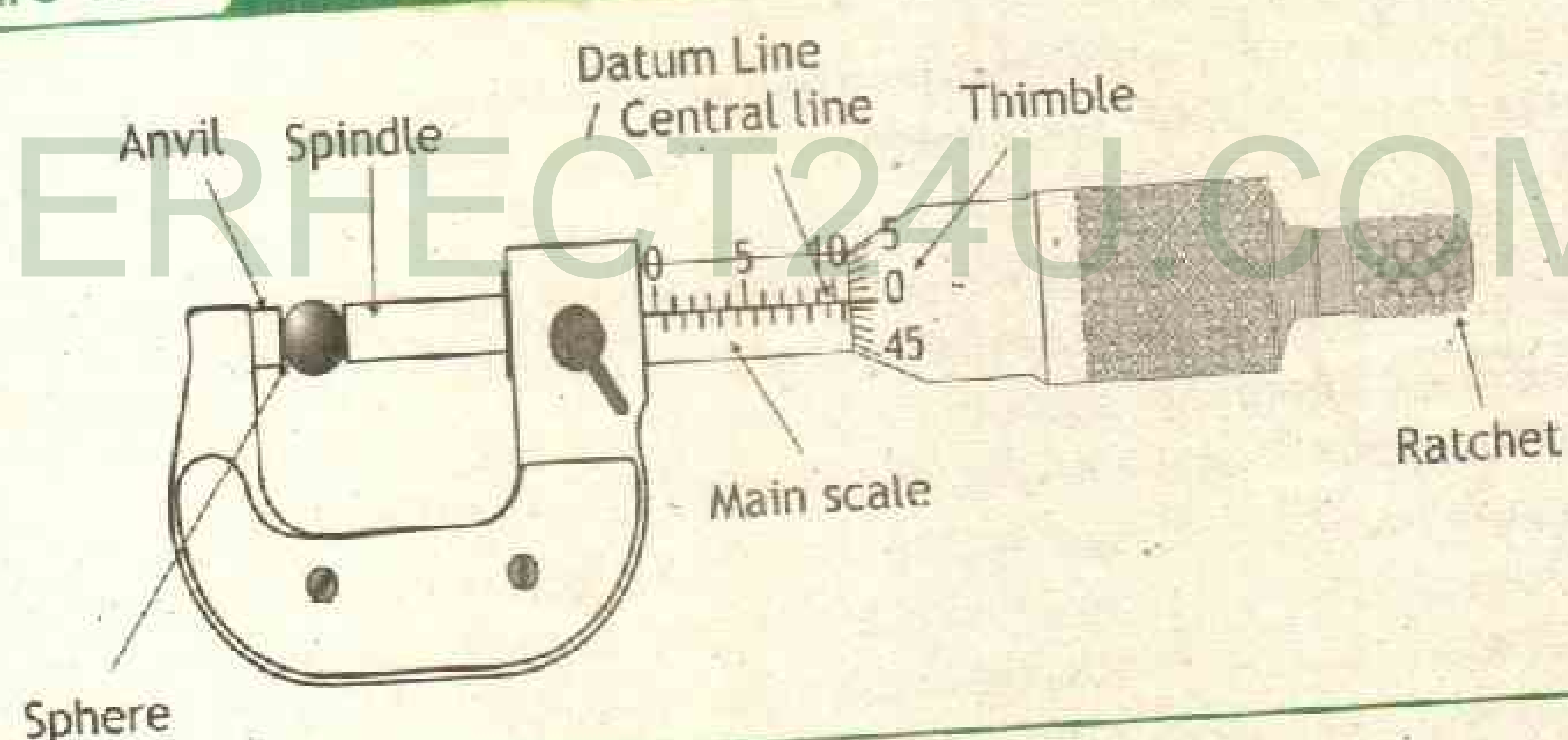
1.6.3 SCREW GAUGE

'A device used to measure a fraction of smallest scale division by rotatory motion of circular scale over it is known as screw gauge'.

Pitch of Screw Gauge:

The distance traveled by the circular scale on linear scale in one rotation is called the pitch of the screw gauge.

Figure 1.3 Screw Gauge



Least Count of Screw Gauge:

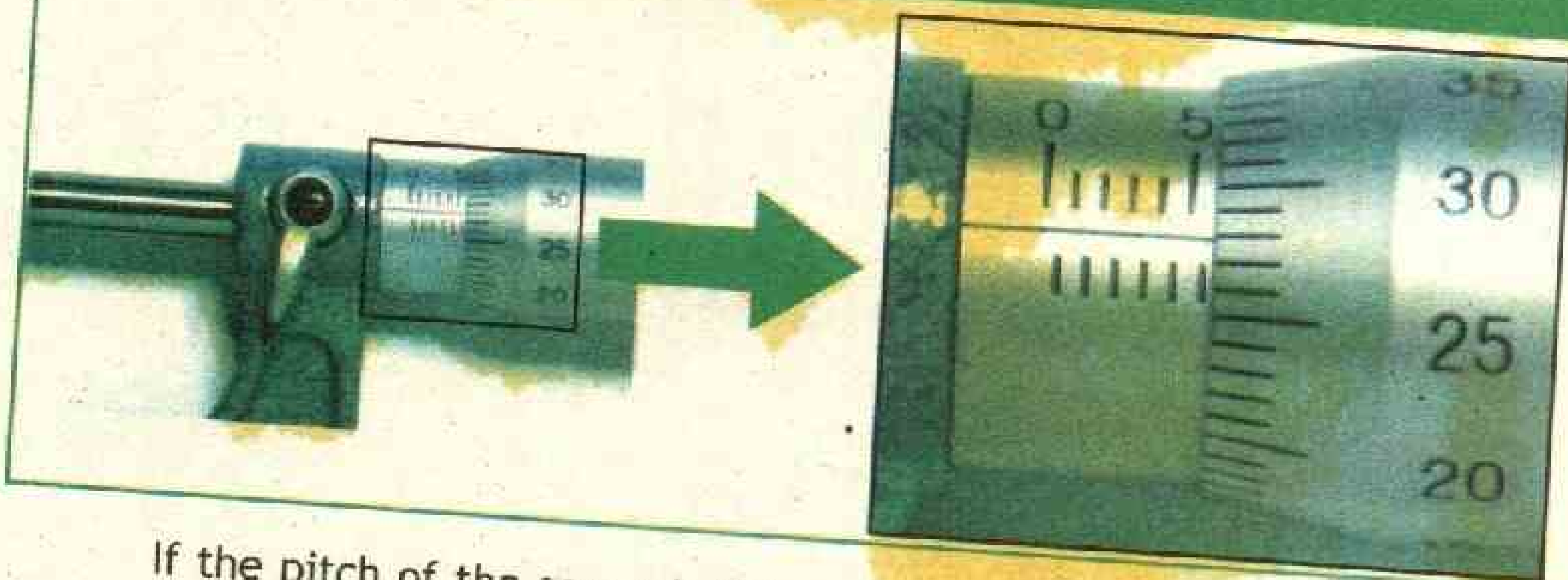
The minimum length which can be measured accurately by a screw gauge is called least count of the screw gauge. The least count of screw gauge is found by dividing its pitch by the total number of circular scale divisions.

$$Least\ Count = \frac{\text{Pitch of Screw Guage}}{\text{Total Number of Divisions on Circular Scale}}$$

If the pitch of the screw gauge is 0.5 mm and the number of divisions on circular scale is 50 then

e.g. $Least\ Count = \frac{0.5mm}{50} = 0.01mm$

Figure 1.4 Screw Gauge



If the pitch of the screw is 0.5 mm and the number of divisions on the circular scale are 50 then the diameter of small sphere is measured by using a screw gauge by the following method.

1. Note the pitch and least count of the screw gauge.
2. Place the object between thimble and anvil. Now turn the thimble until the anvil and spindle gently grip the object. Then turn the ratchet until it starts to click. The ratchet prevents the user from exerting too much pressure on the object.
3. Read the main scale reading. For example, in figure 1.4 the edge of circular scale is lying between 5.5 mm and 6.0 mm, i.e. the diameter of the sphere is more than 5.5 mm and less than 6.0 mm.
4. To know the part more than 5.5 mm. We look for the division of circular scale (Thimble scale) which is in front of the datum line. In figure 1.4 it is 28.
5. Now multiplying 28 by the least count which is 0.01 mm we get 0.28 mm. Add this product to 5.5 mm.

$$5.5 \text{ mm} + 0.28 \text{ mm} = 5.78 \text{ mm}$$

Thus 5.78 mm is the diameter of the sphere

ZERO ERROR IN SCREW GAUGE

Turn the thimble until the anvil and spindle meet. If the zero mark on the thimble scale does not lie directly opposite the datum line of the main scale we say that there is zero error. The zero error and its correction will be discussed in laboratory work.

LAB WORK

Measure the thickness of a metal strip or a wire by using a screw gauge.

ACTIVITY THICKNESS OF PHYSICS BOOK AND PAGE

With your ruler find the thickness of the book excluding cover, now divide the number by the number of pages in the book also compare the result with the measurement you take with screw gauge.

Assignment 1.6 WHICH INSTRUMENT IS MORE ACCURATE?

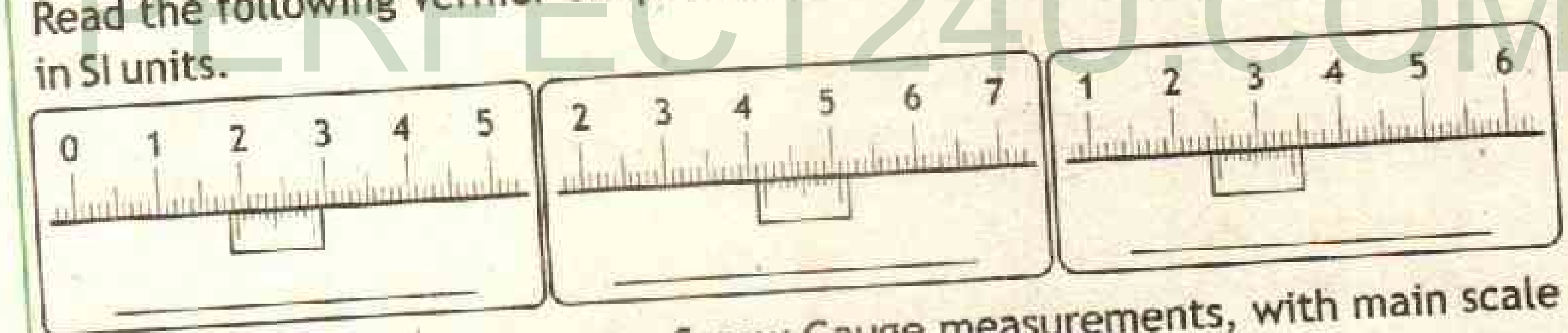
Which of the following is the accurate device for measuring length :

A) a vernier callipers with main scale of 1 mm marking and 50 divisions on the sliding scale

B) a screw gauge of pitch 1 mm and 25 divisions on the circular scale

ACTIVITY READINGS OF VERNIER CALIPERS AND SCREW GAUGE

Read the following Vernier Caliper measurements, with main scale calibrated in SI units.



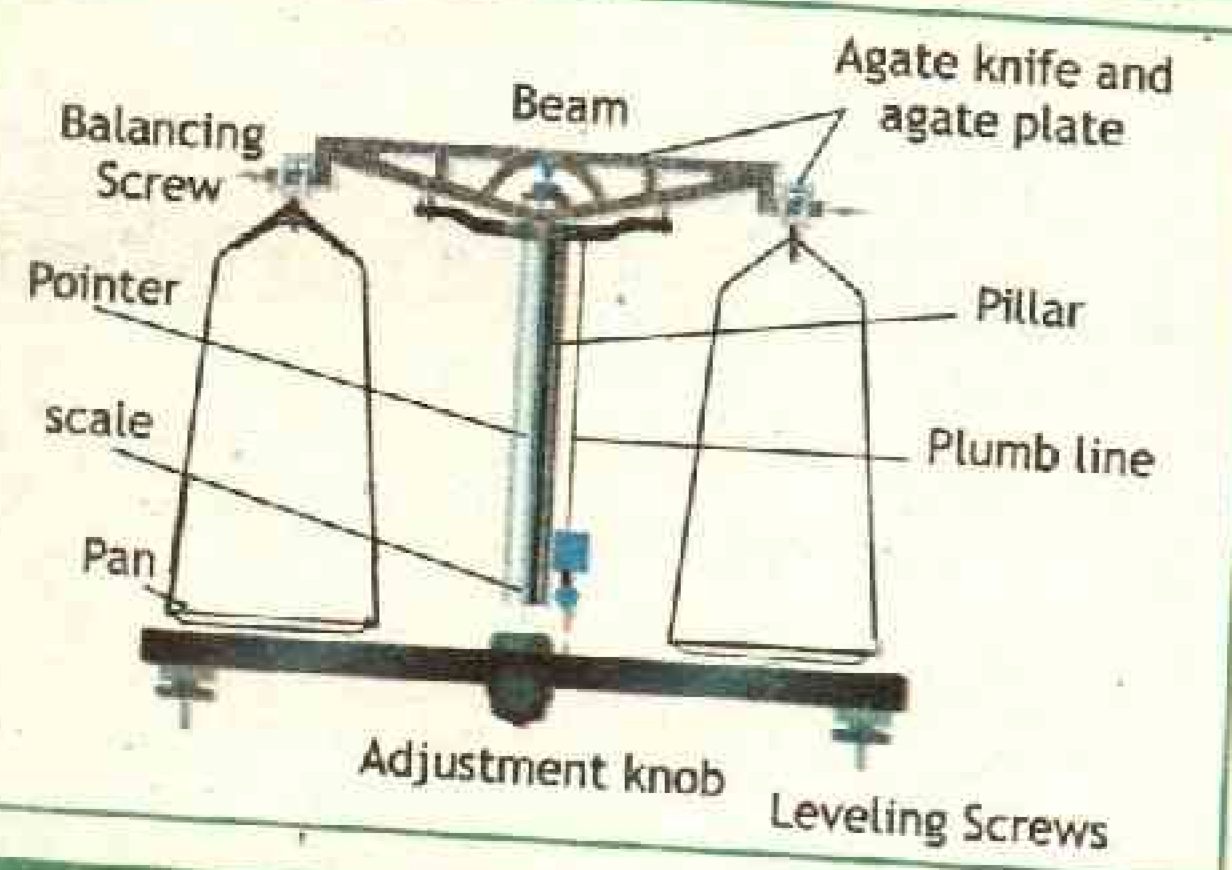
Read the following Micrometer Screw Gauge measurements, with main scale calibrated in SI units.

1.6.4 PHYSICAL BALANCE

The mass of a body is difficult to determine, but it can be compared easily against a body of known mass. This process of comparing the masses of two bodies is commonly known as weighing process. This weighing is carried out through a balance.

Physical balance is just a common balance where there are two pans and you measure weight of an object by putting it in one pan and a known weight in the other.

A physical balance is a very sensitive common balance which can measure weights in milligram order. It is placed in a protective glass case so that even dust and wind can not affect the accuracy of the instrument.



1.6.5 STOP WATCH

The duration of time of specific interval is measured by a stop watch. It has two main types i.e. mechanical and digital.

A) Mechanical / Analogue Stop Watch:

It consists of two hands a small minute hand and a long second hand. Scales for each hand are marked on a circular dial. To note the time both the hands are set at zero by pressing and releasing the knob. As the knob is pressed and released again, the watch starts.

When the second's hand completes two rotations of 30 seconds each, the minute hand advances by one division. When it is required to be stopped, again the same knob is pushed, the watch stops, and time can be noted.

ANALOGUE STOP WATCH

A Mechanical / analogue stop watch can measure up accuracy of 0.1 second, this is the least count of mechanical or analogue stop watch.

B) Digital Stopwatch:

The timing functions in digital stopwatch are usually controlled by two buttons on the case. Pressing the top button starts the timer running, and pressing the button a second time stops it, leaving the elapsed time displayed.

A press of the second button then resets the stopwatch to zero. The second button is also used to record split times or lap times. When the split time button is pressed while the watch is running, the display

DIGITAL STOP WATCH

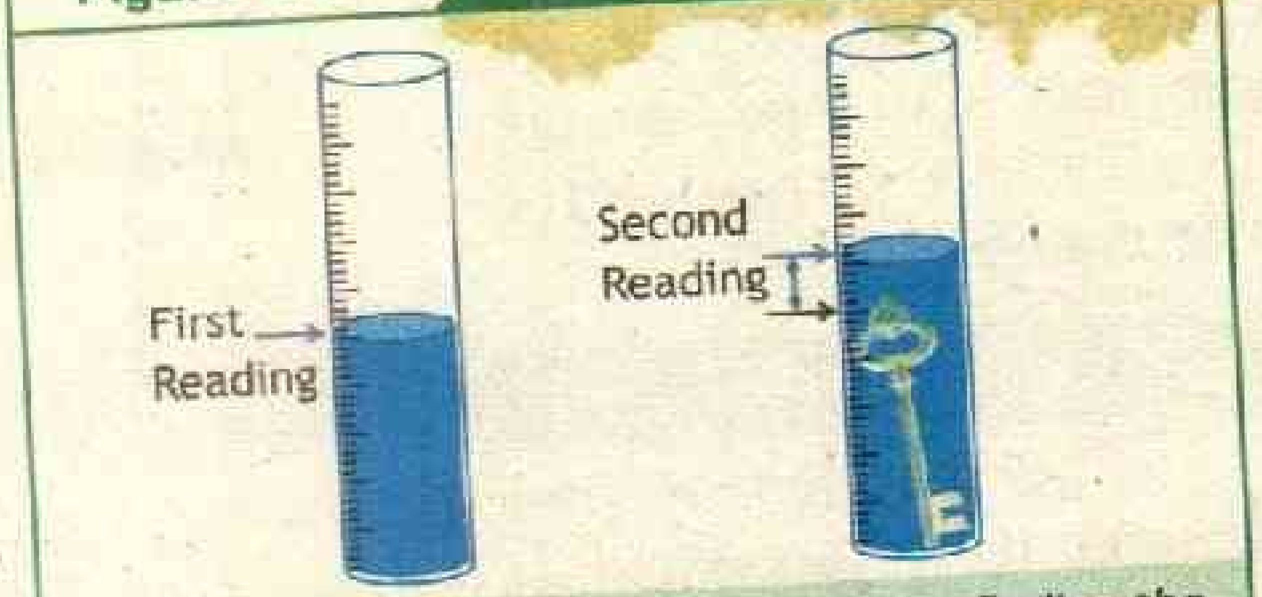
A digital stop watch can measure up accuracy of 0.01 second (centisecond) this is the least count of digital stop watch.

freezes, allowing the elapsed time to that point to be read, but the watch mechanism continues running to record total elapsed time. Pressing the split button a second time allows the watch to resume display of total time.

1.6.6 MEASURING CYLINDER

The volume of a liquid can be found by measuring cylinder which is made of transparent plastic or glass and it has a vertical scale in milliliter (ml) or cubic centimeter (cm^3). Measuring cylinder can be used for measuring the volume of an irregular solid body such as key as shown in figure 1.5.

Figure 1.5 Measuring Cylinder



Volume of the key can be calculated by finding the difference in the rise of water level.

Water is poured into a measuring cylinder until the cylinder is about half full. The volume is measured, and then an irregular shaped object is lowered gently into it.

When the object is completely immersed the volume of the water is read again. The volume of the object is found by subtracting the first reading from the second.

POINT TO PONDER

Why 20 °C is written on Measuring Cylinders?

Example 1.6 ONE LITER MILK IN SI UNITS

A liter (L) is the volume of a cube that is 10 cm by 10 cm. If you drink 1 L of milk, how much volume (a) in cubic centimeters and (b) in cubic meters would it occupy in your stomach?

SOLUTION

(a) The volume of a cube of side l is $V = l^3$. The volume in cm^3 is found directly from l = 10 cm. Calculate the volume in cm^3 is

$$V = l^3 = (10\ cm)^3 = 10^3\ cm^3$$

(b) To find the volume in m^3, convert cm^3 to m^3 using the conversion factor 1 cm = 10^{-2} m.

$$10^3\ cm^3 = 10^3\ cm^3 \times \left(\frac{10^{-2}\ m}{1cm}\right)^3$$

or $10^3\,cm^3 = 10^3\,cm^3 \times \frac{10^{-6}\,m^3}{1\,cm^3}$

therefore $10^3\,cm^3 = 10^{-3}\,m^3$ — **Answer**

Assignment 1.7 mL CONVERSION

A beaker contains 200 mL of water, what is volume of water in cm^3 and m^3.

1.7 SIGNIFICANT FIGURES

There are two types of values, exact and measured. Exact values are those that are counted clearly. For example while reporting 3 pencils or 2 books, we can indicate the exact number of these items.

On the other hand values associated with measurements of any kind are uncertain to some extent. For example, if we want to measure the length of a pencil with an ordinary metre ruler having least count of 1mm and we note that the length of the pencil is greater than 67 mm and less than 68 mm. We can estimate that the length of the pencil is 67.5 mm. This length is accurate in mm up to 67, but the last fraction of mm has been guessed. There is a chance of error in the last figure. It is known as the doubtful figure.

The number of accurately known figures and the first doubtful figure are known as significant figures.

GENERAL RULES FOR WRITING SIGNIFICANT FIGURES

1. NONZERO digits are always significant. That is all the digits from 1 to 9 are significant. For example the number of significant figures in 47.73 is 4.
2. ZERO in between two significant digits is always significant. For example the number of significant figures in 32.50063 is 7.
3. ZEROs to the left of significant figures are not significant. For example the number of significant figures in 0.00467 is 3.
4. ZEROs to the right of the significant figure

CALCULATORS DO NOT SHOW CORRECT SIGNIFICANT FIGURES

Some time through calculations the calculator shows more significant digits than required, these numbers should be rounded off to proper number of significant digits.

For example when we want to convert mm to inch (1 mm = 0.0393701 inch), then by multiplying 67.5 mm to inch will give us 2.65748175 inches we have to round off the number to proper significant digits.

may or may not be significant. In decimal fractions zero to the right of a decimal fraction are significant. For example in 7.400 there are 4 significant figures. However if the number is an integer number of significant figures can be found out by accuracy of the measuring instrument. For example in number 80,000 we may have 1, 2 or even 5 significant figures.

5. In scientific notation or standard form the figures other than power of ten are all significant, for example mass of electrons is 9.11×10^{-31}kg. There are three significant figure in it.

RULES FOR ROUNDING OFF SIGNIFICANT FIGURES

1. If the last digit is less than 5 then it will be ignored. e.g. 2.6573 is rounded to 2.657.
2. When the dropping digit is greater than 5 then the last retained digit increases by 1 e.g. 2.6578 is rounded to 2.658.
3. When the dropping digit is 5 and the last retained digit is even then the last digit i.e. 5 will be dropped without affecting the next one. e.g. 2.6585 is rounded to 2.658.
4. If the last digit is 5 and the 2nd last is an odd digit then the 2nd last digit is increased by 1 in order to round off 5, e.g. 2.6575 is rounded to 2.658.

ROUNDING OFF
2.6574818

2.6574818
↓
2.657482
↓
2.65748
↓
2.6575
↓
2.658
↓
2.66

KEY POINTS

Physics: The branch of science which deals with the study of properties of matter and energy along with their mutual interaction.

Physical Quantities: Quantities that can be measured.

International system of units: The international system of units which consists of seven base units and a number of derived units.

Seven Base Units: metre, kilogram, second, ampere, candela, Kelvin and mole are base units of system international.

Scientific Notation: An internationally accepted way of writing numbers in which numbers are recorded using the power of ten and there is only one non zero digit before the decimal.

Vernier callipers: A device used to measure a fraction of smallest scale division by sliding another scale over it.

Screw Gauge: A device used to measure a fraction of smallest scale division by rotatory motion of circular scale over it.

Stop Watch: It is an instrument used for measurement of time interval.

Significant Figures: The accurately known digits and first doubt full digit in any measurement.

PROJECTS

GROUP - A

NOBEL LAUREATES: Find out who were the Nobel laureates for physics last year, and research their work. Alternatively, explore the history of the Nobel Prizes. Who founded the awards? Why? Who delivers the award? Where? Document your sources and present your findings in a brochure, poster, or presentation.

GROUP - B

STANDARD UNITS: Create a poster, chart or other presentation to be displayed in the classroom depicting standard units for length, mass and time. Depict examples ranging from the very large to the very small.

GROUP - C

PAKISTAN COUNCIL OF SCIENCE AND TECHNOLOGY: Write a publication essay for school library on Pakistan Council of Science and Technology. Define its role and function.

GROUP - D

HISTORY OF SI UNITS: Write an article for school library on how SI units of measurements came into being. Also describe how they are more convenient units.

GROUP - E

METRE RULE: Make a simple length measuring metre rule (from paper or any other easily available material) for use in school laboratory.

EXERCISE

MULTIPLE CHOICE QUESTIONS

1. How many millimeters are there in 10 cm?
   A. 100 mm B. 200 mm C. 50 mm D. 10 mm
2. Which of the following quantity can be measured using a micrometer?
   A. current B. force C. length D. mass
3. The instrument best measures the internal diameter of a pipe is
   A. screw gauge B. vernier caliper
   C. meter rule D. measuring tape
4. Which prefix represents a largest value?
   A. mega B. giga C. peta D. exa
5. Which of the following is the smallest prefix?
   A. atto B. pico C. nano D. femto
6. Which of the following numbers shows one significant digit?
   A. 1.1 B. 6.0 C. 7.1 D. 6×10^{2}
7. Which of the following numbers shows 4 significant digits?
   A. 900.8 B. 4 C. 5174.00 D. 0.0002
8. A light year is distance traveled by light in one year. It travels about 9.460×10^{15} m. How many significant figures are in this number
   A. 6 B. 2 C. 3 D. 4
9. 0.2 mm in units of meters is
   A. 0.0002m B. 2×10^{-4}m C. none D. both A and B
10. KITAB UL MANAZIR is the name of book written by
    A. Yaqub Kindi B. Ibnal Haitham
    C. Al Beruni D. none

CONCEPTUAL QUESTIONS

Give a brief response to the following questions.

1. How technology is shaped by physics?
2. Physics and biology are considered different branches of science, how physics links with biology?
3. Why are measurements important?
4. Why area is a derived quantity?
5. Name any four derived units and write them as their base units?
6. Why in physics we need to write in scientific notation?
7. What is least count? How least count for vernier calliper and screw gauge are defined?
8. How can we find the volume of a small pebble with the help of measuring cylinder?

COMPREHENSIVE QUESTIONS

Give an extended response to the following questions.

1. Define physics. How physics play a crucial role in science technology and society?
2. What is SI? Name SI base quantities and their units.
3. What are physical quantities? Distinguish between base and derived physical quantities.
4. What is standard form or scientific notation?
5. What are prefixes? Explain with examples.
6. Describe the construction and use for measurement of the following instruments:

   a. Vernier Calipers　　b. Screw gauge
7. What is meant by the significant figures of measurement? What are the main points to be kept in mind while determining the significant figures of a measurement?

NUMERICAL QUESTIONS

1. Write the number in prefix to power of ten **a.** Mechanical nano-oscillators can detect a mass change as small as 10^{-21} kg. **b.** The nearest neutron star (a collapsed star made primarily of neutrons) is about 3.00×10^{18} m away from Earth. **c.** Earth to sun distance is 149.6 million km

2. An angstrom (symbol Å) is a unit of length (commonly used in atomic physics), defined as 10^{-10} m which is of the order of the diameter of an atom.
   - **a.** How many nanometers are in 1.0 angstrom?
   - **b.** How many femtometers or fermis (the common unit of length in nuclear physics) are in 1.0 angstrom?
   - **c.** How many angstroms are in 1.0 m?

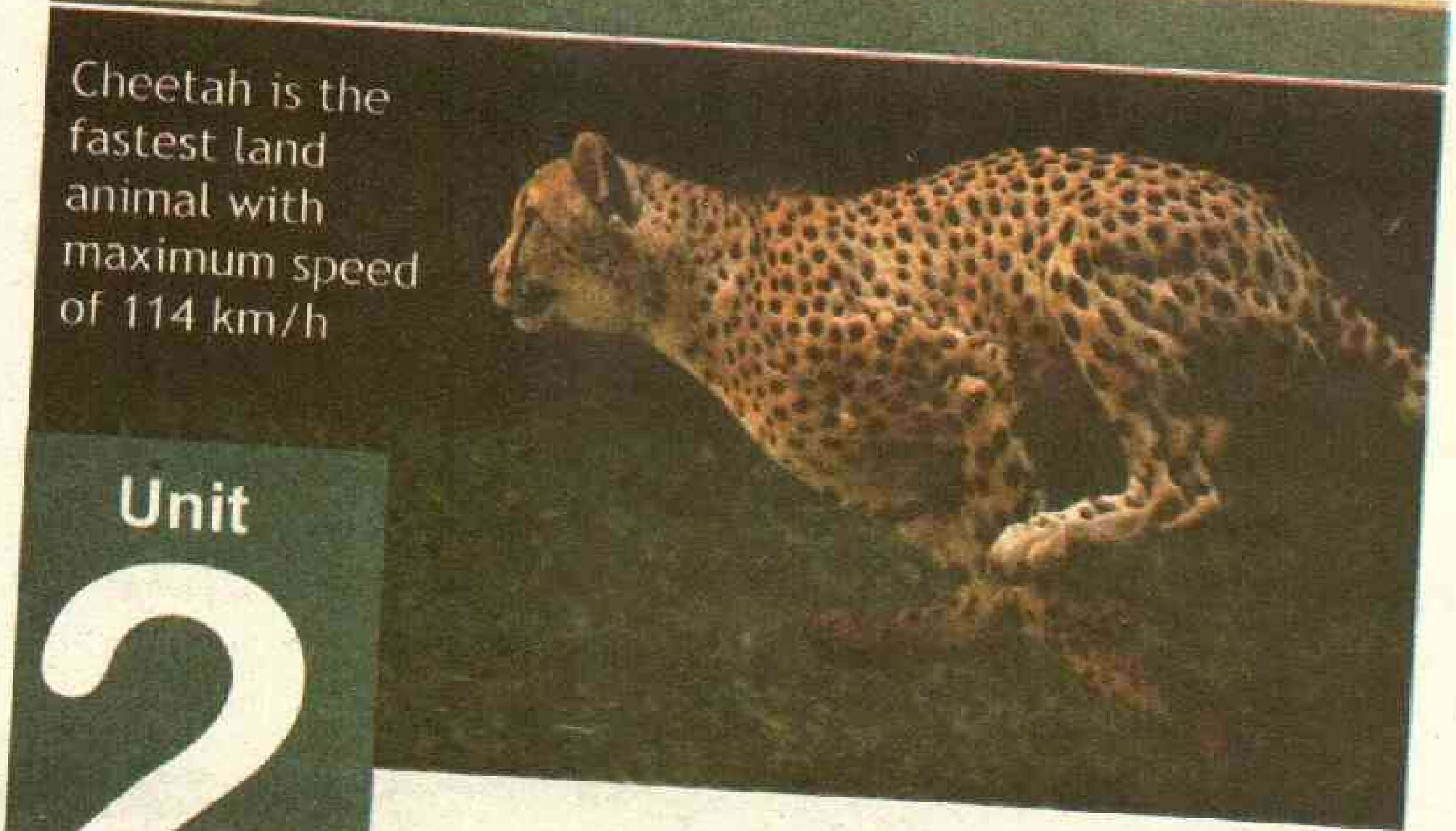
3. The speed of light is c = 299,792,458 m/s.
   - **a.** Write this value in scientific notation.
   - **b.** Express the speed of light to
     i. five significant figures, ii. three significant figures.

4. Express the following in terms of powers of 10.
   a. 7 nanometre **b.** 96 megawatt **c.** 2 gigabite
   d. 43 picofarad **e.** 2 millimetre.

5. Write the following numbers in standard form:
   - **a.** Mass of Bacterial cell: 0.000,000,000,005 kg
   - **b.** Diameter of Sun: 1,390,000,000 m

WEB LINKS

http://www.introduction-to-physics.com/
http://www.bipm.org/en/about-us/
http://www.rapidtables.com/convert/number/scientific-notation-converter.htm
http://www.flippingphysics.com/significant-figures.html



Unit 2

KINEMATICS

CHECK LIST

After studying this unit you should be able to:

- ✓ describe using examples how objects can be at rest and in motion simultaneously.
- ✓ identify different types of motion i.e; translatory, (rectilinear, curvilinear, and random); rotatory and vibratory motions and distinguish among them.
- ✓ differentiate with examples between scalar and vector quantities.
- ✓ differentiate with examples between distance and displacement, speed and velocity.
- ✓ represent vector quantities by drawing.
- ✓ define the term speed, velocity and acceleration.
- ✓ plot and interpret distance-time graph and speed-time graph.
- ✓ determine and interpret the slope of distance-time and speed-time graph.
- ✓ determine from the shape of the graph, the state of a body.
- ✓ i. at rest ii. moving with constant speed iii. moving with variable speed.
- ✓ calculate the area under speed-time graph to determine the distance traveled by the moving body.
- ✓ derive equations of motion for a body moving with a uniform acceleration in a straight line using graph.
- ✓ solve problems related to uniformly accelerated motion using appropriate equations.
- ✓ solve problems related to freely falling bodies using $10\ ms^{-2}$ as the acceleration due to gravity.

Mechanics is the oldest of all physical sciences. Mechanics deals with the study of motion of objects.

Everything in our universe is in a state of motion. Our solar system moves through space in the Milky Way Galaxy. Earth revolves around the Sun while rotating about its own axis. People, animals, air, and countless other objects move about on Earth's surface. The elementary particles that make up all matter, too, are constantly in motion.

There are two main branches of mechanics. They are Kinematics and Dynamics. Kinematics will be focus of study in this unit.

Kinematics is derived from the Greek word for motion. Kinematics is the branch of physics which deals with the study of motion without going into detail of what causes the motion.

2.1 REST AND MOTION

A body is at **rest** with respect to an observer if it does not change its position with respect to an observer. A body is in state of **motion** with respect to an observer if it changes its position with respect to that observer.

POSITION:

In order to describe the motion of an object, we must first be able to describe its position—where it is at any particular time. More precisely, we need to specify its position relative to a convenient reference.

Position is the location of object relative to some reference.

Earth is usually taken as reference, and we often describe the position of an object as it relates to stationary objects on earth. For example, a teacher's position could be described in terms of where she is in relation to the nearby teaching board.

We can equally use references that are not stationary but are in motion relative to the Earth. For example, to describe the position of a person in an airplane, we use the airplane as the reference, not the Earth as shown in the figure.

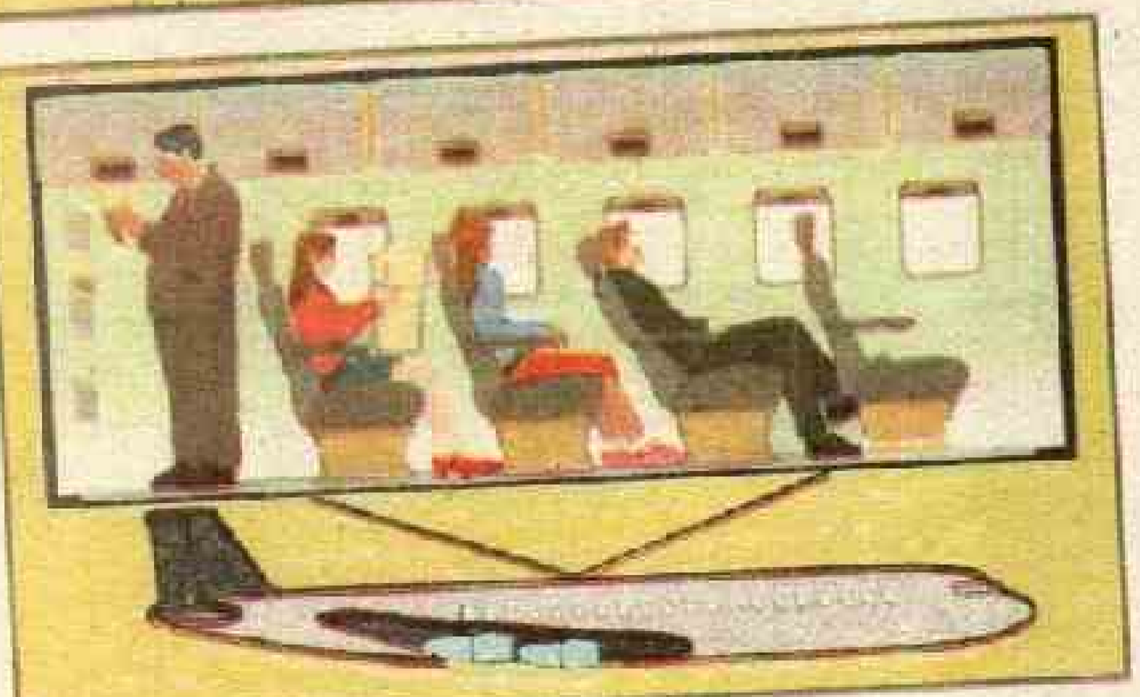


TABLE 2.1 TYPES OF MOTION

Type	Description	Examples
1. Translatory Motion	Changes in position of a body as a whole. The line or path of motion could be straight or curved.	Motion of a horse or motion of a ball, moving car, falling bodies, rowing boats, flying birds
Translatory motion is again divided into following types		
A. Rectilinear Motion	Straight line motion	Motion of free falling bodies
B. Curvilinear Motion	Circular or curved path motion	Motion of cricket ball being hit for six
C. Random Motion	Irregular motion	Flight of butterfly or motion of gas molecules
2. Rotatory Motion	Rotation of a body as a whole around a fixed axis, in this type of motion the particles of the body moves in a circle	Motion of wheel of a cycle, the hands of a clock, the wings of a turning fan
3. Vibratory Motion	The repeated forward and backward motion of an object about its mean position	The oscillation of a mass attached to an elastic spring, motion of swing and the vibration of a plucked violin string.

The motion of a body can be translatory, rotatory, vibratory or any combination of the three at the same time. e.g The motion of a cricket ball can have translatory as well as spin (rotatory) motion. The atoms/ molecules of gas can vibrate, rotate on its axis and at the same time can move freely in its container.

Objects can be at rest and in motion at same time:

For same event two observers can have different observations. For example a body in train is in motion with respect to an observer on ground. Whereas the same object is at rest with respect to another observer in train moving with the object. Thus the motion and rest are not absolute but relative. This means that we have to specify the observer while telling about the rest or motion of the body.

Rest and motion are relative:

As position needs reference, therefore rest and motion also need specification of observer.

For example when teacher changes her position in the classroom while students are sitting on their chairs. According to students observation the teacher is in motion. Interestingly, teacher while moving also observes the students to move as well. Similarly, when Sara leaves in train and her cousin John sees her off. As the train starts moving Sara see John moving to the right, (as shown in the figure 2.1) with same speed as John see Sara moving to the left.

Figure 2.1 Relative Motion

What Sara see from train

What John see from platform

2.2 SCALARS AND VECTORS

Physical quantities can also be categorized on the basis of their directional properties.

In order to fly a plane, pilots needs not only to know how much crosswind is blowing but in what direction in which they intend to fly. In order to build bridges, engineers need to know what load a particular design will support. In such conditions the directional properties of physical quantities become more important.

Figure 2.2 Importance of Vectors

A. Scalars or Scalar Quantities:

Physical quantities which can be completely described by only its magnitude (or size). Magnitude means number with proper unit, for example mass is a scalar quantity and can be specified as 2 (number) with kilogram (proper unit). We do not need to know in what direction mass is needed.

These quantities can be added, subtracted and multiplied by using ordinary algebra. For example if we took 2 kg of sugar and add another 3 kg of sugar we will have (2kg + 3kg) 5 kg of sugar.

Examples of scalars are density, speed, distance, energy, charge, volume, power, temperature, electrical resistance, electric current and heat etc.

B. Vectors or Vector Quantities:

Physical quantities which can be completely described by its magnitude (or size) as well as direction are called vectors or vector quantities. Some quantities (such as weight, velocity, or friction) require both a magnitude (or size) and a direction for a complete description and are called vectors or vector quantities.

Representation of vectors:

Vectors can be represented in two ways.

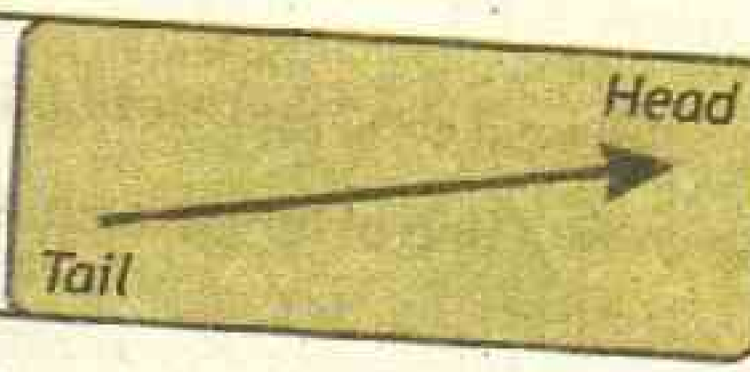
A. Symbolic representation:

Symbolically a vector is represented by a bold face letter either capital or small. (e.g **A**, **a**). Vector can also be represented by a simple face letter with an arrow over or below it. In this book we will represent vectors by letter with an arrow over it. For example $\vec{A}$, $\vec{B}$, $\vec{C}$, or $\vec{D}$.

B. Graphical Representation:

A graph is a visual representation of information, showing how one quantity varies with another related quantity. Graphically a vector is **represented by an arrow, the length of the arrow gives the magnitude (under certain scale) and the arrow head points the direction of the vector.**

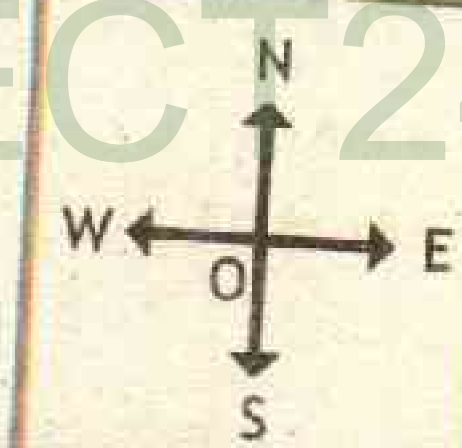
The starting point of the vector is called tail of the vector and the ending point is called head of the vector as shown in the figure.



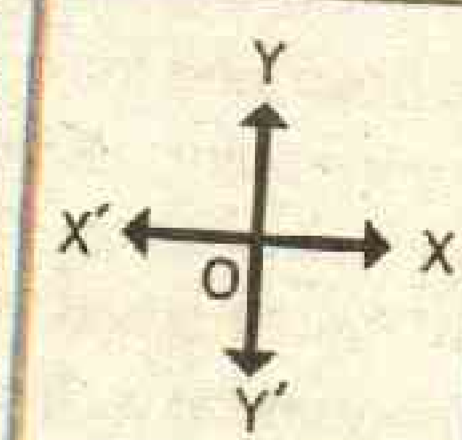
Coordinate Systems are used to represent vectors:

Vectors are considered with reference to coordinate axes (any sets of values that indicate the position of a point in a given reference system). To use vectors in applications we place them on a coordinate system. Description of two coordinate systems (Geographical Coordinate System and Cartesian coordinate system) is given in figure 2.3

Figure 2.3 Coordinate Systems



Geographical Coordinate System: One coordinate system is the Geographical Coordinate System having different directions as North (N), East (E), West (W) and South (S) NEWS as shown in figure.



Cartesian Coordinate System: The Cartesian coordinate system consists of a horizontal line called the x-axis (XOX′) and a vertical line called the y-axis (YOY′) intersecting at a point called the origin O.

Steps to Represent a Vector in Coordinate System

The following method is used to represent a vector

1. Draw a coordinate system.
2. Select a suitable scale.
3. Draw a line in the specified direction. Cut the line equal to the magnitude of the vector according to the selected scale.
4. Put an arrow in the direction of the vector.

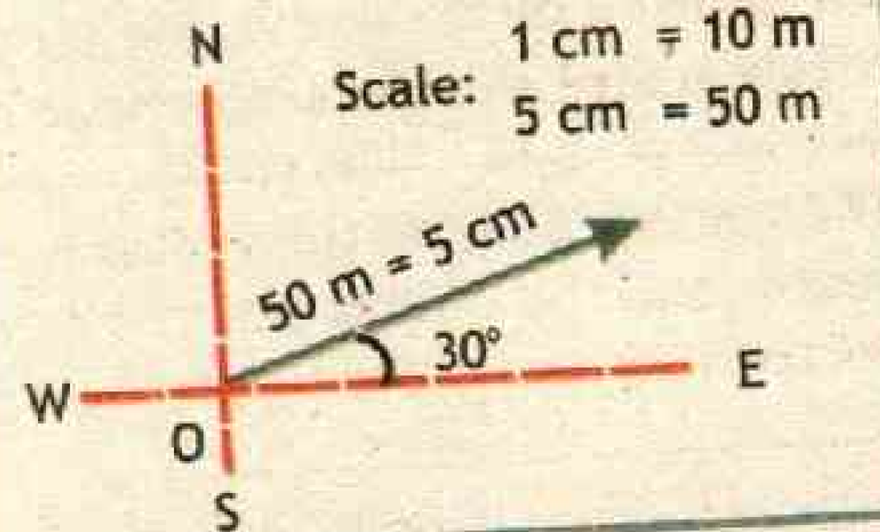
For example the representation of Al-Khalid tank (main battle tank jointly developed by China and Pakistan) as it moves to 50 m from origin towards 30° North of East, in both coordinate systems is

Figure 2.4 The position of Al khalid tank

Draw NEWS coordinate system and select a suitable scale

10 m = 1 cm, therefore 50 m = 5 cm

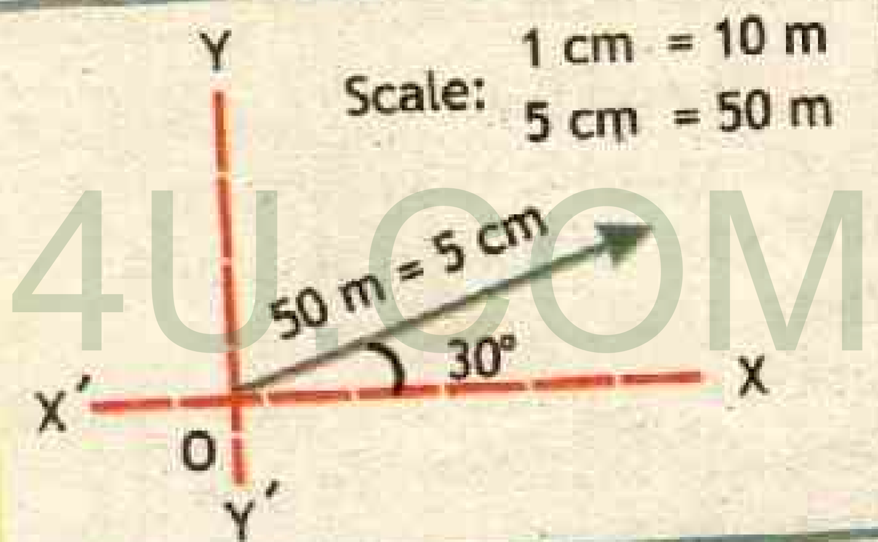
We draw a line of length 5 cm an angle of 30° from East towards North.



Draw Cartesian coordinate system corresponding to Geographical Coordinate System and select a suitable scale

10 m = 1 cm, therefore 50 m = 5 cm

We draw a line of length 5 cm at an angle of 30° from X-axis (taken as east).



2.3 Terms associated with motion:

Position of an object can be described in rectangular coordinate system. Where origin O can serve as a reference point. If one or more coordinates of an object change, we say that the object is in motion. The choice of a set of axes in a frame of reference depends upon the situation. For example, for describing motion in one dimension, we need only one axis. To describe motion in two/three dimensions, we need a set of two/ three axes.

Position of an object is usually represented with letters x, r, s, l or d.

2.3.1 DISTANCE

'The length of path traveled between two positions is called distance'.

Distance has no direction and therefore it is a scalar quantity. Distance is usually denoted by Δx, Δr, Δs, Δl or Δd, and has SI unit as meter.

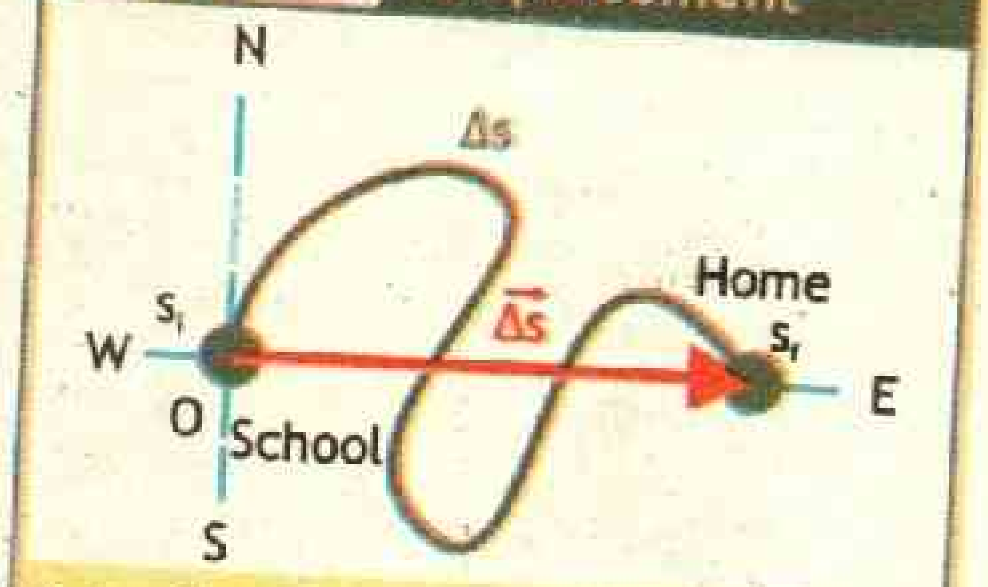
2.3.2 DISPLACEMENT

'The shortest directed distance between two positions is called displacement. Straight distance from one point to another is called displacement'.

Displacement has direction and therefore it is a vector quantity. Displacement is usually denoted by $\Delta\vec{x}$, $\Delta\vec{r}$, $\Delta\vec{s}$, $\Delta\vec{l}$ or $\Delta\vec{d}$, and has SI unit as meter (same as distance).

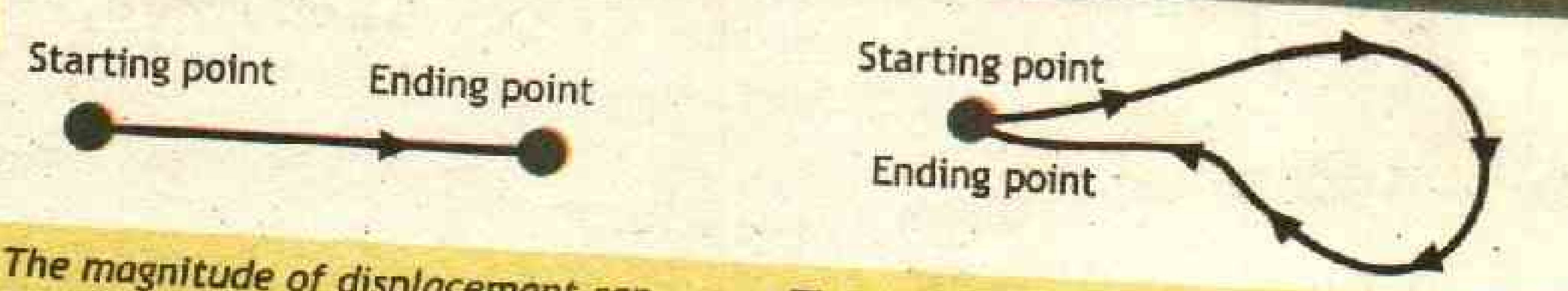
For example, if your friend asks you how far is your home from school and you tell him that it is about 4 km from school. You actually told him the length of the path covered by road, it could be a complicated motion (twisted, zig-zag and curved), you specified distance of your home. On the other hand if you reply that it 1.6 km straight towards east, this time you are telling him displacement of your home. The situation is shown in figure 2.5.

Figure 2.5 Displacement



School is taken at the origin of geographical coordinate system. distance to home is shown with blue color line and displacement to home is shown with red arrow.

Figure 2.6 Distance and Displacement



The magnitude of displacement can be equal to the path length traversed by an object (distance). For example straight line motion.

The magnitude of the displacement for a course of motion may be zero but the corresponding path length (distance) is not zero. For example same starting and ending points.

2.3.3 SPEED

'Measure of the distance (Δs) covered with passage of time (Δt) is called speed (denoted by v)'. Mathematically

$$speed = \frac{\text{distance}}{\text{elapsed time}} \quad \text{or} \quad v = \frac{\Delta s}{\Delta t} \quad \text{or} \quad v = \frac{s_f - s_i}{t_f - t_i} \qquad (2.1)$$

As distance is a scalar quantity, therefore speed is also a scalar quantity having SI Unit of meter per second (m/s or ms^{-1}).

Speed tells quantitatively how fast an object is in motion. For example while going from Peshawar to Islamabad through motor-way M1, we leave at 2:00 pm and cross Sawabi interchange about 80 km from Peshawar interchange at 3:00 pm. Our speed can be obtained by using equation 2.1 as

$$v = \frac{80\,km - 0\,km}{3\,hr - 2\,hr} = \frac{80\,km}{1\,hr} = 80\,km/hr$$

We are traveling at 80 km/hr.

INFORMATION

Representing Change in Quantity:

Here we used symbol Δ for both distance and displacement; it is the Greek letter delta, Δ, and is used to represent a change in a quantity. For initial position s_i and final position s_f change in displacement is defined as

$$\Delta\vec{s} = \vec{s}_f - \vec{s}_i$$

Similarly elapsed time Δt is the difference between the ending time t_f and beginning time t_i

$$\Delta t = t_f - t_i$$

A. Average speed:

'Average speed is the net (total) distance (s) divided by the total time (t)'. Mathematically

$$<v> = \frac{\text{Total distance}}{\text{Total time}} \quad \text{or} \quad <v> = \frac{s}{t} \qquad (2.2)$$

For example total distance to islamabad is 155 km via M1 motor way, we take total time of 3.5 hr (3 hour and 30 minutes), our average speed is calculated by using equation 2.2

$$<v> = \frac{155\,km}{3.5\,hr} = 44.3\,km/hr$$

So our average speed is 44.3 km/h, however we know that at times we traveled faster than this and on other occasions we were slow. Even we took rest at restaurant in our way for about half an hour. So we are sometimes not interested in average speed, but the speed at any particular instant of time. This speed is called instantaneous speed.

B. Instantaneous Speed:

'Instantaneous speed is speed for short time interval Δt (very small such that limit approaching to zero)'. Mathematically

$$v = \lim_{\Delta t \to 0} \frac{\Delta s}{\Delta t} \qquad (2.3)$$

The Limit Δt approaching to ZERO, (close to zero but not zero) indicates that we are observing the change in distance in a time as small as possibly close to zero. This is the speed the speedometer of our car shows, which keep track of changes in speed within a fraction of a second.

Uniform and variable speed:

Uniform speed as the name indicates is the speed which does not change otherwise it is called **variable speed.**

'If a body covers equal distances in equal intervals of time we say that the speed is uniform'. When a body moves with uniform speed the average and instantaneous speed are same.

Example 2.1 SPEED OF SNAIL

In the Guinness Gastropod Championship, the fastest speed for garden snail was recorded. The snail covered 330-millimetre distance in 2 minutes and 20 seconds; what was the speed of snail?

SOLUTION

GIVEN:

Distance covered $\Delta s = 330\ mm = 330 \times 10^{-3}\ m = 0.330\ m$

Total time $t = 2$ min and $20\ s = (2 \times 60\ s) + 20\ s = 140\ s$

REQUIRED:

speed $v = ?$

From the definition of average speed, equation 2.3 we have

$$<v> = \frac{\text{Total distance}}{\text{Total time}} \quad \text{or} \quad <v> = \frac{s}{t}$$

putting values $<v> = \dfrac{0.330\,m}{140\,s}$

therefore $<v> = 0.0024\,m/s$ — Answer

The world record speed for a garden snail is only 0.0024 m/s (0.000066 km/h) at this speed it will take nearly five days for a garden snail to move constantly through 1 km.

EXTENSION EXERCISE 2.1

Why we used average speed formula in this example?

Also convert 0.0024 m/s to 0.000066 km/h.

Assignment 2.1 FASTEST MAN

In 2009 a Jamaican sprinter Usain Bolt created a World Record in Berlin by running 100 m in just 9.58 s. What is his average speed?

ACTIVITY CRICKET BOWLING SPEEDS

Pakistani Cricketer Shoaib Akhtar bowled the fastest recorded ball in the history of cricket in the World Cup match at Newlands. The last ball of his second over was recorded at 161.3 km/h, convert this speed into m/s. Also record the bowling speed of your friend, and compare the result with the bowling speed of Shoaib Akhtar.

TABLE 2.2: TYPICAL SPEED VALUES

Item	speed (m/s)	speed (km/h)
Continental drift.	3×10^{-10}	1×10^{-9}
Moon receding from the Earth	1.3×10^{-9}	4.68×10^{-9}
Growth rate of bamboo	1.4×10^{-5}	5.0×10^{-5}
Comfortable bicycling speed.	6-7	20-25
Car (freeway); cheetah	30	110
Fastest recorded ball speed (a golf ball)	91	328
Wind speed of a powerful tornado	130	468
Muzzle velocity of M16 rifle	975	3510
Speed of the Earth in orbit around Sun.	29,800	107,280
Speed of light (fastest speed)	299,792,458	1.1×10^{9}

2.3.4 VELOCITY

'Measure of displacement covered ($\Delta\vec{s}$) with passage of time ($\Delta\vec{t}$) is called velocity (denoted by $\vec{v}$)'. Mathematically

$$velocity = \frac{\text{displacement}}{\text{elapsed time}} \quad \text{or} \quad \vec{v} = \frac{\Delta\vec{s}}{\Delta t} \quad \text{or} \quad \vec{v} = \frac{\vec{s}_f - \vec{s}_i}{t_f - t_i} \qquad (2.4)$$

As displacement is a vector quantity, therefore velocity is also a vector quantity having same direction as displacement vector. The SI unit of velocity is meter per second (m/s).

When we know both the speed and the direction of an object, we simply call it as velocity.

A) Average Velocity:

'Average Velocity is the net (total) displacement divided by the total time "t"; unlike speed the average velocity can be positive and negative depending upon the sign of displacement'. Mathematically

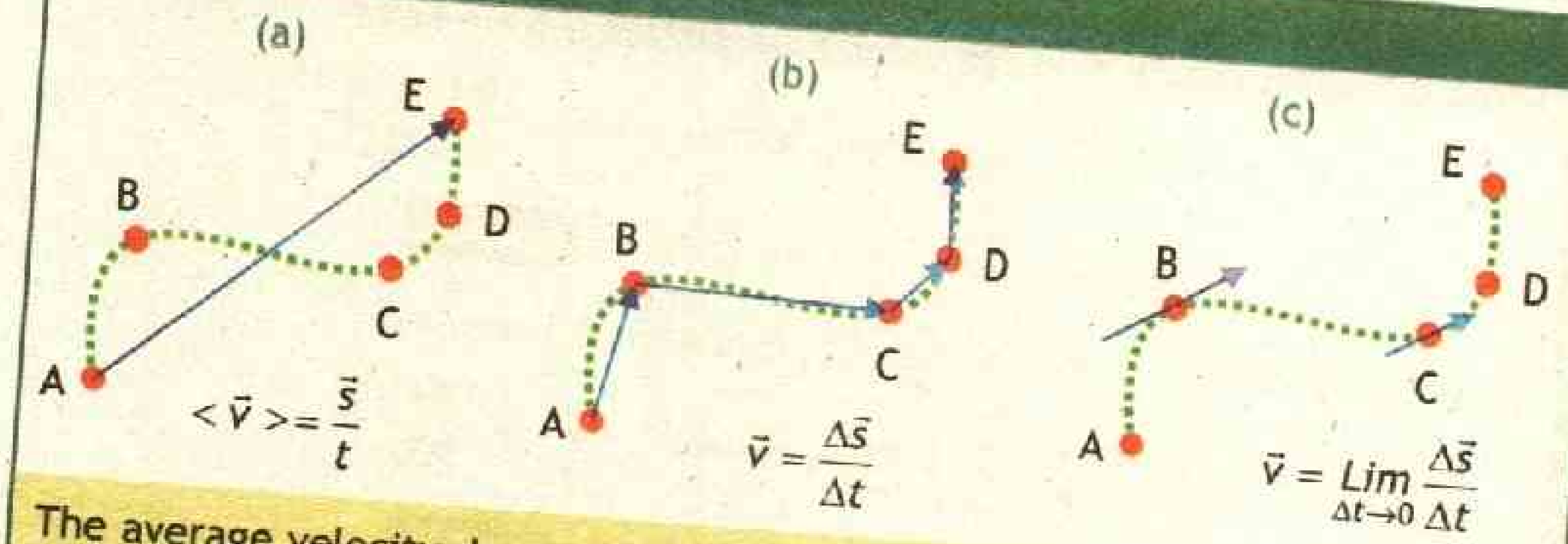
$$<\vec{v}> = \frac{\text{Total displacement}}{\text{Total time}} \quad \text{or} \quad <\vec{v}> = \frac{\vec{s}}{t} \qquad (2.5)$$

B) Instantaneous Velocity:

Things in motion often have variations in speed or direction. 'The *instantaneous velocity is the velocity for very short time interval Δt (very small such that limit approaching to zero)'*. Mathematically

$$\vec{v} = \lim_{\Delta t \to 0} \frac{\Delta \vec{s}}{\Delta t} \quad \text{--- 2.6}$$

Figure 2.7 Velocity



The average velocity does not convey detailed information about the motion during the corresponding time interval Δt. Suppose a car moves on a curved track, through points A, B, C, D and E as shown in the figure. **(a)** The average velocity is defined over the entire journey, **(b)** the measure of velocity in shorter interval of time is different both in magnitude and direction at different points. **(c)** The instantaneous velocity will be tangent to the curved path of the motion of car.

A body is said to have **uniform velocity** if its average and instantaneous velocity become equal. Otherwise it is non uniform.

Example 2.2 STRAIGHT ROAD

A straight track is 1200 m in length. A runner begins at the starting line, runs due east for the full length of the track, turns around and runs halfway back. The time for this run is five minutes. What is her (a) average velocity, and (b) average speed?

GIVEN:

Distance covered Δs = 1200 m + 600 m = 1800 m

Displacement Δs = 1200 m - 600 m = 600 m

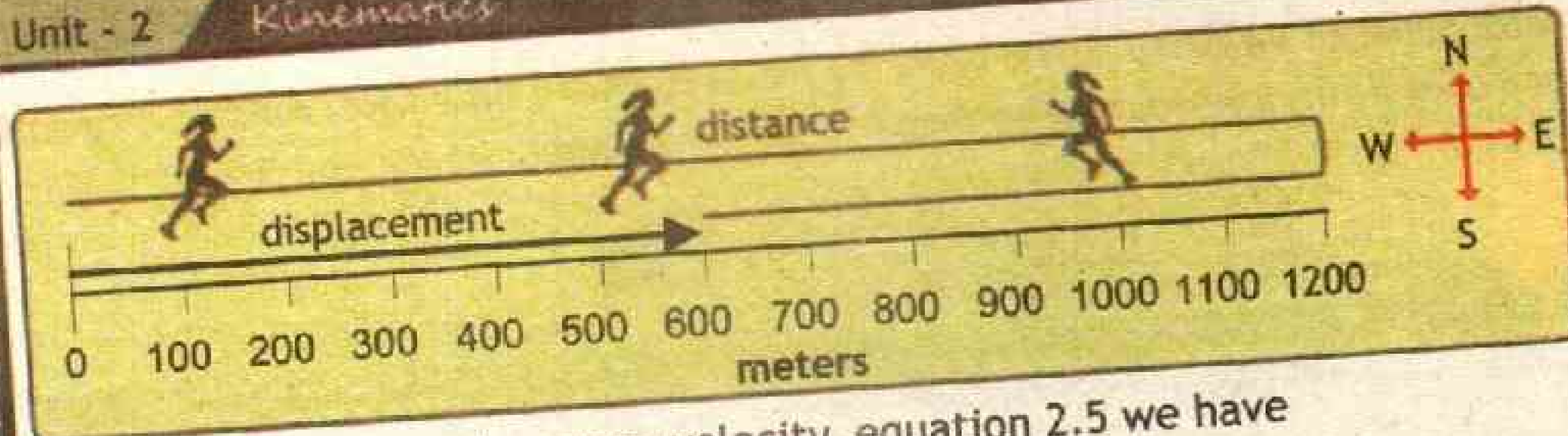
time Δt = 5 min = (5 × 60 s) = 300 s

REQUIRED:

(a) average speed <v> = ?

(b) average velocity <v> = ?

SOLUTION



From the definition of average velocity, equation 2.5 we have

$$<\vec{v}> = \frac{\vec{s}}{t} \qquad \text{putting values} \quad <\vec{v}> = \frac{600\,m(East)}{300\,s}$$

therefore $<\vec{v}> = 2\,m/s\,East$ — **Answer**

From the definition of average speed, equation 2.3 we have

$$<v> = \frac{s}{t} \qquad \text{putting values} \quad <v> = \frac{1800\,m}{300\,s}$$

therefore $<v> = 6\,m/s$ — **Answer**

Her average velocity is **2 m/s** East, while her average speed is **6 m/s**.

Assignment 2.2 AVERAGE VELOCITY OF COMPLETE LAP

A runner makes one lap around a 270 m circular track in 30 s. What is his (a) average speed and (b) average velocity?

2.3.5 ACCELERATION:

'The measure of change in velocity Δv with the passage of time 'Δt' is called acceleration. (or) Time rate of change of velocity is called acceleration $\vec{a}$'.

Mathematically

$$\text{acceleration} = \frac{\text{change in velocity}}{\text{elapsed time}} \quad \text{or} \quad \vec{a} = \frac{\Delta\vec{v}}{\Delta t} \quad \text{or} \quad \vec{a} = \frac{\vec{v}_f - \vec{v}_i}{t_f - t_i} \qquad (2.7)$$

Acceleration is also a vector quantity having same direction as change in velocity. SI Unit of acceleration is meter per second squared (m/s^2). Acceleration is a measure of how rapidly the velocity is changing.

A) Average Acceleration:

'Average acceleration $<\vec{a}>$ is the net (total) velocity $\vec{v}$ divided by the total time t'.

$$<\vec{a}> = \frac{\text{Total change in velocity}}{\text{Total time}} \quad \text{or} \quad <a> = \frac{\vec{v}}{t} \qquad (2.8)$$

B) Instantaneous Acceleration:

'Acceleration 'a' at particular instant of time is known as instantaneous acceleration'. The value of instantaneous acceleration is obtained, if Δt is made smaller and smaller such that it approaches to ZERO.

$$\vec{a} = \lim_{\Delta t \to 0} \frac{\Delta \vec{v}}{\Delta t} \quad \text{—— 2.9}$$

Uniform Acceleration:

A body is said to have uniform acceleration if its average and instantaneous acceleration become equal.

LAB WORK

To find the acceleration of a ball rolling down an angle iron by drawing a graph between 2S and T^2.

Deceleration/Retardation:

When an object is slowing down, we can say it is decelerating. But be careful: deceleration/retardation does not mean that the acceleration is necessarily negative. The velocity of an object moving to the right along the positive x-axis is positive; if the object is speeding up, the acceleration is positive; however if the object is slowing down, the acceleration is negative. But the same object moving to the left (decreasing x), and slowing down, has positive acceleration that points to the right. We have a deceleration whenever the magnitude of the velocity is decreasing; thus the velocity and acceleration point in opposite directions when there is deceleration.

TID-BIT

People Enjoy acceleration, amusement rides thrill us by accelerating our bodies. Each curve, drop, loop, launch, or brake alters the rider's state of motion and cause acceleration. The balance between comfort and thrill is maintained which amuses the riders.

POINT TO PONDER

Velocity is a vector quantity it can change with change in direction. If the speed of the object is not changing and only direction is changing will it still be acceleration?

CAN YOU TELL?

A car is dripping mobile oil at constant rate. Which diagram describe the car moving with steady speed, speeding and slowing down.

Example 2.3 ACCELERATION OF CAR

You observe that your car accelerate from rest to 140 km/h in just 17.6 seconds on straight road towards east. What is the acceleration of your car.

SOLUTION

GIVEN:

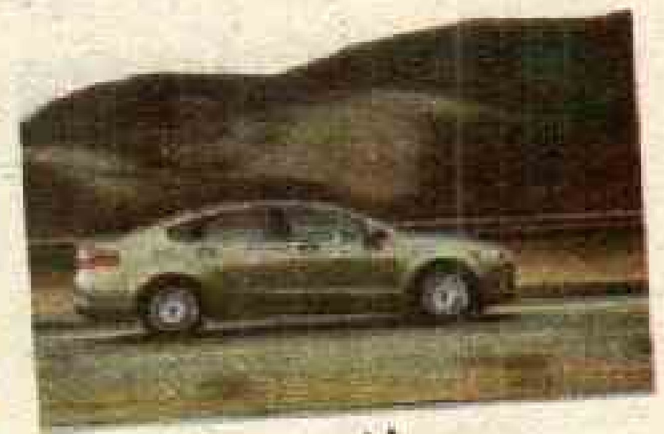
initial velocity v_i = 0 km/h East = 0 m/s East

final velocity v_f = 140 km/h East = 38.88 m/s East

time elapsed Δt = 17.6 s

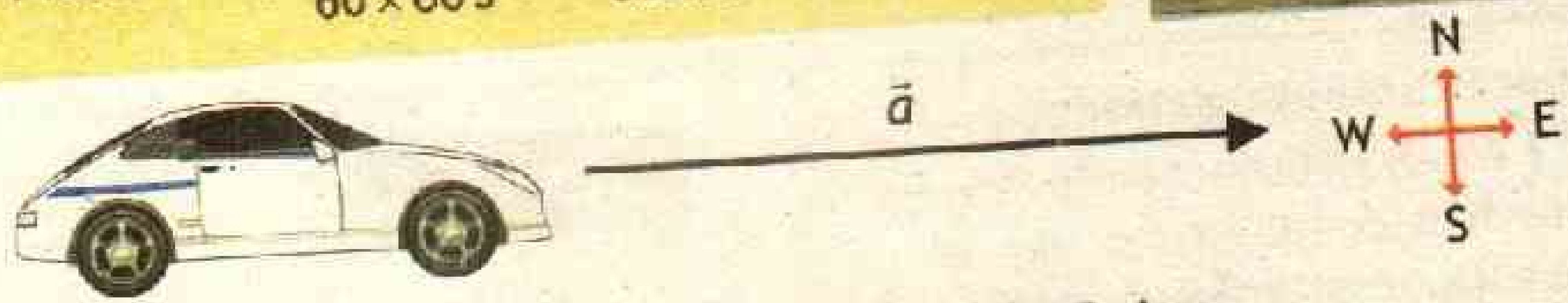
REQUIRED:

acceleration a = ?



Conversion from km/h to m/s

$$140\,km/h = \frac{140 \times 10^3\,m}{60 \times 60\,s} = \frac{140{,}000}{3600\,s} = 38.9\,m/s$$



From the definition of acceleration, equation 2.7 gives

$$\vec{a} = \frac{\Delta \vec{v}}{\Delta t} \quad \text{or} \quad \vec{a} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t}$$ putting values $$\vec{a} = \frac{(38.9 - 0)m/s}{17.6\,s} \text{ East}$$

$$\text{or} \quad \vec{a} = \frac{38.9\,m/s}{17.6\,s} \text{ East}$$

$$\text{therefore} \quad \vec{a} = 2.2\,m/s^2 \text{ East}$$ — **Answer**

EXTENSION EXERCISE 2.2

In this example, when the driver apply breaks in what direction will the resulting acceleration points?

Assignment 2.3 CAR'S ACCELERATION

If in the same experiment you take the readings of the speedometer of the car as 20 km/h in the 4^{th} second and 32 km/h in the 9^{th} second. What is the acceleration of your car in this interval?

INTERESTING INFORMATION CONTINENTAL DRIFT

Continental Drift is the movement of the Earth's continents relative to each other, thus appearing to 'drift' across the ocean bed. The continental plates (therefore continents) move across the surface of the Earth at the geologically slow rate of 1-10 cm/year or 1-10 m/century. This is about the same speed that fingernails and hair grow.

2.4 GRAPHICAL ANALYSIS OF MOTION

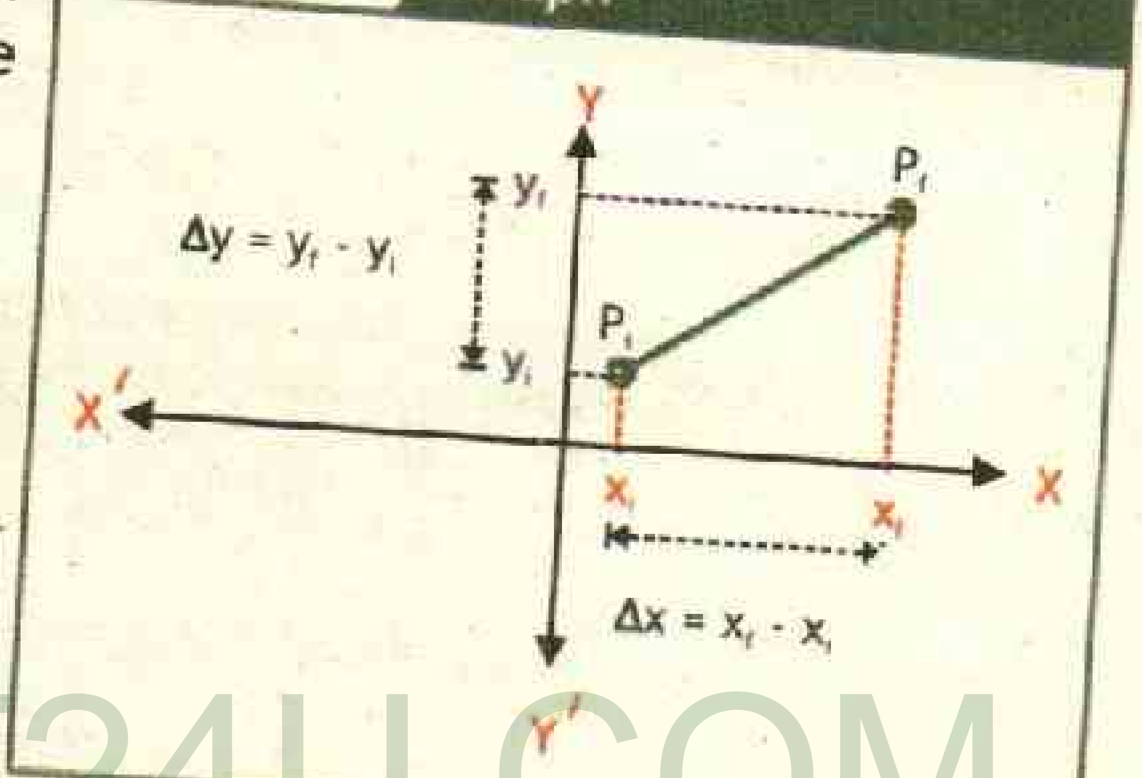
Graph is an effective way for showing the relationship between physical quantities. Graph contains horizontal and vertical lines at equal distances and coordinate systems to show relationship in various quantities. Interpretation of graph is an effective tool for Physicist.

Slope of Graph:

The slope of the graph means vertical coordinate difference divided by horizontal coordinate difference.

The slope of the graph in cartisian coordinate system can be calculated as

Figure 2.8 Graph



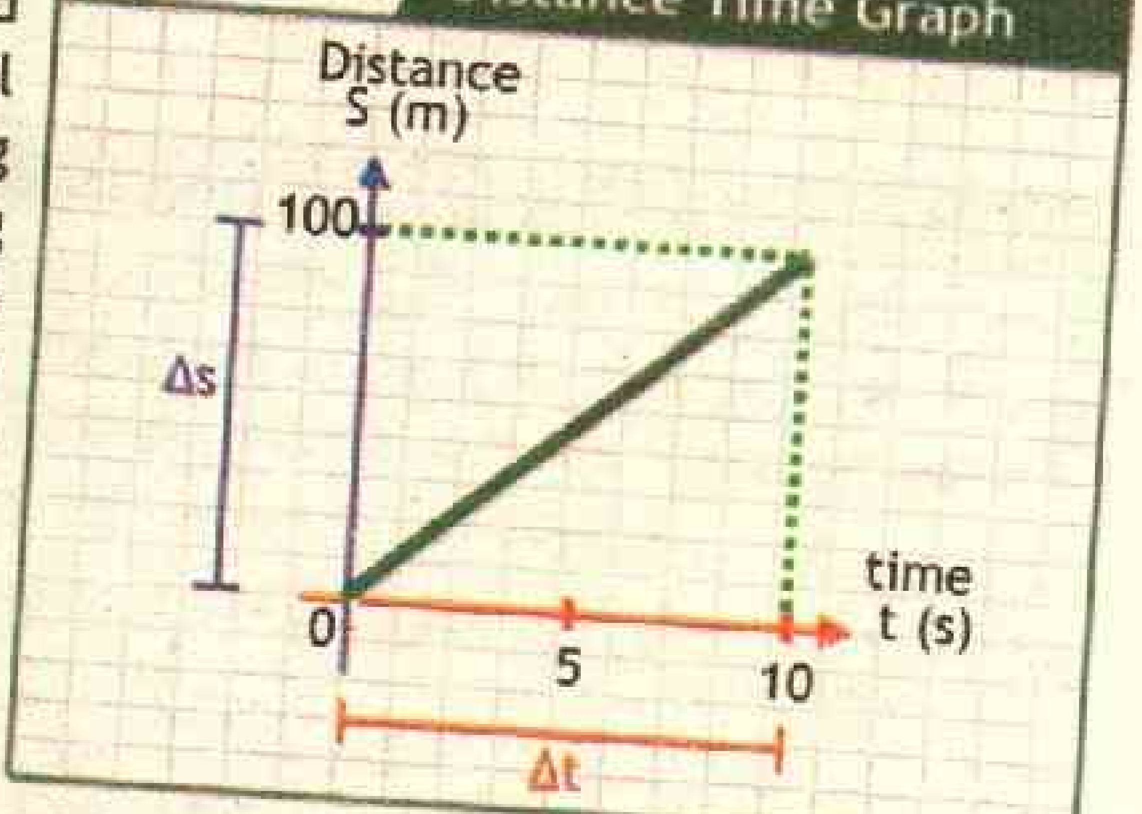
1. Pick two points P_i and P_f.
2. Determine the coordinates $P_i(x_i, y_i)$ and $P_f(x_f, y_f)$, by drawing perpendicular on x and y-axis from both points.
3. Determine the difference between x-coordinates ($\Delta x = x_f - x_i$) and y coordinates ($\Delta y = y_f - y_i$).
4. Dividing the difference in y-coordinates by difference in x-coordinates gives slope. Mathematically

$$slope = \frac{\Delta y}{\Delta x} = \frac{y_f - y_i}{x_f - x_i} \quad \text{--- 2.10}$$

2.4.1 DISTANCE-TIME GRAPH

The graph plotted between distance (s) and time (t) is called distance-time graph. In this graphical analysis the distance is plotted along vertical axis (y-axis) and time along horizontal axis (x-axis). Distance time graph is always in the positive XY plane, as with passage of time distance never goes to negative axis, irrespective of the direction of motion.

Figure 2.9 Distance Time Graph



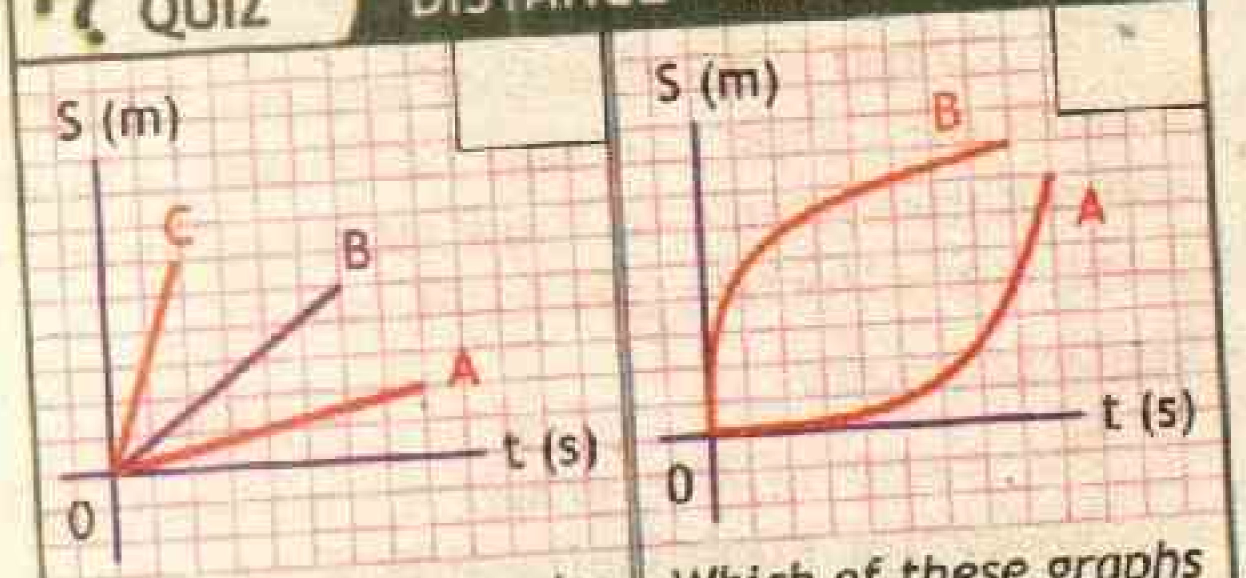
The slope of distance time curve only gives speed. Consider the motion of the object which covers a distance of 100 m in 10 s, the slope of distance time graph will give speed as equation 2.10 can be written as

$$slope = \frac{\Delta s}{\Delta t} = \frac{s_f - s_i}{t_f - t_i}$$

from equation 2.1 it is definition of speed, therefore

$$speed\ v = \frac{100\,m - 0\,m}{10\,s - 0\,s} = \frac{100\,m}{10\,s} = 10\,ms^{-1}$$

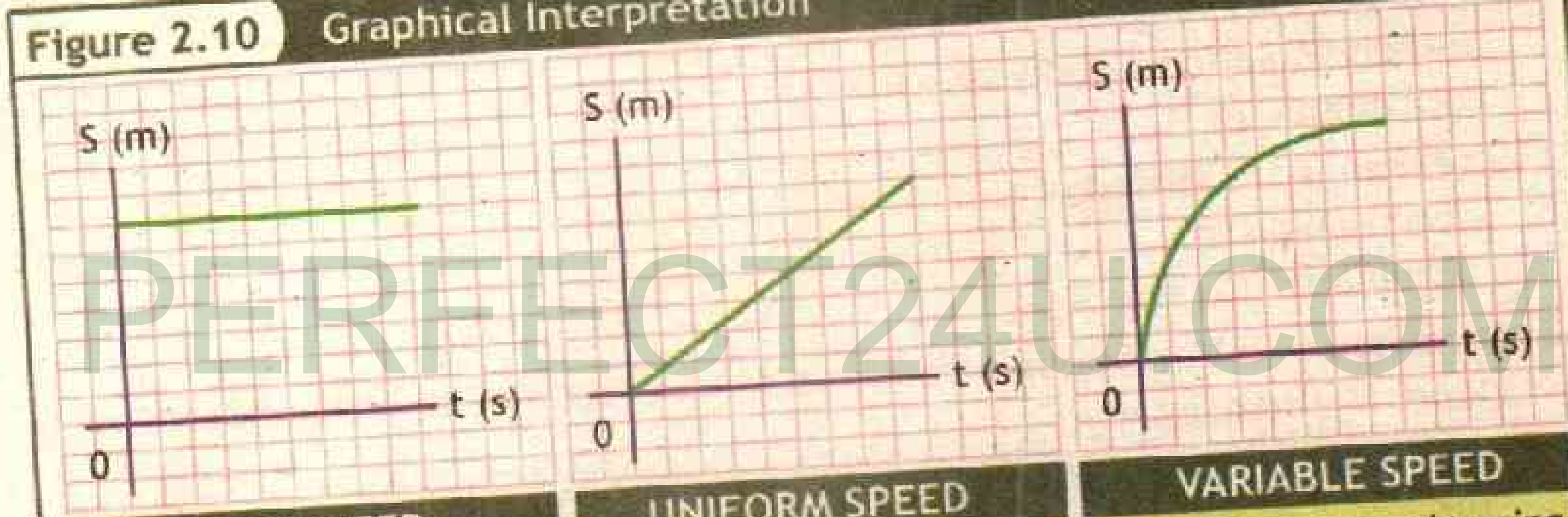
QUIZ DISTANCE- TIME GRAPH



Which of these graphs has higher speed?

Which of these graphs show increasing speed?

Figure 2.10 Graphical Interpretation



ZERO SPEED

Time is passing and no change in distance is seen. It means the body is at rest. Since there is no slope so the speed is zero.

UNIFORM SPEED

The distance is increasing linearly with time. The slope is constant therefore object is moving with uniform speed.

VARIABLE SPEED

The distance is changing non-linearly with time (spiking down). The slope is changing therefore object is moving with variable speed.

2.4.2 SPEED - TIME GRAPH

The graph plotted between speed (v) and time (t) is called speed-time graph. In this graphical analysis the speed is plotted along vertical axis (y-axis) and time along horizontal axis (x-axis). Speed time graph is useful for two purposes.

A. Slope or gradient of the graph gives magnitude of acceleration

B. Area under the graph gives distance traveled.

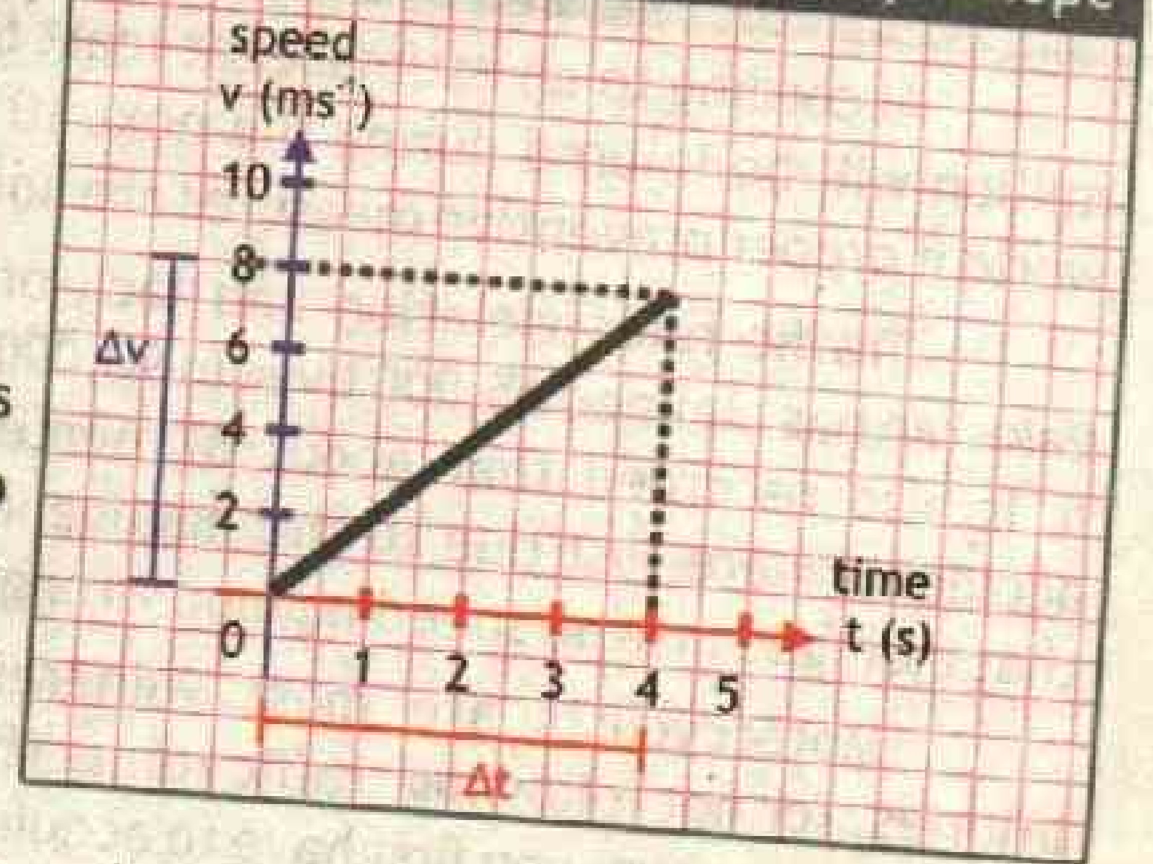
A. The slope of speed time curve gives magnitude of acceleration.

Consider the motion of the object which speeds up from 0 m/s to 8 m/s in 4 s, the slope of speed time graph will give magnitude of acceleration which can be written as

$$slope = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i}$$

Since acceleration is change in velocity with respect to time. Therefore change in speed with respect to time will only give magnitude of acceleration.

Figure 2.11 Speed Time Graph Slope



$$\text{Magnitude of acceleration} |a| = \frac{8\,ms^{-1} - 0\,ms^{-1}}{4\,s - 0\,s} = \frac{8\,ms^{-1}}{4\,s} = 2\ ms^{-2}$$

B) Area under speed time graphs represent the distance traveled:

When we speak of the area under a graph, we are not talking about the literal number of square centimeters of paper but the quantities under discussion. From equation 2.1 the speed is defined as

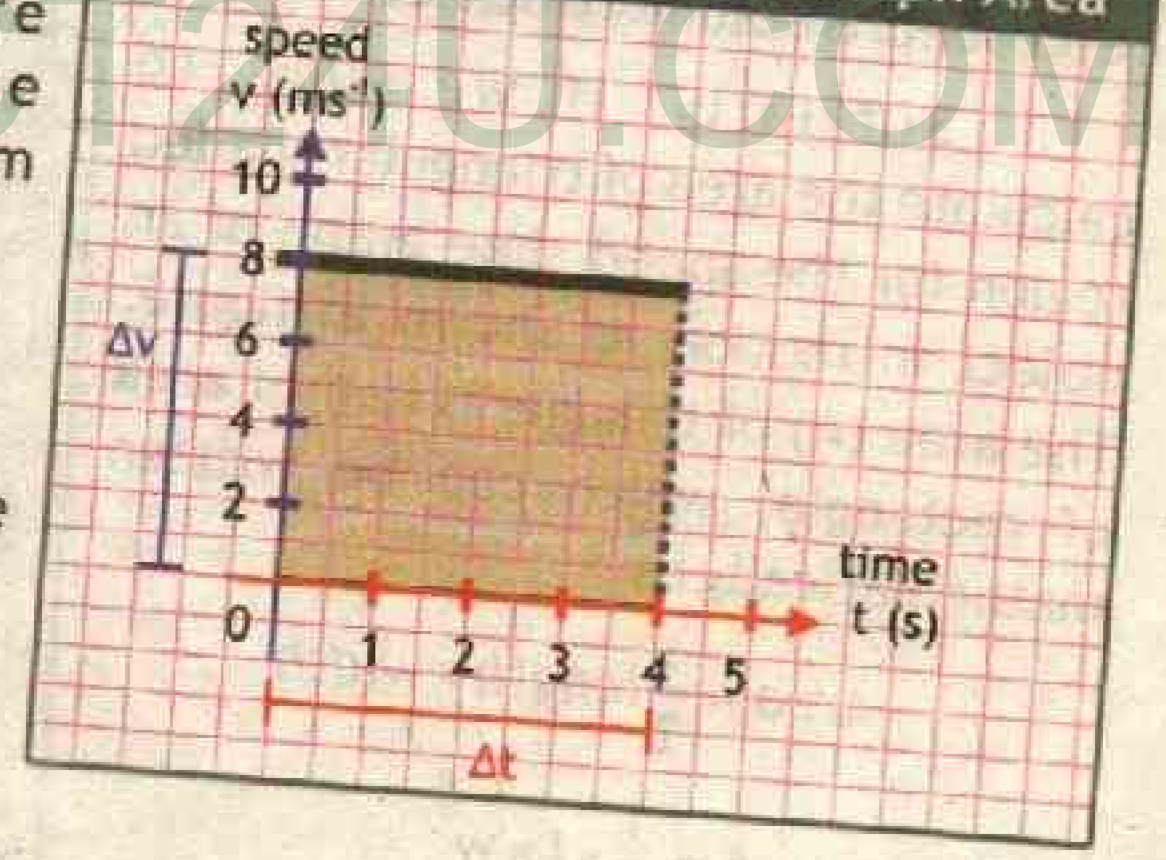
$$\text{speed} = \frac{\text{distance}}{\text{elapsed time}} \quad \text{or} \quad v = \frac{\Delta s}{\Delta t}$$

The above equation can be written as

$$\text{distance} = \text{speed} \times \text{elapsed time}$$

$$\text{or} \quad \Delta s = v \times \Delta t \qquad (2.11)$$

Figure 2.12 Speed Time Graph Area



This quantity in speed-time graph is represented as area under the curve. For example if we want to calculate the area of rectangular shaded region for the speed time graph of an object in motion as shown in figure 2.12 The area 'A' of rectangle mathematically is length 'l' into width 'w'.

$$Area = length \times width \quad \text{or} \quad A = l \times w \quad \text{or} \quad A = \Delta t \times \Delta v = \Delta v \times \Delta t$$

putting values from graph $A = (8 - 0)\,ms^{-1} \times (4 - 0)\,s$ or $A = 8\frac{m}{s} \times 4\,s$

therefore $A = 32\,m$

CASE STUDIES OVER SPEEDING & MOTORCYCLE ACCIDENTS

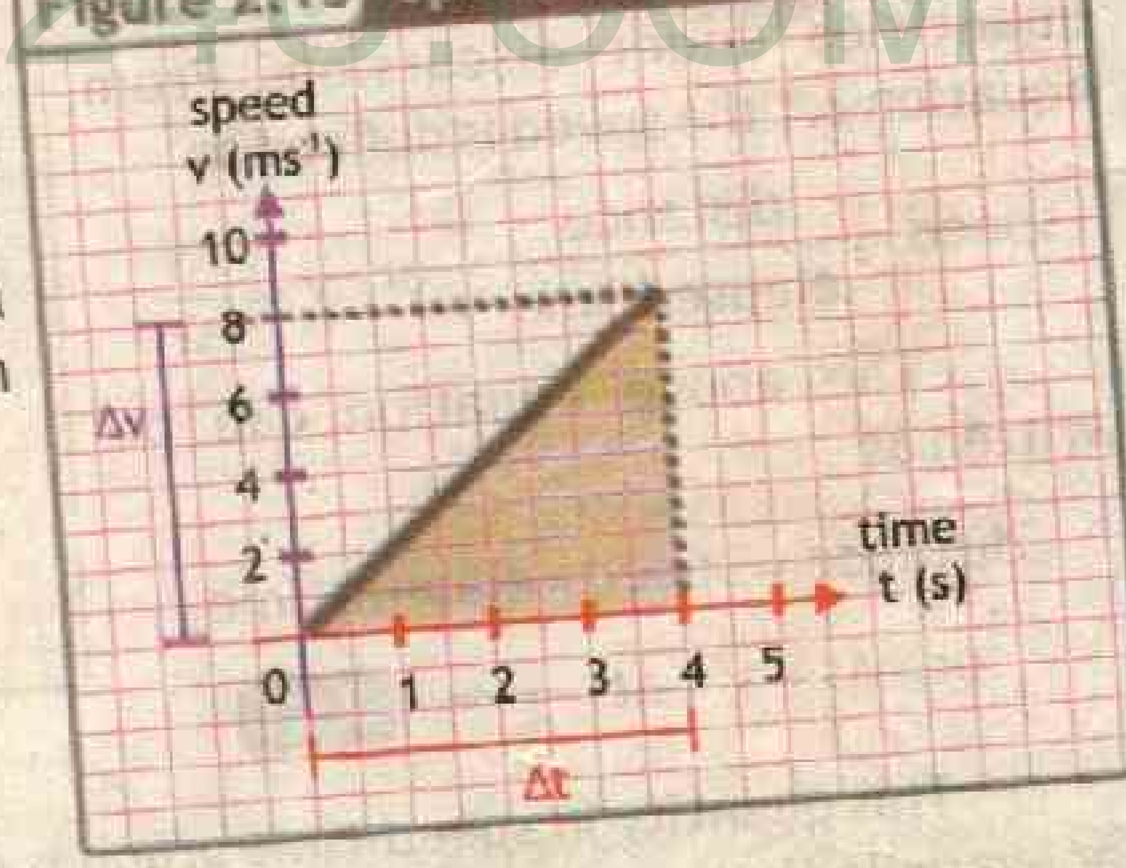
According to an estimate, at least 6 million more people will die and 60 million will be injured during the next 10 years in road accidents all over the world if proper preventive measures are not taken.

Traffic rules violation and lack of adequate road safety standards in Pakistan has claimed 45,000 lives in 90,000 road accidents in the last nine years. It is also recorded that about 87 percent of these accidents were just due to the negligence of drivers that indulged in over-speeding, and wrong overtaking.

Motorcyclists are most vulnerable to fatal injuries, for not following traffic rules. Therefore KIDS when you grow up, you first have to acquire license and then make yourself aware of safety standards before driving and remember the words - **SPEEDING THRILLS BUT IT KILLS.**

The area of rectangular shaded region in figure is 32 m. The quantity it represents is actually distance the body traveled.

Figure 2.13 Speed Time Graph Slope



Similarly, if we want to calculate the area of triangular shaded region for the speed time graph of an object in motion as shown in figure. The area (A) of triangle is half of area of rectangle, which can be written mathematically as

$$Area = \frac{1}{2} length \times width$$

$$A = \frac{1}{2} \times l \times w$$

or $$A = \frac{1}{2} \times \Delta t \times \Delta v = \frac{1}{2} \times \Delta v \times \Delta t$$

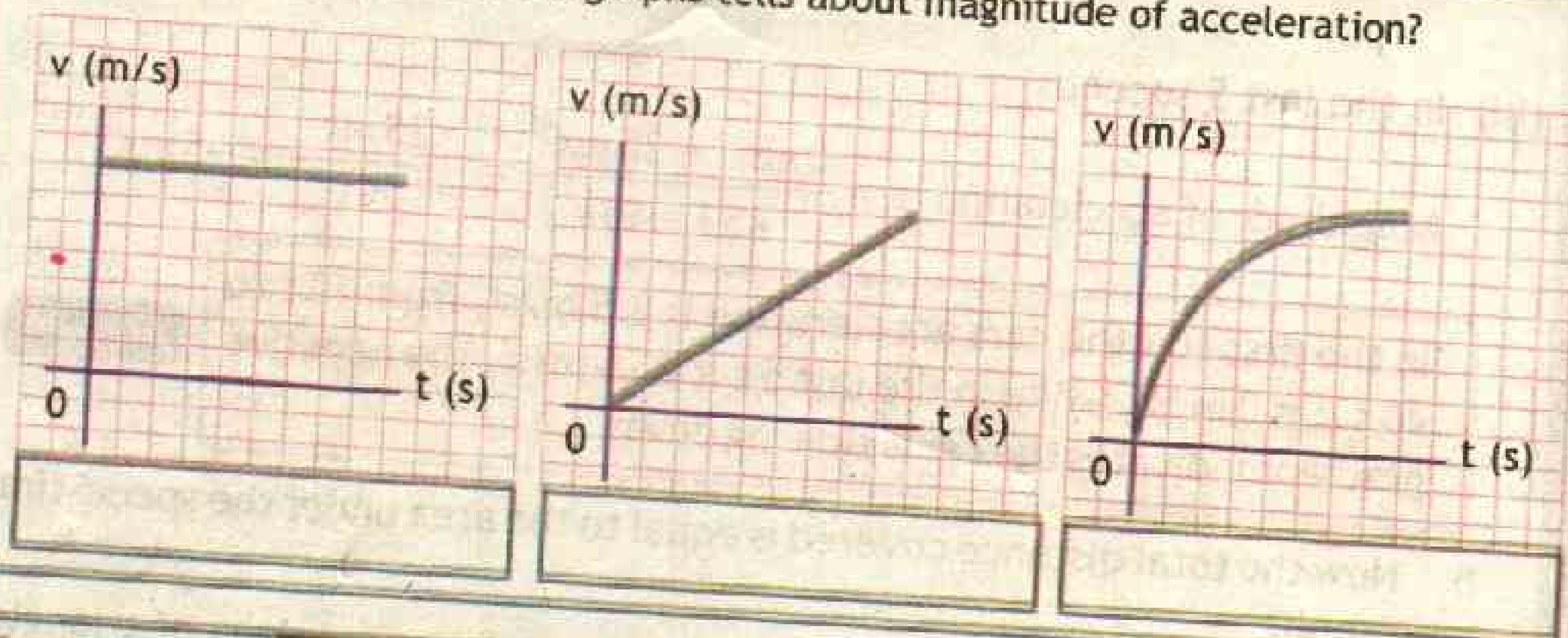
putting values from graph $$A = \frac{1}{2} \times (8-0) ms^{-1} \times (4-0) s$$

or $$A = \frac{1}{2} \times 8 \frac{m}{s} \times 4 s$$ therefore $$A = 16 m$$

The area of triangular shaded region in figure 2.13 is 16 m. The quantity it represents is actually distance the body traveled.

ACTIVITY — SPEED- TIME GRAPH

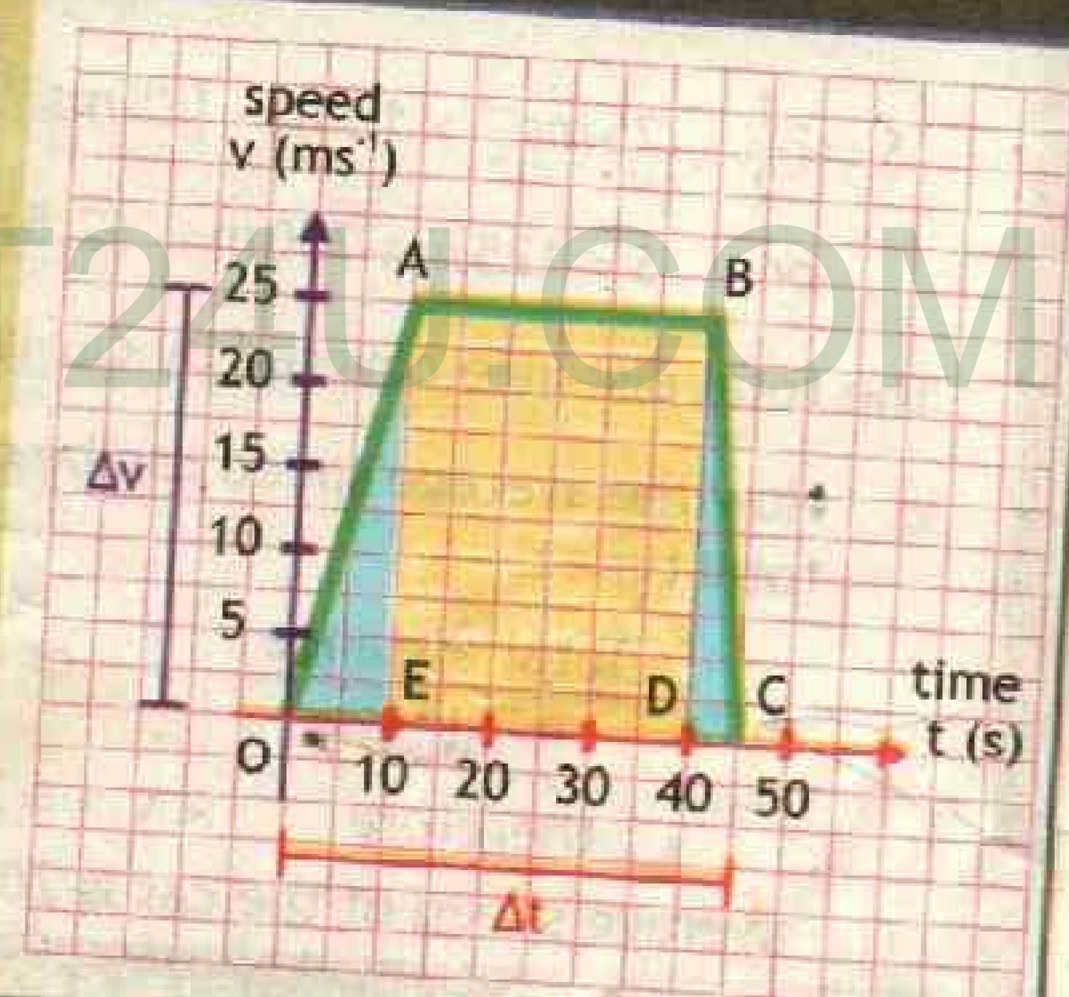
What does the slope of these graphs tells about magnitude of acceleration?



Example 2.4 — GRAPHICAL ANALYSIS OF CAR'S SPEED

A car increases its speed from ZERO to a 25 ms^{-1} in 10 s. Then it moves with uniform speed for the next 30 seconds and then the driver apply brakes and the speed of the car decreases uniformly to ZERO in the next 5 seconds. The graph is plotted for the journey, use this graph to calculate:

a. magnitude of acceleration (i) in first 10 s. (ii) from 10 s to 40 s and(iii) in last 5 seconds, b. total distance covered and c. average speed of the car for whole journey.



SOLUTION

a. The slope of the graph will give magnitude of acceleration

$$slope = \frac{\Delta v}{\Delta t} = \frac{v_f - v_i}{t_f - t_i} = magnitude\ of\ acceleration$$

(i) For the first 10 seconds, OA line represents the slope

$$\text{Magnitude of acceleration } a = \frac{25\,ms^{-1} - 0\,ms^{-1}}{10\,s - 0\,s} = \frac{25\,ms^{-1}}{10\,s} = 2.5\,ms^{-2}$$

(ii) From 10 s to 40 s, The slope is represented by line AB

Magnitude of acceleration $a = \frac{25\,ms^{-1} - 25\,ms^{-1}}{40\,s - 30\,s} = 0\,ms^{-2}$

(iii) In the last 5 seconds

Magnitude of acceleration $a = \frac{0\,ms^{-1} - 25\,ms^{-1}}{45\,s - 40\,s} = -\frac{25\,ms^{-1}}{5\,s} = -5\,ms^{-2}$

In the first 10 s the cars acceleration is 2.5 m/s^2, from 10 s to 40 s it is 0 m/s^2, while in the last 5 s it is -5 m/s^2, the negative gradient indicates the car is slowing down. **Answer**

b. Now the total distance covered is equal to the area under the speed-time graph.

Total distance covered = Area of triangle Δ OAE + Area of rectangle ABDE + Area of triangle Δ CDB

$S = \{\frac{1}{2} \times (25\,ms^{-1} \times 10\,s)\} + \{25\,ms^{-1} \times 30\,s\} + \{\frac{1}{2} \times (25\,ms^{-1} \times 5\,s)\}$

or $S = 125\,m + 750\,m + 62.5\,m = 937.5\,m$ — **Answer**

The total distance covered by car is 937.5 m

c. Now the average speed can be calculated when distance s is divided by total time t.

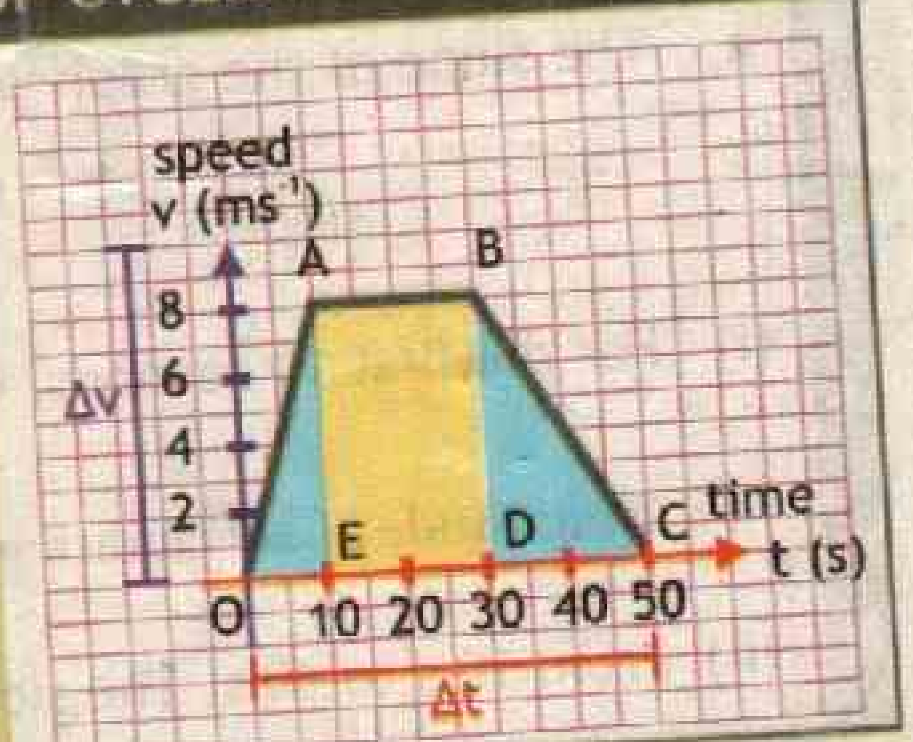
$<v> = \frac{\text{Total distance}}{\text{Total time}}$ or $<v> = \frac{937.5\,m}{45\,s}$

therefore $<v> = 20.8\,m/s$ — **Answer**

The average speed of the car is 20.8 m/s

Assignment 2.4 GRAPHICAL ANALYSIS OF CYCLIST

A cyclist increases his speed from ZERO to 8 ms^{-1} in 10 s. Then he moves with uniform speed for the next 20 seconds and then its speed decreases uniformly to ZERO in the next 20 seconds. The graph is plotted for the journey, use this graph to calculate the total distance covered.



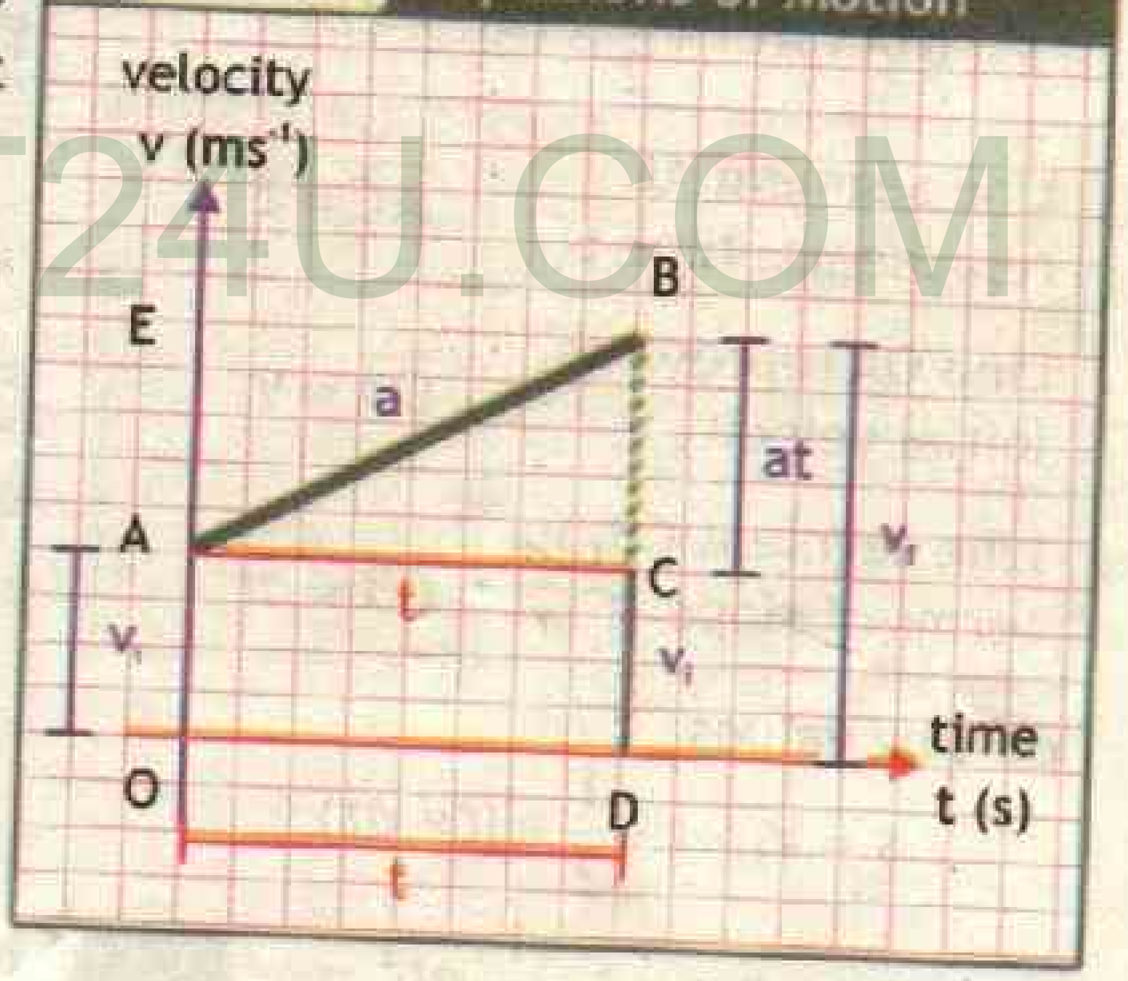
2.5 EQUATIONS OF MOTION

Terms associated with motion can be related and calculated from equations called equations of motion. These equations can be utilized for any motion that can be described as being either a constant velocity motion (an acceleration of 0 m/s^2) or a constant acceleration motion (i.e. the instantaneous and average accelerations are equal). They can never be used over any time period during which the acceleration is changing. Graphical method will be used to prove the equations of motion for uniformly accelerated motion.

We use the definitions of average velocity and acceleration to derive a set of valuable equations that relate x, a, v and t when a is constant, allowing us to determine any one of these variables if we know the others. We can then solve many interesting Problems.

In this discussion we chose the initial time to be zero $t_i = 0$, and final time $t_f = t$ such that $\Delta t = t_f - t_i = t - 0 = t$. Also we chose initial position to be zero $s_i = 0$ and final position $s_f = s$, such that displacement $\Delta s = s_f - s_i = s - 0 = s$.

Figure 2.14 Equations of Motion



The object has initial velocity v_i at point A, which changes uniformly to point B as v_f. In the plot OA = DC represents initial velocity v_i and DB represent final velocity v_f. Here time t is represented by OD = AC = t. The slope of the line AB is

$$slope = \frac{\overline{CB}}{\overline{AC}}$$

The slope of ...ocity-time graph gives acceleration a, since AC = t, therefore

$$a = \frac{\overline{CB}}{t} \qquad \overline{CB} = at$$

A. First Equation of Motion:

First eq... motion gives the relation of final velocity 'v_f' in terms of initial velocity ... and acceleration 'a' in time t. From the graph it is clear that

Line DB represents, final velocity v_f	$\overline{DB} = v_f$
Line DC represents, initial velocity v_i	$\overline{DC} = v_i$
Line segment CB, in terms of slope gives	$\overline{CB} = at$

$$\overline{DB} = \overline{DC} + \overline{CB}$$

putting these values in graph equation we get

$$v_f = v_i + at \quad \text{2.12}$$

B. Second Equation of Motion:

Second equation of motion relates displacement s with initial velocity 'v_i' and acceleration 'a' in time 't'. As the area under velocity-time curve represents the displacement 's' as shown in figure 2.14. Therefore, the displacement s of the object is:

displacement s = Area of rectangle OACD + Area of triangle Δ ACB

$$s = (\overline{OA} \times \overline{AC}) + \frac{1}{2} \times (\overline{AC} \times \overline{CB})$$

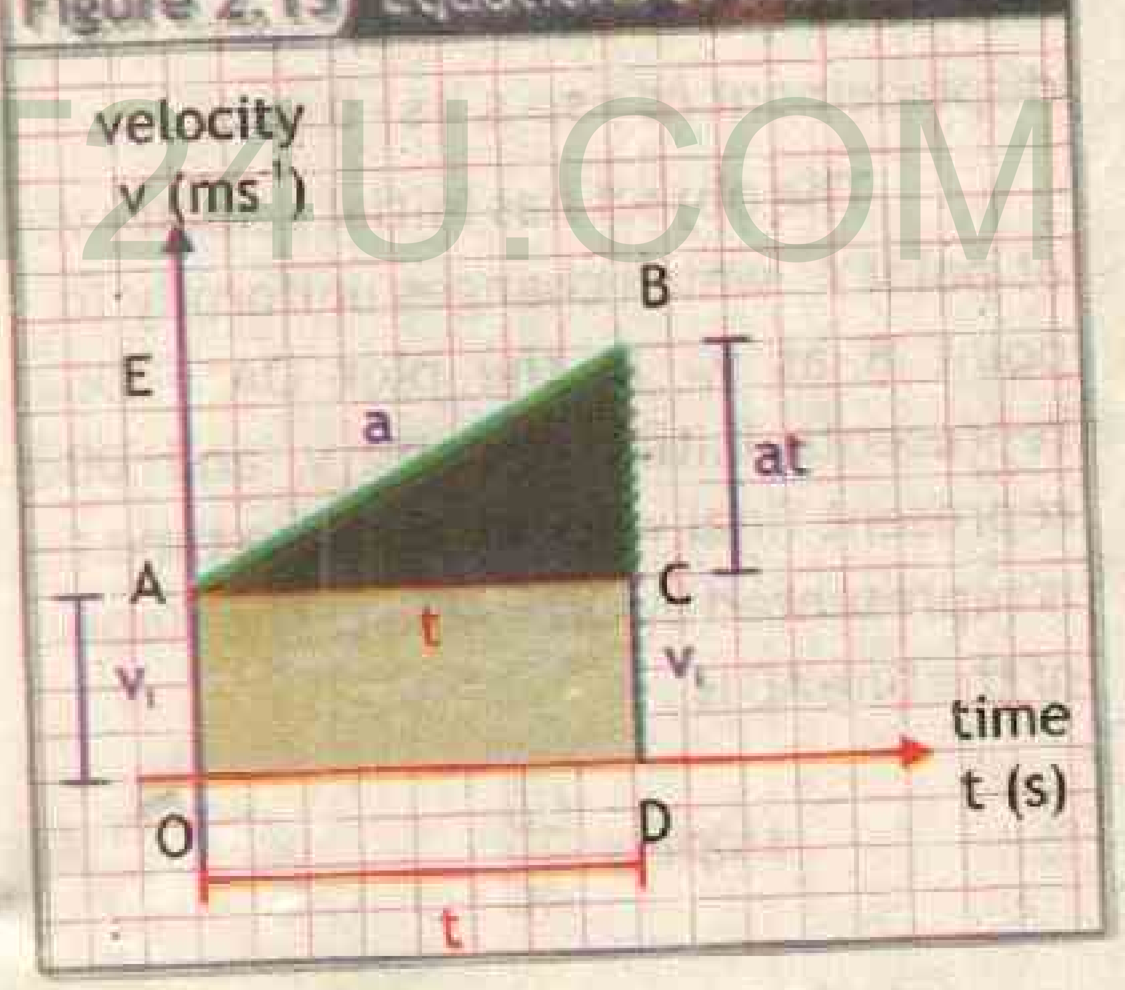
Line segment AC represents, time t	$\overline{AC} = t$
Line OA represents, initial velocity v_i	$\overline{OA} = v_i$
Line segment CB, in terms of slope is	$\overline{CB} = at$

putting values

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

therefore $s = v_i t + \frac{1}{2} at^2$ — 2.13

Figure 2.15 Equations of Motion



C. Third Equation of Motion:

Third equation relate position s, velocity v (both final velocity v_f and initial velocity v_i), and constant acceleration a **without including time t.** The area under the curve can be calculated by taking the total area of the trapezium OABD. The velocity-time graph the area of a trapezoid OABD will give the total displacement

$$s = \frac{1}{2}(\overline{OA} + \overline{DB}) \times \overline{OD}$$

Line DB represents, final velocity v_f	$\overline{DB} = v_f$
Line OA represents, initial velocity v_i	$\overline{OA} = v_i$
Line segment OD represents, time t	$\overline{OD} = t$

putting values $s = \frac{1}{2}(v_i + v_f) \times t$

From first equation of motion

$$v_f = v_i + at$$

or $at = v_f - v_i$ or $t = \frac{v_f - v_i}{a}$

The above equation becomes

$$s = \frac{1}{2}(v_i + v_f) \times \frac{(v_f - v_i)}{a}$$

$$s = \frac{1}{2a}(v_i + v_f)(v_f - v_i)$$

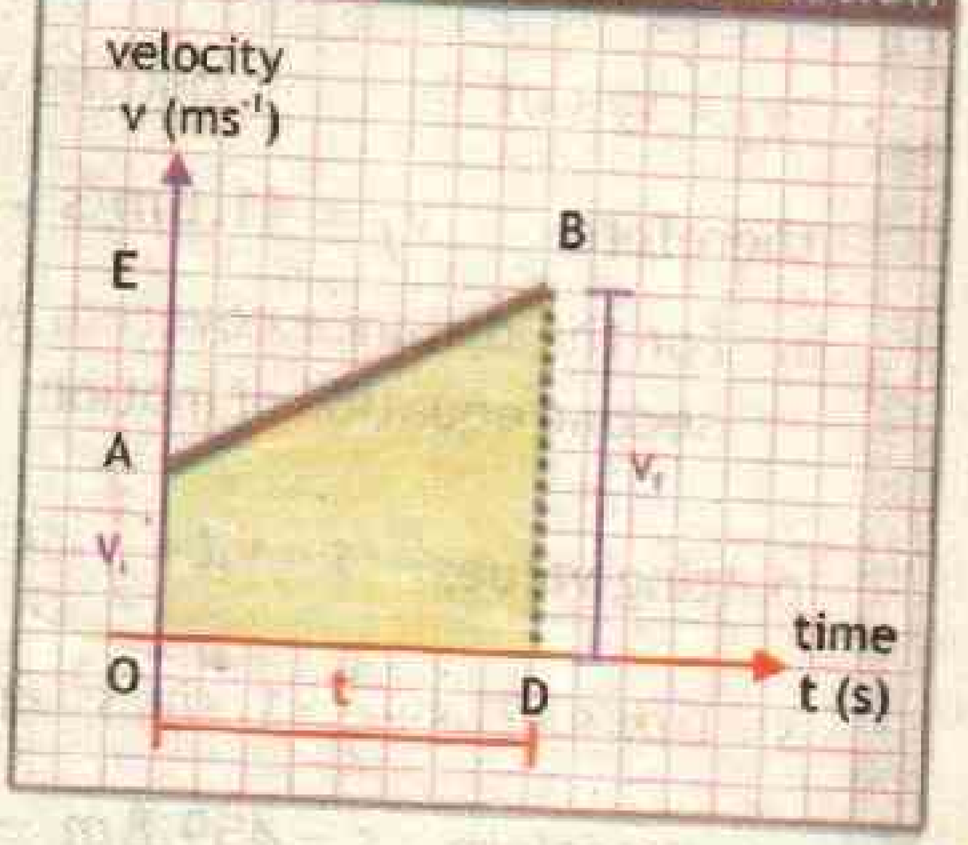
since $(a+b) \times (a-b) = a^2 - b^2$

therefore $(v_i + v_f)(v_f - v_i) = v_f^2 - v_i^2$

or $s = \frac{v_f}{2a}$

therefore $2as = v_f^2 - v_i^2$ — 2.14

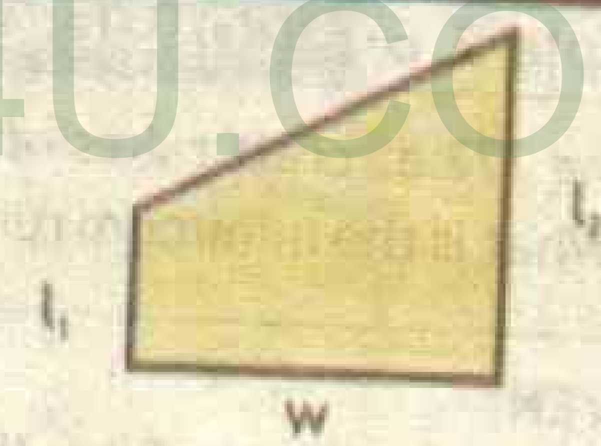
Figure 2.16 Equations of Motion



TIP km/h to m/s

To convert km/h to m/s, divide by 3.6

Figure 2.17 Trapezoid



The area of a trapezoid is given by

$$A = \frac{1}{2}(l_1 + l_2) \times w$$

which is simply the average of the parallel sides multiplied by the base.

Example 2.5 SPEEDING MOTORCYCLIST

A motorcyclist start ... and moves with uniform acceleration of 1.9 m/s² for 22s. Find the (a) ... (b) distance covered?

GIVEN:

initial vel ...

acceleratic ... m/s²

Total time t 22 s

REQUIRED:

a. Final velocity v_f = ?

b. Distance s = ?

SOLUTION

a. To find final velocity we can use the first equation of motion

$v_f = v_i + at$ putting values $v_f = 0\,m/s + 1.9\,m/s^2 \times 22\,s$

therefore $v_f = 41.8\,m/s$ — **Answer**

b. For the distance covered, we will use second equation of motion

putting values $s = v_i t + \frac{1}{2}at^2$

$s = 0\,m/s \times 22\,s + \frac{1}{2} \times 1.9\,m/s^2 \times (22\,s)^2$

therefore $s = 459.8\,m$ — **Answer**

EXTENSION EXERCISE 2.3

This problem is captioned speeding motorcyclist. Is 41.8 m/s safe speed for motorcycle ride? Also verify the distance covered in this problem by third equation of motion.

Assignment 2.5 CYCLIST MOTION

A cyclist is moving with uniform acceleration of 1.2 m/s^2. How much time will it require to change his velocity from 6 m/s to 12 m/s.

Example 2.6 COMMERCIAL AIRCRAFT RUNWAY LENGTH

A Boeing 777 aircraft takes off at 295 km/h after accelerating from rest at 2.80 m/s^2. What is the minimum runway length required?

SOLUTION

GIVEN:

initial velocity v_i = 0 km/h = 0 m/s

final velocity v_f = 295 km/h = 81.9 m/s

acceleration = 2.80 m/s^2

REQUIRED:

distance s = ?

Conversion from km/h to m/s

$$295\,km/h = \frac{295 \times 10^3\,m}{60 \times 60\,s} = \frac{295{,}000}{3600\,s} = 81.9\,m/s$$

Time is not given so we will use the third equation of motion

$2as = v_f^2 - v_i^2$ or $s = \frac{v_f^2 - v_i^2}{2a}$ putting values $s = \frac{(81.9\,ms^{-1})^2 - (0\,ms^{-1})^2}{2 \times 2.80\,ms^{-2}}$

$$s = \frac{6707.61\,m^2/s^2}{5.6\,m/s^2}$$

or $s = 1197.7875\,m$ — **Answer**

The units came out correctly as for displacement (meters) but we have to correct the number and express in three significant figures.

$s = 1200\,m \quad s = 1.20 \times 10^3\,m \quad s = 1.20\,km$

A runway needs to be longer than 1.2 km as this was calculated minimum length to give a margin of safety. Most commercial airport runways are between 2 km and 4 km long.

EXTENSION EXERCISE 2.4

At landing, the 777 s velocity is about the same as at takeoff, and after touchdown its acceleration is normally between $-2.0\,m/s^2$ to $-2.4\,m/s^2$.

How does this affect consideration of a safe runway length?

Assignment 2.6 BREAKING CAR

On Motorway M1, a car is moving at speed limit of 120 km/h. By applying breaks the car comes to rest after covering a distance of 30 m. What is the deceleration of the car?

2.5 MOTION DUE TO GRAVITY:

Everyone has observed the effect of gravity as it causes objects to fall downward. In the absence of air resistance, it is found that all bodies at the same location above the earth fall vertically with the same acceleration. Furthermore, if the distance of the fall is small compared to the radius of the earth, the acceleration can be considered constant throughout its fall. **The motion, in which air resistance is neglected and the acceleration is nearly constant, is known as free-fall.**

The acceleration of a freely falling body is called the acceleration due to gravity, and its magnitude (without any algebraic sign) is denoted by the symbol g. The acceleration due to gravity is directed downward, toward the center of the earth. Near the earth's surface, g is approximately

$$g = 9.80\,m/s^2 \text{ or } 32.2\,ft/s^2$$

Figure 2.18 Free Fall

(a) Air filled tube (b) Evacuated tube

(a) In the presence of air resistance, the acceleration of the rock is greater than that of the paper.

(b) In the absence of air resistance, both the rock and the paper have the same acceleration.

Figure a shows the well-known phenomenon of a rock falling faster than a sheet of paper. The effect of air resistance is responsible for the slower fall of the paper. When air is removed from the tube, as in Figure b, the rock and the paper have exactly the same acceleration due to gravity. In the absence of air, the rock and the paper both fall freely.

Since the acceleration is constant in free-fall, the equations of kinematics can be used. In these equations we replace acceleration 'a' with acceleration due to gravity 'g' and distance 's' with height 'h'.

$$v_f = v_i + gt \qquad (2.15)$$

$$h = v_i t + \frac{1}{2} gt^2 \qquad (2.16)$$

$$2gh = v_f^2 - v_i^2 \qquad (2.17)$$

When an object moves with the gravity acceleration due to gravity is taken as positive (+g) and when object moves against gravity, acceleration due to gravity is taken negative (-g).

LAB WORK

Find the value of "g" by free fall method.

Example 2.7 HEIGHT OF BRIDGE FROM WATER SURFACE

A stone is dropped from the Attock Bridge. The stone reaches the water in 3.2 s. Find the **a.** height of the bridge from water and **b.** velocity of the stone when it strikes the water.

SOLUTION

GIVEN:

Time t = 3.2 s

Initial velocity $v_i = 0\ ms^{-1}$

Acceleration due to gravity $g = 9.8\ ms^{-2}$

REQUIRED:

a. Height h = ?

b. Final velocity v_f = ?

a. By second equation of motion $h = v_i t + \frac{1}{2} gt^2$

putting values $h = 0\,ms^{-1} \times 3.2s + \frac{1}{2} \times 9.8\,ms^{-2} \times (3.2)^2$

therefore $h = 50.176\,m$

Rounding off to correct significant figures $h = 50\,m$ — **Answer**

b. By First equation of motion $v_f = v_i + gt$

putting values $v_f = 0ms^{-1} + 9.8ms^{-2} \times 3.2s$

therefore $v_f = 31.36ms^{-1}$

Rounding off to correct significant figures $v_f = 31ms^{-1}$ — Answer

Assignment 2.7 CRICKET BALL

In a cricket match ball go straight up with a velocity of 40 m/s. Calculate
a) maximum height ball will reach b) time to reach that height.

KEY POINTS

Mechanics: The branch of Physics, which deals with the motion of bodies.

Kinematics: The branch of physics, which deals with discussion of motion of object without reference to the forces causing the motion.

Dynamics: It is the study of motion of bodies under the action of a force.

Rest: A body is said to be at rest if it does not change its position with respect to an observer.

Motion: A body is said to be in motion if it changes its position with respect to an observer.

Types of Motion: There are three main types of motion

a) Translatory Motion b) Rotatory Motion c) Vibratory Motion

Scalars: Physical quantities completely specified by its magnitude, that is, a proper unit and a number are called scalars.

Vectors: Physical quantities completely specified by magnitude, as well as direction are called vectors.

Position: The distance and direction of a body from a fixed point shows its position.

Displacement: The shortest distance from the initial and final position of a body is called displacement.

Speed: time rate of change of distance is called speed it is a scalar quantity.

Velocity: The time rate of change of displacement is called velocity it is a vector quantity.

Acceleration: The time rate of change of velocity is called acceleration.

Equations of Motion: The inter-relationship of velocity, uniform acceleration, time interval and displacement of an object are expressed by the following equations:

a. $v_f = v_i + at$ b. $s = v_it + \frac{1}{2}at^2$ c. $2as = v_f^2 - v_i^2$

P R O J E C T S

GROUP - A

GALILEO'S WORK: Research Galileo's work on falling bodies. What did he wanted to demonstrate? What arguments did he use to prove that he was right? Did he used experiments, logic, findings of other scientists, or other approaches?

GROUP - B

SPEEDS AND ACCELERATIONS OF ANIMALS: Research typical values for speeds and accelerations of animals. Find out how long it gets for different animals to attain their top speed. Why the predators (lion or cheetah) likes to get close to the prey (gazelle, deer or buffalo) to launch an attack? How the predator to prey distance affect a kill.

GROUP - C

OVER SPEEDING: Write a publication essay for school library on over-speeding issues related to different means of transportation and speed limits.

GROUP - D

DESIGN OF PARK RIDES AND TRANSPORTATION DEVICES: Research the maximum acceleration a human body can withstand without blacking out. Discuss how acceleration impacts the design of common entertainment (such as park rides) or transportation devices.

GROUP - E

CAR RIDE: Go by a car, record the odometer, and the speedometer for every 20 s for about 5 min. Create representation of the car's motion by distance-time and speed-time graphs. And show that area under the speed-time curve gave the same result as the difference in the initial and final readings on odometer.

EXERCISE

MULTIPLE CHOICE QUESTIONS

1. The average speed of a bus is $20 ms^{-1}$, how far can it travel in 10s?
   A. 100 m B. 200m C. 150m D. 250m
2. A truck accelerates uniformly from $15 ms^{-1}$ to $20 m^{-1}$ in 5 s. What is the acceleration of the truck?
   A. $2 ms^{-2}$ B. $1.5 ms^{-2}$ C. $1 ms^{-2}$ D. $2.5 ms^{-2}$
3. A car moving along a straight line at $20 m s^{-1}$ under goes an acceleration of $4 ms^{-2}$. After 2s, its speed will be
   A. $28 ms^{-1}$ B. $16 ms^{-1}$ C. $12 ms^{-1}$ D. $8 ms^{-1}$
4. A bird begins to accelerate at a constant $0.3 m/s^2$ for 3 s. Its change in velocity is
   A. 0.9 m/s B. 1.5 m/s C. 1.95 m/s D. 2.4 m/s
5. A car is going backwards at 5 m/s. After 10 s of uniform acceleration, the car is going forward at 10 m/s. The acceleration is
   A. $0.5 m/s^2$ B. $0.75 m/s^2$ C. $1.5 m/s^2$ D. $5 m/s^2$
6. The slope of distance-time graph represents:
   A. acceleration B. change in acceleration C. speed D. distance
7. The area under a speed-time graph represents:
   A. acceleration B. change in acceleration C. distance D. velocity
8. A student riding his bicycle on a straight flat road covers one block every 7 seconds. If each block is 100m long, he is traveling at:
   A. Constant speed B. Constant velocity C. 10m/s D. Both A and B
9. You drop a rock from a bridge to the river below. When the rock has fallen 4 m, you drop a second rock. As the rocks continue their free fall, their separation
   A. increase B. decrease C. stay the same D. none

CONCEPTUAL QUESTIONS

Give a brief response to the following questions.

1. Is it possible that displacement is zero but not the distance. Under what condition displacement will be equal to distance.
2. Does a speedometer measure a car's speed or velocity?
3. Is it possible for an object to be accelerating and at rest at the same time? Explain with example.
4. Can an object have zero acceleration and nonzero velocity at the same time? Give example.
5. A person standing on the roof of a building throws a rubber ball down with a velocity of 8.0 m/s. What is the acceleration (magnitude and direction) of the ball?
6. Describe a situation in which the speed of an object is constant while the velocity is not.
7. Can an object have a northward velocity and a southward acceleration? Explain.
8. As a freely falling object speeds up, what is happening to its acceleration – does it increase, decrease, or stay the same?
9. A ball is thrown upward with an initial speed of 5 m/s. What will be its speed when it returns to starting point?

COMPREHENSIVE QUESTIONS

Give an extended response to the following questions.

1. What is motion? Describe that motion is relative. How two observers in relative motion can have conflicting views about same object?
2. Explain different types of motion and give an example of each.
3. Define scalar and vector quantities. Explain with example the graphical representation of vector quantities.
4. What is position. Explain the difference between distance traveled, displacement, and displacement magnitude.
5. State and explain the terms:

   a. speed b. velocity c. acceleration

6. Use velocity-time graph to prove the following equations of motion

   a. $v_f = v_i + at$ b. $s = v_i t + \frac{1}{2} at^2$ c. $2as = v_f^2 - v_i^2$

7. What is free-fall, what is its value near the surface of earth. Explain with example that rock and sheet of paper will fall at the same rate without air resistance.

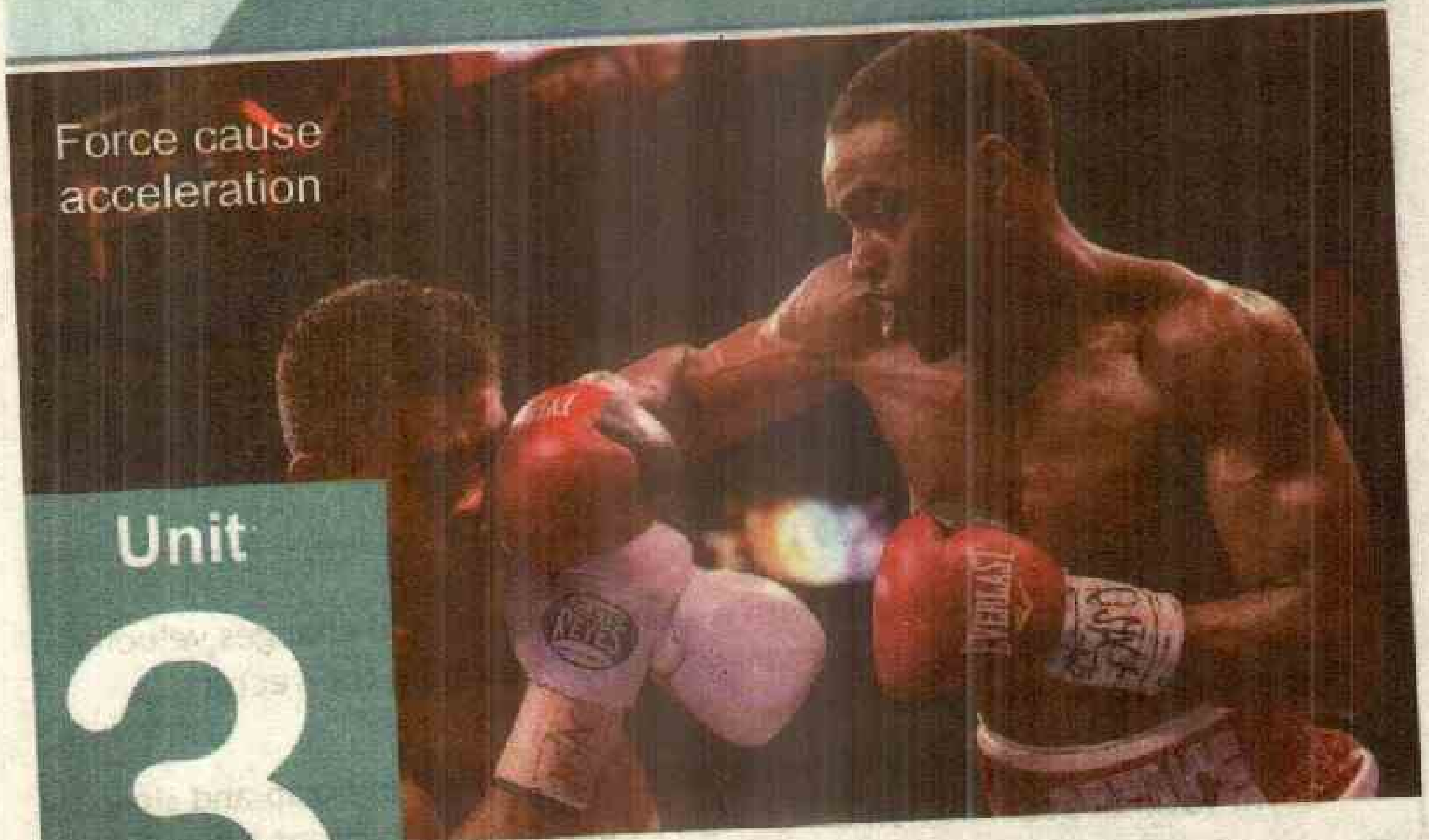
NUMERICAL QUESTIONS

1. A squash ball makes contact with a squash racket and changes velocity from 15 m/s west to 25 m/s east in 0.10 s. Determine the vector acceleration of the squash ball.
2. A golf ball that is initially traveling at 25 m/s hits a sand trap and slows down with an acceleration of -20 m/s^2. Find its displacement after 2.0 s.
3. A bullet accelerates the length of the barrel of a gun 0.750 m long with a magnitude of 5.35×10^5 m/s^2. With what speed does the bullet exit the barrel?
4. A driver is traveling at 18 m/s when she sees a red light ahead. Her car is capable of decelerating at a rate of 3.65 m/s^2. If she applies brakes when she is only 20.0 m from the intersection when she sees the light, will she be able to stop in time.
5. An antelope moving with constant acceleration 2 m/s^2 covers crosses a point where its velocity is 5 m/s. After 6.00 s how much distance it has covered and what is its velocity ?
6. With what speed must a ball be thrown vertically from ground level to rise to a maximum height of 50 m?

WEB LINKS

http://www.physicsclassroom.com/Physics-Interactives/1-D-Kinematics

https://phet.colorado.edu/en/simulations/category/physics/motion



Unit 3

DYNAMICS

CHECK LIST

After studying this unit you should be able to

- ✓ Define momentum, force, inertia, friction, centripetal force.
- ✓ Solve problem using the equation :Force= change in momentum/change in time.
- ✓ Explain the concept of force by practical examples of daily life.
- ✓ State Newton's laws of motion.
- ✓ Distinguish between mass and weight and solve problem using F=ma and w=mg.
- ✓ Calculate tension and acceleration in a string during motion of bodies connected by the string and passing over frictionless pulley, using second law of motion.
- ✓ State the law of conservation of momentum.
- ✓ Use the principle of momentum conservation in the collision of two objects.
- ✓ Determine the velocity after collision of two objects using the law of conservation of momentum.
- ✓ Explain the effect of friction on the motion of a vehicle in the context of tyre surface, road conditions including skidding, braking force.
- ✓ List various methods to reduce friction.
- ✓ Explain that motion in a curved path is due to a perpendicular force on a body that changes direction of motion but not speed.
- ✓ Calculate centripetal force on a body moving in a circle using mv^2/r.
- ✓ State what will happens to you while you are sitting inside a bus when the bus
- ✓ 1. starts moving suddenly 2. stops moving suddenly 3. turns a corner suddenly
- ✓ Write a story about what may happen to you when you dream that all frictions suddenly disappeared. Why did your dream turn into night mare?

As discussed earlier mechanics deals with the study of motion of objects. But few questions like why some objects are accelerated and others are not? How and why a moving object changes its direction of motion? These questions can be answered when we extend our discussion of motion of objects to another branch of mechanics known as Dynamics. In this unit we will learn about force, momentum, newton's laws, friction and circular motion.

Kinematics is the **"how"** of motion and **Dynamics** is the **"why"** of motion.

Dynamics is derived from the Greek word for force. The branch of physics which deals with the study of motion by analyzing the cause of motion is called dynamics.

3.1 FORCE

A force is a kind of a push or a pull on an object. When we push a stilled car, hit the nail with hammer or drag a chair, we are exerting a force in each case.

We can think of different ways in which we can move this textbook. We can push or pull it, or we can tie a string around it and pull on the string. We often call these *contact forces* because the force is exerted when one object comes in contact with another object. As we are holding this physics textbook right now, our hands are exerting a contact force on it. There are other ways in which we can change the motion of the textbook. We can drop it, as we learned in Chapter 2 Kinematics, it would accelerate as it falls to the ground. This time the gravitational force of Earth (which is not a contact force) is acting on the book which is causing this acceleration. We call such forces as ***non-contact forces***, ***field forces*** or ***action-at-a-distance forces***.

Figure 3.1 Non Contact Forces

Can you think of other kinds of field forces?

If you have ever experimented with magnets, you know that they exert forces without touching.

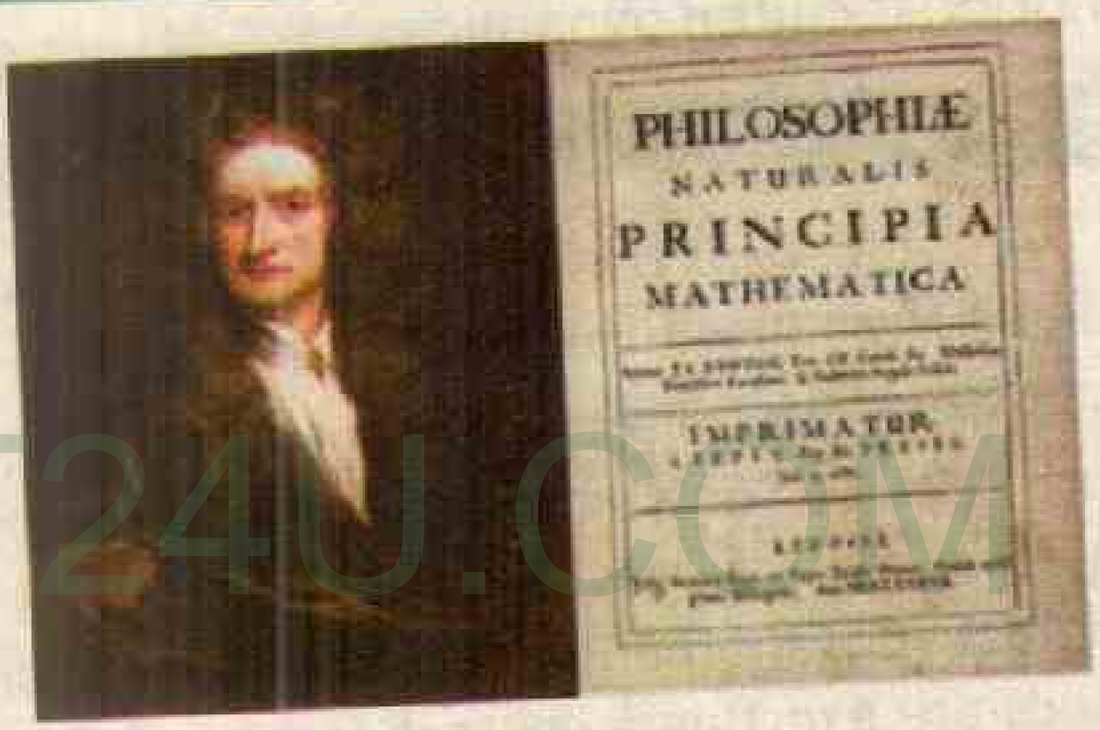
Forces can cause objects to start moving, speed up, slow down, or change direction as they move. In other words, to accelerate an object, a force is needed. But sometimes we apply force and object does not move. For example when we apply force on a wall— wall does not move. At times we cannot even stop a moving body. For example, we fail to stop a moving truck even if we apply force.

DEFINITION OF FORCE Force is a physical quantity which moves or tends to move a body, stops or tends to stop a moving body.

In other words force is a physical quantity changes or tends to change the velocity (both in magnitude and/or direction – acceleration) of a body. In System International (SI) the unit of force is **newton** (first letter small) and is represented by symbol **N.** One newton is defined as the force that produces acceleration of **one meter per second square** ($a = 1\ m/s^2$) in a body of mass **one kilogram (1 kg).**

$$1N = 1kg \times 1m/s^2 \quad \text{or} \quad N = kg\,m/s^2$$

3.2 NEWTON'S LAWS OF MOTION:



Isaac Newton (1642-1727) was born in England, he proposed a theory of the causes of motion. Collectively they are called **"Newton's laws of motion"** and provide the basis for understanding the effect that forces have on an object. This book was written in Latin with title Philosophiae Naturalis Principia Mathematica, as shown in figure. The English title of Newton's 1687 treatise is The Mathematical Principles of Natural Philosophy, which is often referred to as Newton's Principia.

3.2.1 NEWTON'S FIRST LAW OF MOTION:

Statement:

If the net (external) force acting on an object is zero, the object will maintain its state of rest or of uniform motion (constant velocity).

In other words, if there is no net force acting on an object, its velocity will not change. If it is at rest, it will remain at rest; if it is moving, it will continue to move with constant velocity (zero acceleration; no change in speed or direction). Mathematically, first law can be expressed as

$$\vec{F}_{net} = 0 \quad \text{then} \quad \Delta\vec{v} = 0 \quad \text{or} \quad \vec{a} = 0$$

Newton's first law indicates that a state of rest (zero velocity) and a state of constant velocity are equivalent, because both of them does not require a net force to sustain it. The study of first law of motion can be divided into two parts.

Bodies At Rest:

The first part of the law sates that a body at rest will remain at rest if no net force acts on it. This part of first law is easy to understand and goes with our common observation. For example a chair lying in a room will remain stationary and will not start moving or flying around by itself unless some one moves it by applying a net force.

Figure 3.2 Bodies at Rest

Bodies In Motion:

The second part of the law states that a body in motion will continue to move in a straight line with uniform speed if no net force acts on it. However our daily observation is against this. For example if we roll a ball it comes to rest after some time. But careful study of the moving ball shows that there are forces (like friction and air resistance) which oppose the motion of the ball.

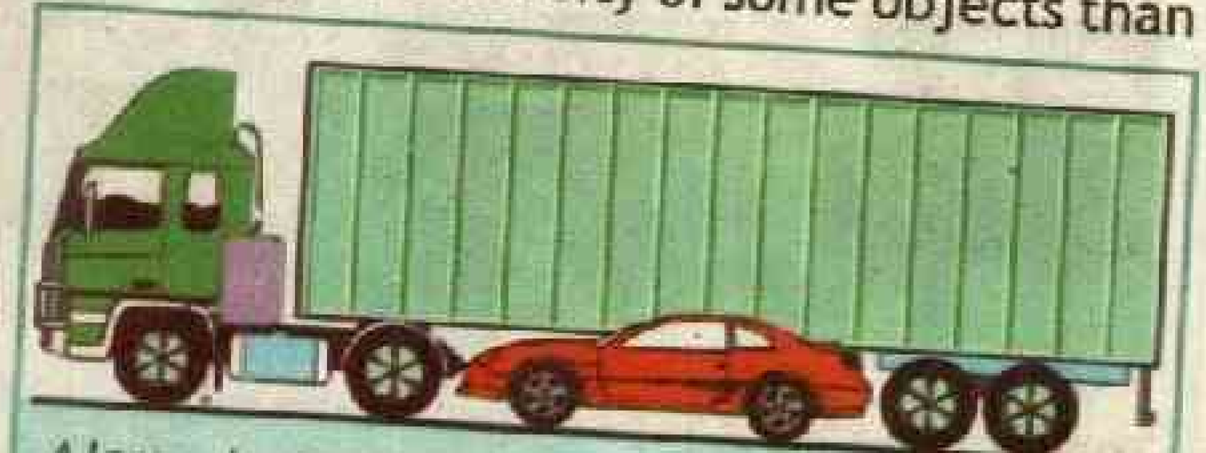
Figure 3.3 Bodies in Motion

This means that object would continue to move in a straight line for ever, with uniform speed if the forces opposing the motion of the object are removed. In space where there are negligible opposing forces, objects move in a straight line and no applied force has to be maintained by an engine to keep them moving.

Inertia:

A greater net force is required to change the velocity of some objects than of others.

For instance, a net force that is just enough to move a car will cause only a small change in motion of a truck. In comparison to the car, the truck has a much greater tendency to remain at rest.



A larger body (in mass) has a greater resistance to a change in its motion than does a smaller one.

Therefore, we say that the truck has more inertia than a car.

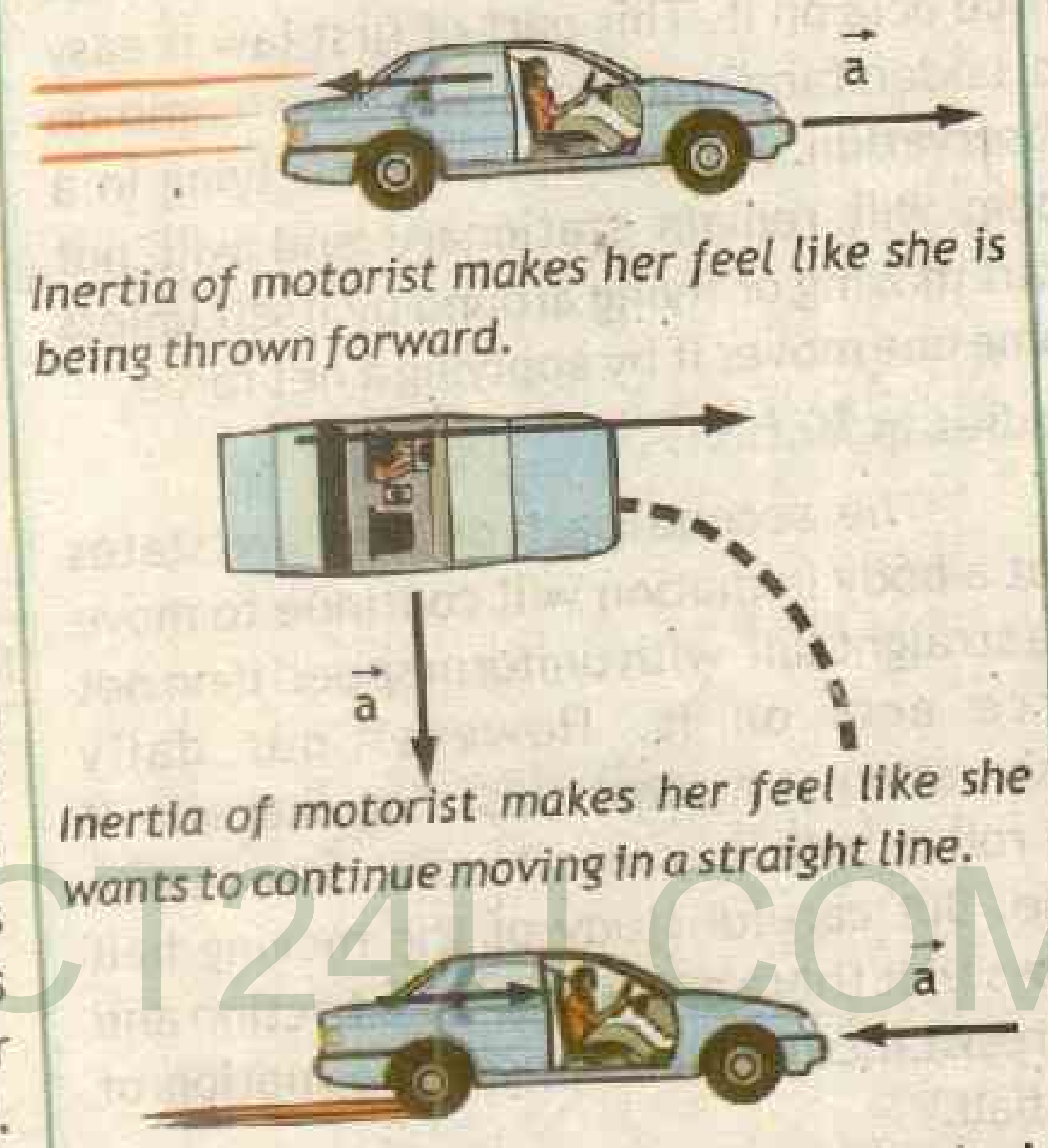
A) Newton's first law is sometimes called the law of inertia:

Using Newton's first law of motion help us to define inertia, therefore it is also called **law of inertia**. Inertia is the natural tendency of an object to remain at rest or in motion at a constant velocity. **The mass of an object is a quantitative measure of inertia.** SI Unit of Inertia and Mass is kilogram (kg). The larger the mass, the greater is the inertia.

B) We can feel inertia:

When we are in a moving car, we can feel the effects of our own inertia. If the car accelerates forward, we feel as if our body is being pushed back against the seat, because our body resists the increase in speed. If the car turns a corner, we feel as if our body is being pushed against the door, because our body resists the change in the direction of motion. If the car stops suddenly, we feel as if our body is being pushed forward, because our body resists the decrease in speed. These situations are shown in the figure 3.4, where a motorist feel the effects of changing accelerations.

Figure 3.4 Feeling Inertia



Inertia of motorist makes her feel like she is being thrown forward.

Inertia of motorist makes her feel like she wants to continue moving in a straight line.

Inertia of motorist makes her feel like she is being pushed backward.

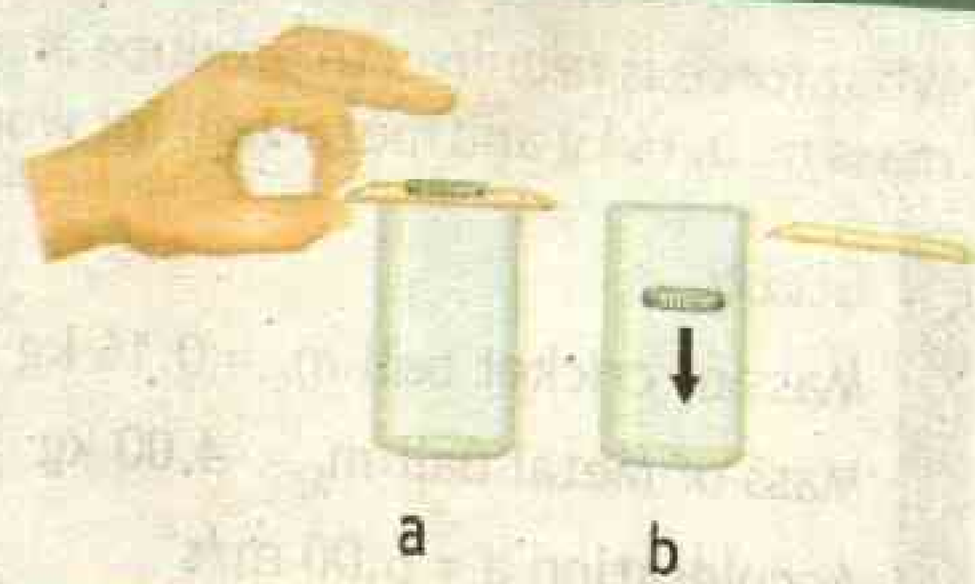
TID-BIT

Using Newton's first law we could remove the cloth without toppling or breaking items placed on it . . .

The trick to keeping the dishes on the table is to use a very smooth tablecloth without any hem and very quickly jerk the tablecloth backward in a slightly downward direction. We suggest that you practice with heavy objects on plastic plates. Remember that the more mass placed on the plates, the greater is the inertia.

ACTIVITY **DEMONSTRATION OF INERTIA**

Place a card on top of a glass. Then place a coin on top of the card as in Fig (a). Quickly flick the card horizontally. The inertia of the coin tends to keep it at rest horizontally. The force that causes the coin to move is the vertical force of gravity, which pulls it straight down into the glass as in Fig. (b).



3.2.2 NEWTON'S SECOND LAW OF MOTION

Statement:

The net force 'F' on a body is equal to the product of the body's mass m and its acceleration a.

OR

A net force (unbalanced force) applied on the body produces an acceleration 'a' in the body. This acceleration is directly proportional to the magnitude of the net force and inversely proportional to the mass of the object.

$$a \propto F \quad \text{—— (1)}$$

$$a \propto \frac{1}{m} \quad \text{—— (2)}$$

The acceleration is in the same direction as that of the net force. Combining equation 1 and 2 we get

$$a \propto \frac{F}{m} \quad \text{or} \quad a = k\frac{F}{m}$$

If m = 1 kg and a = 1 m/s^2, then F = 1 N.

Substituting in F = kma, we get k = 1 and so we can write

$$a = 1 \times \frac{F}{m} \quad \text{or} \quad a = \frac{F}{m} \quad \text{therefore} \quad F = ma \quad \text{—— (3.1)}$$

Newton's second law tells us that acceleration 'a' will be largest when force 'F' is large and mass 'm' small.

POINT TO PONDER

Kilogram of Cotton and Gold: Which has more mass: a kilogram of cotton balls or a kilogram of gold?

POINT TO PONDER

In Pakistan the bus does not halt completely for male passengers on bus stop. They momentarily reduce speed and we are told to step down the bus in the direction in which the bus is moving. Why?

TIP

When two things are directly proportional to each other, as one increases, the other increases also. However, when two things are inversely proportional to each other, as one increases, the other decreases.

To change proportionality into equality usually a constant is used.

Example 3.1 FORCES ON SPORTS BALLS

What force is required to produce an acceleration of 6.00 m/s^2 in a cricket ball of mass m_c 0.16 kg and metal ball for women shot-put game with mass $m_s = 4$ kg.

SOLUTION

GIVEN:

Mass of cricket ball m_c = 0.16 kg

Mass of Metal Ball m_s = 4.00 kg

Acceleration a = 6.00 m/s^2

REQUIRED:

Force on cricket ball F_c = ?

Force on metal ball F_s = ?

By Newton's second law $F_C = m_C a$

putting values $F_C = 0.16\,kg \times 6.00\,m/s^2$ or $F_C = 0.96\,kg\,m/s^2$

since $N = kg\,m/s^2$

therefore $F_C = 0.96\,N$ — Answer

By Newton's second law $F_S = m_S a$

putting values $F_S = 4.00\,kg \times 6.00\,m/s^2$

or $F_S = 24\,kg\,m/s^2$

since $N = kg\,m/s^2$ therefore $F_S = 24\,N$ — Answer

This example shows us that for same acceleration a large force is required for large mass, and small force is required for small mass.

EXTENSION EXERCISE 3.1

What will be accelerations if you apply the same net force N= 10 N on both cricket ball and metal ball in this example?

Assignment 3.1 TRUCK AND CAR ACCELERATIONS

Find the acceleration produced in engine force of 3500 N in car of mass 600 kg and truck of mass 2400 kg.

3.2.3 NEWTON'S THIRD LAW OF MOTION

Statement:

When one object exerts a force on a second object, the second object exerts a force of the same magnitude and opposite direction on the first object. When an object A exert force on object B written as F_{AB}, object B also exert equal force on object A written as F_{BA} but in opposite direction

$$\vec{F}_{AB} = -\vec{F}_{BA} \quad (3.2)$$

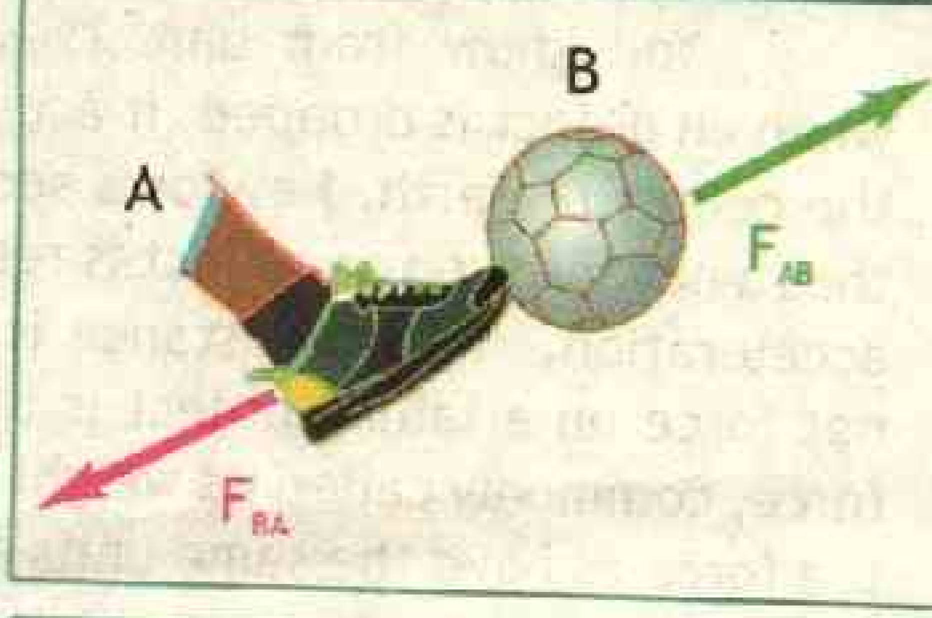
Here the negative sign shows that force F_{BA} is opposite to force F_{AB}.

When a football is kicked, the foot exerts the force F_{AB} on the football and as a reaction to that a foot ball exerts an equal and opposite force F_{BA} on the foot.

$$F_{AB} = -F_{BA}$$

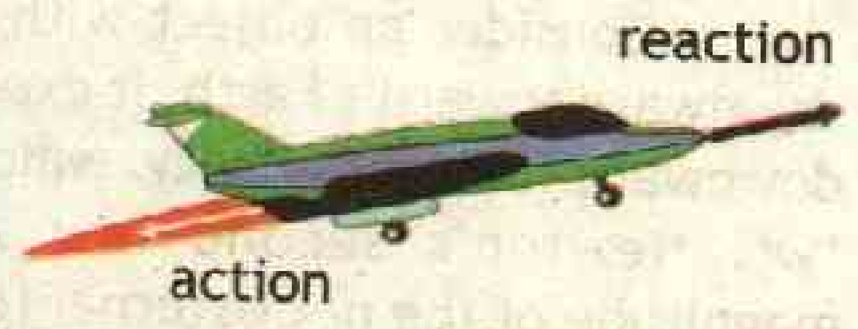
The force of A on B is equal in magnitude and opposite in direction of the force of B on A.

Figure 3.5 Third Law of Motion



Sir Isaac Newton described these two forces as action - reaction pair. To every action there is an equal and opposite reaction. Action reaction cannot neutralize each other because they act on different bodies (action on one body and reaction on another body).

Figure 3.6 Action-Reaction

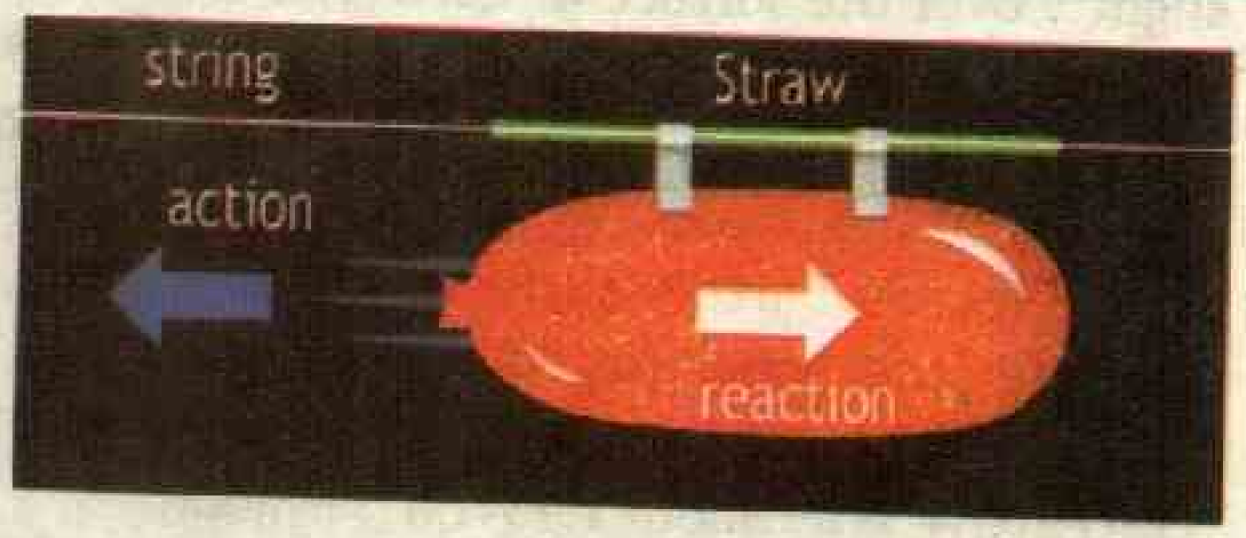


For example, the jet plane eject gases at high speed as an action, and air as reaction apply force on the plane to make it move forward.

We can feel reaction:

When we push against the edge of a table (action). Our hand's shape is changes, this shows that a force is being exerted on it (reaction). We can see the edge of the table pressing into our hand. The harder we push against the desk, the harder the desk pushes back. (We only feel forces exerted on us; when we exert a force on another object, what we feel is that object pushing back on us.)

ACTIVITY — BALLOON FORCING AIR OUT



- Tie one end of the string to a chair. Thread the other end of the string through the straw.
- Pull the string tight and tie it to another support in the room.
- Blow up the balloon, but don't tie it. Pinch the end of the balloon and tape the balloon to the straw as shown in figure.
- You're ready for launch. Let go and watch your balloon rocket fly!

3.3 WEIGHT

You know from unit 2: Kinematics that when an object is dropped, it accelerates toward the center of Earth. Newton's second law states that a net force on an object is responsible for its acceleration. If air resistance is negligible, the net force on a falling object is the gravitational force, commonly called its weight w. Since weight is a force as have the same units as force newton (N). Weight can be denoted as a vector w because it has a direction.

Consider an object with mass 'm' falling downward toward's Earth. It experiences only the downward force of gravity, which has magnitude 'w'. Newton's second law states that the magnitude of the net external force on an object is 'F = ma'. Since the object experiences only the downward force of gravity, 'F = w'. We know that the acceleration of an object due to gravity is 'g', or 'a = g'. Substituting these into Newton's second law gives

$$w = mg \quad (3.3)$$

Since $g = 9.80\ m/s^2$ on Earth, the weight of a 1.0 kg object on Earth is 9.8 N, as we see: $w = mg = (1.0\ kg)(9.80\ m/s^2) = 9.8\ N$.

The acceleration due to gravity g varies slightly over the surface of Earth (we will discuss it in detail in chapter 5; gravitation). So that the weight of an object depends on location and is not a property of the object. Weight varies on large scale if one leaves Earth's surface. On the Moon, for example, the acceleration due to gravity is only $1.67\ m/s^2$. A.1.0-kg mass which has a weight of 9.8 N on Earth is only about 1.7 N on the Moon.

POINT TO PONDER

Why does a hose pipe tend to move, backward when the fireman directs a powerful stream of water towards fire?

Common Misconception

Mass vs Weight:

In our daily life we use the term mass and weight in almost the same meaning. For example when we ask a shopkeeper to give 5 kg of rice, it is usually considered as the weight of rice. But in fact 5 kg is the mass of rice. From scientific point of view weight and mass are two different quantities. The mass of an object will remain the same, regardless of its location. However, because weight depends on the acceleration due to gravity, the weight of an object can change when the object enters into a region with stronger or weaker gravity.

Example 3.2 WEIGHT OF GIRL ON EARTH AND MOON

The mass of a girl is 60 kg. How much will she weigh on the (a) Earth? (b) Moon? [take acceleration due to gravity for earth as $g_E = 9.8\ ms^{-2}$ and for moon as $g_M = 1.6\ ms^{-2}$]

SOLUTION

GIVEN:
Mass m = 60 kg
Acceleration due to gravity on earth $g_E = 9.8\ ms^{-2}$
Acceleration due to gravity on moon $g_M = 1.6\ ms^{-2}$

REQUIRED:
weight on Earth w_E = ?
weight on moon w_M = ?

(a) Weight of girl on Earth $w_E = mg_E$

putting values $w_E = 60\,kg \times 9.8\,m/s^2$

or $w_E = 588\,kg\,m/s^2$

since $N = kg\,m/s^2$

therefore $w_E = 588\,N$ — **Answer**

(b) Weight of girl on Moon $w_M = mg_M$

putting values $w_M = 60\,kg \times 1.6\,m/s^2$

or $w_M = 96\,kg\,m/s^2$

since $N = kg\,m/s^2$

therefore $w_M = 96\,N$ — **Answer**

Assignment 3.2 WEIGHT OF ASTRONAUT

The weight of an astronaut and his space suit on the Moon is only 250 N. How much do they weigh on Earth? What is the mass on the Moon? On Earth? [take acceleration due to gravity for earth as $g_E = 9.8\ ms^{-2}$ and moon as $g_M = 1.6\ ms^{-2}$]

CHECKPOINT (NEWTON LAWS)

Q1: What is the acceleration produced by a force of 12 N exerted on an object of mass 3 kg? (Answer: 4 ms^{-2})

Q2: Calculate the mass of a body when a force of 700 N, produces an acceleration of 12.5 ms^{-2}. (Answer: 56 kg)

3.4 LINEAR MOMENTUM:

The linear momentum 'P' of an object is the product of the object's mass 'm' and velocity 'v'. Mathematically

$$\vec{P} = m\vec{v} \qquad (3.4)$$

Linear momentum is a vector quantity that points in the same direction as the velocity. SI Unit of Linear Momentum is kilogram-meter per second (kgm/s or $kgms^{-1}$), or simply newton-second (Ns).

Momentum measure the quantity of motion in a body. It is our common observation that large force will be required to stop a truck than a car moving at same speeds. Because truck has a large mass than a car. Similarly it is easy to stop a rolling drum of coal tar of mass 50kg moving at a speed of 0.1 m/s but it is difficult to stop it if it is moving at 5 m/s.

Example 3.3 MOMENTUM OF AIRGUN SHOT

An iron shot of mass 6 g is fired with an airgun. If the velocity of the shot is 62 ms^{-1}, what is the magnitude of momentum?

SOLUTION

GIVEN:
Mass m = 6 g = 0.006 kg
velocity v = 62 ms^{-1}

REQUIRED:
magnitude of Momentum P = ?

by definition of momentum $\vec{P} = m\vec{v}$

in magnitude $P = mv$

putting values $P = 0.006\,kg \times 62\,m/s$

therefore $P = 0.372\,kg\,m/s$

Hence $P = 0.372\,Ns$ — **Answer**

Assignment 3.3 FASTEST RECORDED BALL SPEED IN ANY GAME

The fastest recorded speed for a golf ball hit by a golfer is 75.8 m/s (273 km/h). If mass of golf ball is 46 g, what is the magnitude of its momentum?

3.4.1 FORCE AND CHANGE IN MOMENTUM

When a force 'F' produces acceleration 'a' in a body of mass 'm'. By Newton's second law of motion it is written as

$$\vec{F} = m\vec{a} \quad \text{——— (1)}$$

The acceleration produced changes the velocity of the body from initial velocity 'v_i' to final velocity 'v_f' during time interval 'Δt'. Then by Definition of acceleration

$$\vec{a} = \frac{\vec{v}_f - \vec{v}_i}{\Delta t} \quad \text{——— (2)}$$

Putting equation 2 in equation 1

$$\vec{F} = m\left(\frac{\vec{v}_f - \vec{v}_i}{\Delta t}\right) \quad \text{or} \quad \vec{F} = \left(\frac{m\vec{v}_f - m\vec{v}_i}{\Delta t}\right) \quad \text{or} \quad \vec{F} = \left(\frac{\vec{P}_f - \vec{P}_i}{\Delta t}\right)$$

since $\Delta\vec{P} = \vec{P}_f - \vec{P}_i$

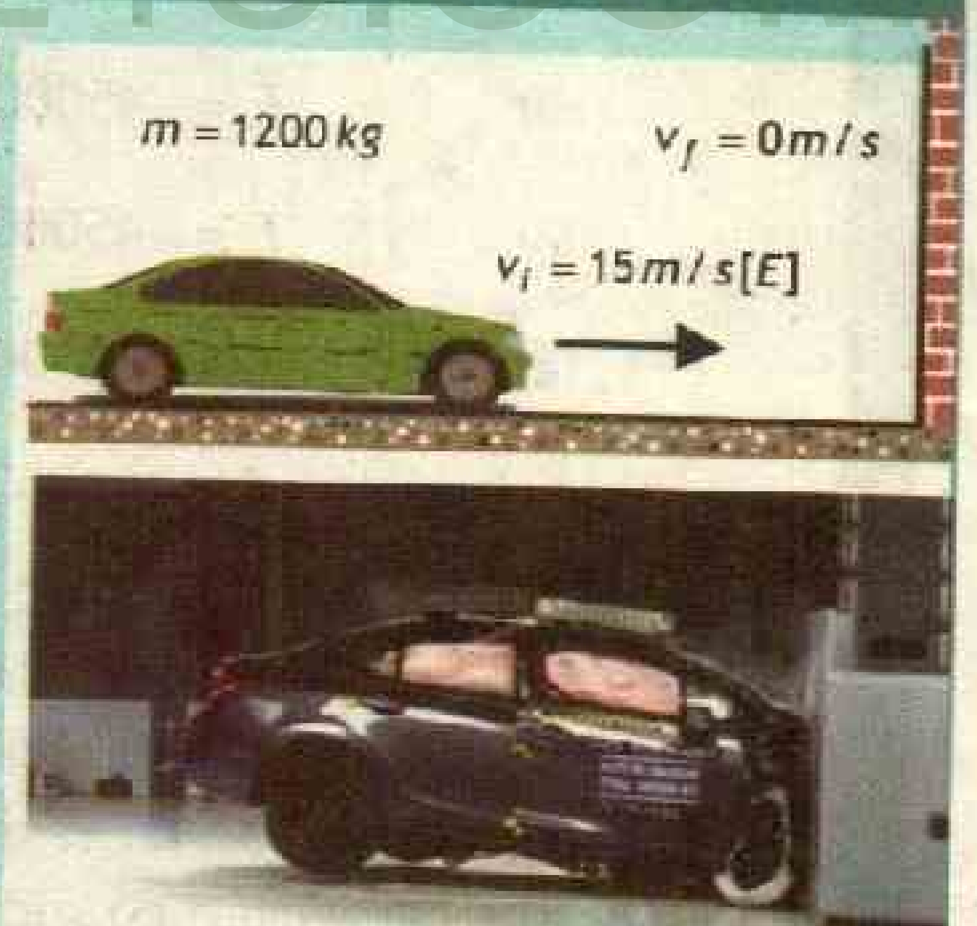
therefore $\vec{F} = \dfrac{\Delta\vec{P}}{\Delta t}$ —— 3.5

The time rate of change of linear momentum of a body is equal to the net force acting on the body. This means that for sudden change in momentum force is large and vice versa.

INTERESTING INFORMATION FRAGILE OBJECTS

Different safety techniques are used in the packaging of fragile objects.

Example 3.4 IMPACT CRUMPLE OF CAR



To improve the safety of motorists, modern cars are built so the front end crumples upon impact. A. 1200-kg car is traveling at a constant velocity of 15.0 m/s [E]. It hits an immovable wall and comes to a complete stop in 0.25 s.

a) What is the average net force exerted on the car.

b) What would be the average net force exerted on the car if it had a rigid bumper and frame that stopped the car in 0.040 s?

GIVEN:

Mass of car m = 1200 kg

initial velocity v_i = 15.0 m/s [E]

final velocity v_f = 0.0 m/s

a) time interval (deforming) Δt = 0.25 s

b) time interval (rigid) Δt = 0.040 s

REQUIRED:

(a) Average net force (deforming) F = ?

(b) Average net force (rigid) F = ?

SOLUTION

a) by Newton's second law in terms of momentum $\vec{F} = m\left(\frac{\vec{v}_f - \vec{v}_i}{\Delta t}\right)$

putting values $\vec{F} = 1200\,kg\left(\frac{0 - 15.0\,m/s[E]}{0.25\,s}\right)$

or $\vec{F} = \frac{-18000\,kg\,m/s[E]}{0.25\,s}$

or $\vec{F} = -72000\,kg\,m/s^2[E]$

or $\vec{F} = -72000\,N[E]$

or $\vec{F} = 72000\,kg\,m/s^2[W]$

therefore $\vec{F} = 72000\,N[W]$ — Answer

b) by Newton's second law in terms of momentum $\vec{F} = m\left(\frac{\vec{v}_f - \vec{v}_i}{\Delta t}\right)$

putting values $\vec{F} = 1200\,kg\left(\frac{0 - 15.0\,m/s[E]}{0.040\,s}\right)$

or $\vec{F} = \frac{-18000\,kg\,m/s[E]}{0.040\,s}$

or $\vec{F} = -450000\,kg\,m/s^2[E]$

or $\vec{F} = -450000\,N[E]$

or $\vec{F} = 450000\,kg\,m/s^2[W]$

therefore $\vec{F} = 450000\,N[W]$ — Answer

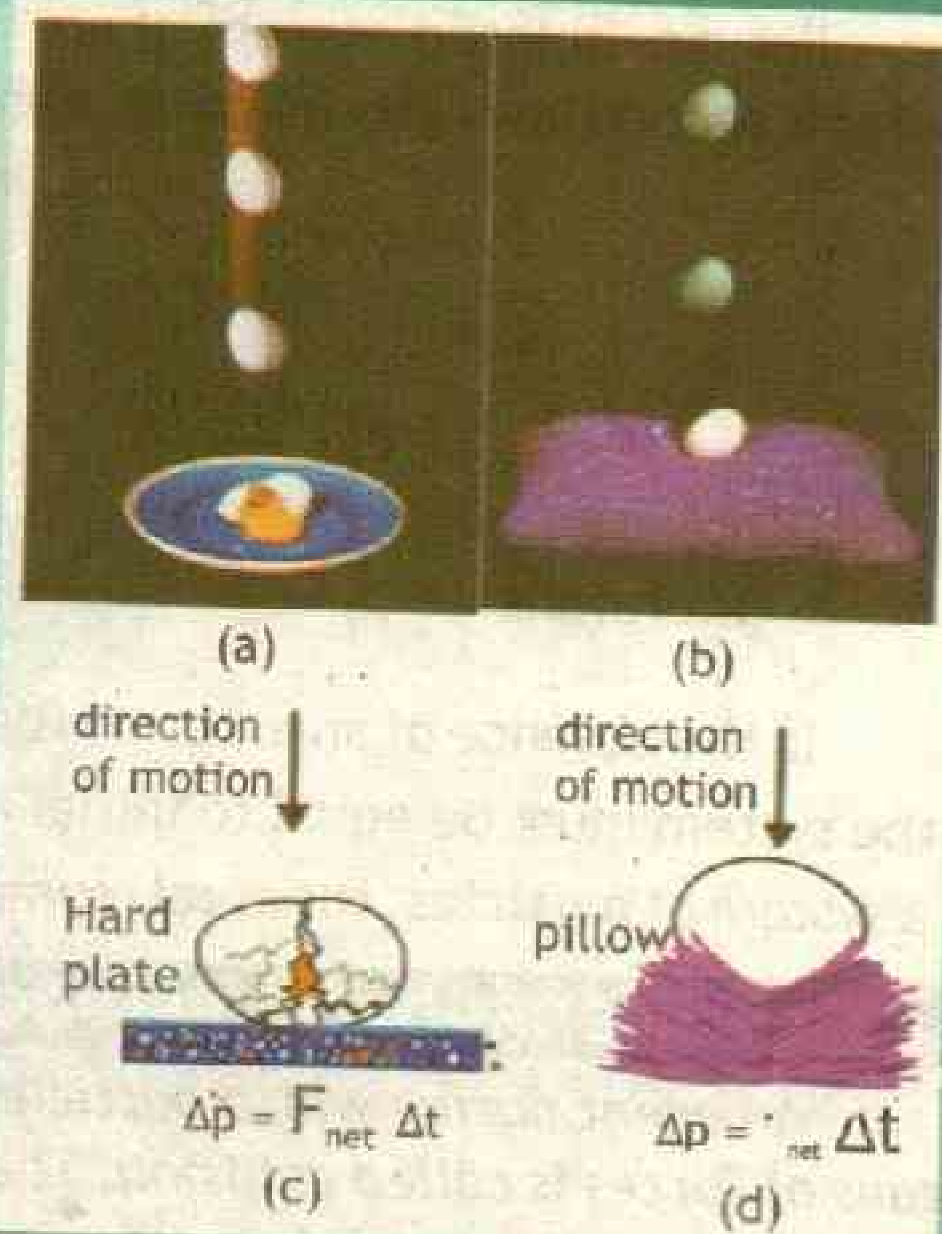
The average net force exerted by the wall on the car is (a) 7.2×10^4 N [W] when it crumples, and (b) 4.5×10^5 N [W] when it is rigid. The change in momentum is the same in both parts is -18000 kgm/s, but the time intervals are different. So the average net force is different in both situations. The magnitude of force on the car with the rigid frame is more than 6 times greater than when the car crumples.

Assignment 3.4 FORCE REQUIRED TO STOP A TRUCK AND CAR

Calculate the force required to stop a car of mass 1200 kg and a loaded truck of mass 9,000 kg in 2 second, if they are moving with same velocity of 10 ms^{-1}.

ACTIVITY FALLING EGG

Consider a falling egg. When the egg hits a hard surface, like the plate in Figure (a), the egg comes to rest in a very short interval of time. The force the hard plate exerts on the egg due to the collision is large. When the egg hits a floor covered with a pillow, as in Figure (b), the egg undergoes the same change in momentum, but over a much longer time interval. In this case, the force required to accelerate the egg to rest is much smaller. By applying a small force to the egg over a longer time interval, the pillow causes the same change in the egg's momentum as the hard plate, which applies a large force over a short time interval. Because the force in the second situation is smaller, the egg can withstand it without breaking.



ISOLATED SYSTEM

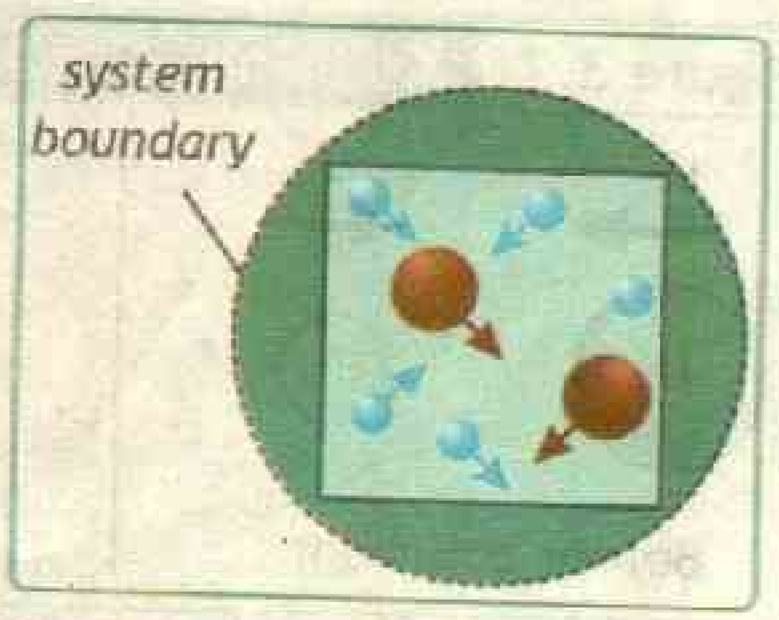
We are often interested in the behavior of a collection of particles that interact only with each other. We can draw an imaginary boundary around the particles, but complications can arise, if some of the particles experience net forces that originate outside the "system" boundary. In order to effectively study interactions between particles, we must limit our focus to isolated systems of particles.

POINT TO PONDER

How rockets move and accelerate in space where there is no air for them to push against.

An isolated system is a collection of particles that can interact with each other but whose interactions with the environment outside the collection have a negligible effect on their motions.

For example, the molecules of a gas enclosed in a vessel can be considered as an isolated system of interacting bodies. Gas molecules interact with each other and with the walls of their container. Other forces, such as those of the table holding up the container and the gravitational force, are considered to have a negligible effect on the motions of the molecules and container.



3.4.2 NEWTON'S LAWS AND CONSERVATION OF MOMENTUM

For an isolated system there is no net force acting F = 0, therefore Newton's second law in terms of momentum (equation 3.5) can be written as

$$0 = \frac{\Delta \vec{P}}{\Delta t}$$

or $$0 = \frac{\vec{P}_f - \vec{P}_i}{\Delta t}$$ by cross multiplication $0 = \vec{P}_f - \vec{P}_i$

therefore $$\vec{P}_f = \vec{P}_i \quad (3.6)$$

In the absence of an external force (isolated system) the final momentum P_f of the system must be equal to initial momentum P_i. If no net external force acts on a system of particles, the total momentum of the system cannot change.

3.4.3 CHANGE OF MOMENTUM AND COLLISIONS

An event during which particles come close to each other and interact by means of forces is called collision. The forces due to the collision are assumed to be much larger than any external forces present.

Consider a system consisting two objects A and B of masses m_1 and m_2 moving with velocities u_1 and u_2 respectively, such that after collisions their velocities change to v_1 and v_2. The total momentum of the system before collision is

$$\vec{P}_i = m_1u_1 + m_2u_2$$

The total momentum of the system after collision changes to

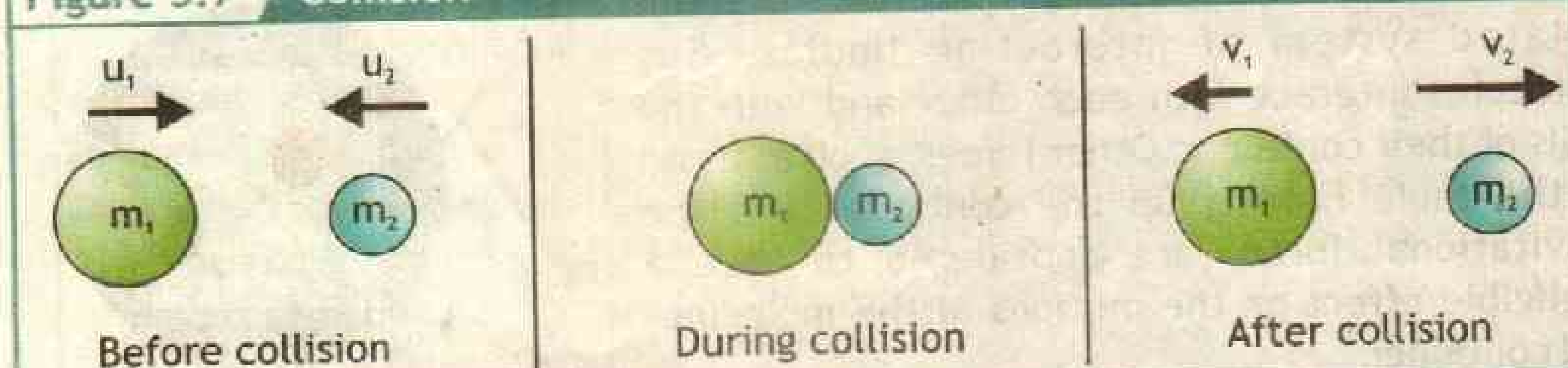
$$\vec{P}_f = m_1v_1 + m_2v_2$$

By law of conservation of momentum

$$\vec{P}_f = \vec{P}_i$$

therefore $$m_1v_1 + m_2v_2 = m_1u_1 + m_2u_2 \quad (3.7)$$

Figure 3.7 Collision



Example 3.5 BALLS COLLISION

Ball A having mass 0.05 kg moving to the right at velocity of 0.50 m/s makes an head-on collision with ball B having mass 0.20 kg that is initially at rest. After the collision, ball A moves to the left at 0.30 m/s. Find the final velocity of the ball B.

SOLUTION

GIVEN:

Mass of ball A $m_1 = 0.05$ kg

Mass of ball B $m_2 = 0.20$ kg

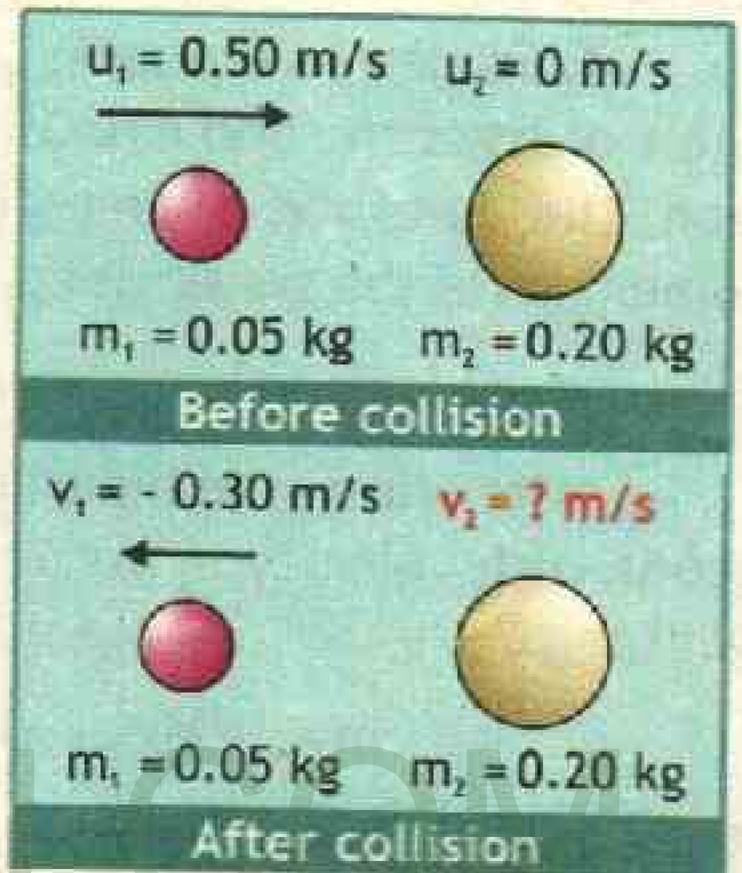
Velocity of ball A before collision $u_1 = 0.50$ m/s

Velocity of ball B before collision $u_2 = 0$ m/s

Velocity of ball A after collision $v_1 = -0.30$ m/s

REQUIRED:

Velocity of ball B after collision $v_2 = ?$



By change of momentum and collision between two bodies

$$m_1v_1 + m_2v_2 = m_1u_1 + m_2u_2$$

rearranging $m_2v_2 = m_1u_1 + m_2u_2 - m_1v_1$

dividing by m_2 on both sides

$$v_2 = \frac{m_1u_1 + m_2u_2 - m_1v_1}{m_2}$$

putting values

$$v_2 = \frac{0.05\,kg \times 0.50\,m/s + 0.20\,kg \times 0\,m/s - 0.05\,kg \times -0.30\,m/s}{0.20\,kg}$$

or $$v_2 = \frac{0.025\,kg\,m/s + 0\,kg\,m/s + 0.015\,kg\,m/s}{0.20\,kg}$$

or $$v_2 = \frac{0.04\,\cancel{kg}\,m/s}{0.20\,\cancel{kg}}$$

therefore $v_2 = 0.2\,m/s$ — **Answer**

Velocity of ball B after collision is 0.2 m/s

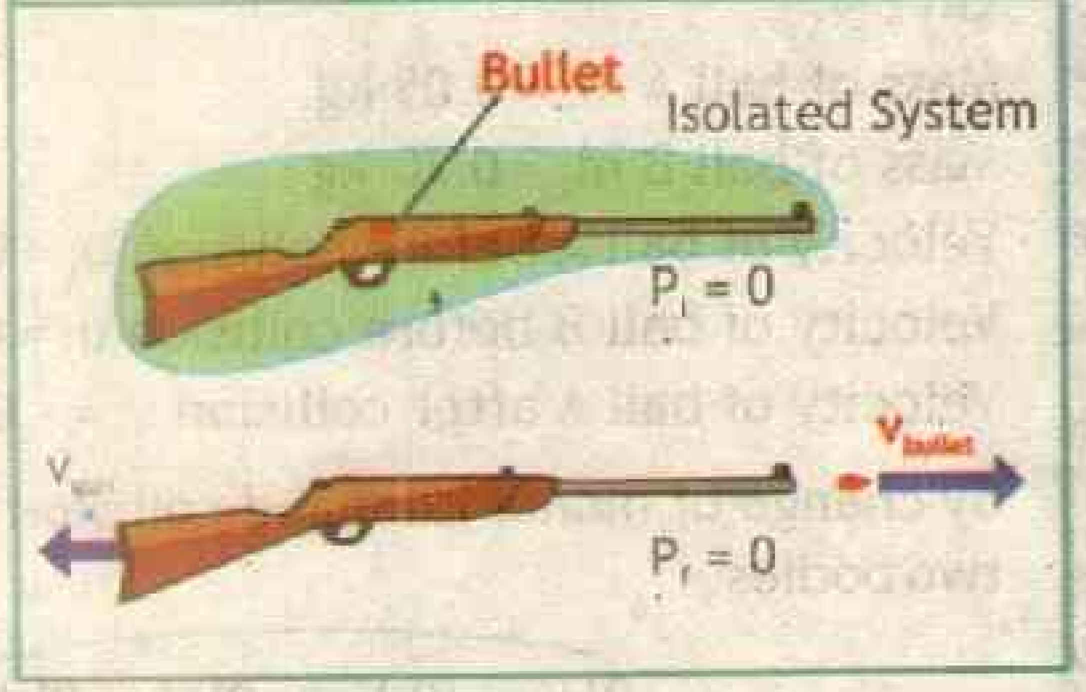
Assignment 3.5 CARROM BOARD COLLISION

In carrom board game the striker of mass having mass 0.015 kg sliding to the right at velocity of 0.40 m/s makes head-on collision with a disk having mass 0.005 kg that is initially at rest. After the collision, striker moves to the right along the direction of disk at 0.20 m/s. Find the final velocity of the disk.

3.7.4 CHANGE OF MOMENTUM AND EXPLOSIVE FORCES

An explosion, where the particles of the system move apart from each other after a brief, intense interaction. Explosion is the opposite of a collision. The explosive forces, which could be from an expanding spring or from expanding hot gases, are internal forces. If the system is isolated, its total momentum during the explosion will be conserved, by the law of conservation of momentum

Figure 3.8 Explosive Forces



Firing of rifle:

Consider an isolated system of bullet of mass m and rifle of mass M. Such that before firing the total momentum of the system is zero.

$$P_i = 0$$

After firing the bullet moves with velocity v_b in one direction and the rifle recoils with velocity v_g in the other direction such that the total momentum is again zero.

$$mv_b + Mv_g = 0 \quad (3.8)$$

Due to the large mass of the rifle it recoils with much lower velocity as compared to the bullet.

Example 3.6 RECOIL OF AK47

A bullet of mass 0.008 kg is fired from Ak47 rifle with mass of 4 kg. If the velocity of the bullet is 715 ms^{-1}, what would be the recoil velocity of the gun?

SOLUTION

GIVEN:

Mass of bullet m = 0.008 kg

Mass of rifle M = 4 kg

Velocity of bullet after fire v_b = 715 m/s

REQUIRED:

Recoil velocity of gun after fire v_g = ?

By change of momentum and in terms of rifle and bullet

$$mv_b + Mv_g = 0 \quad \text{or} \quad Mv_g = -mv_b$$

Dividing both sides by M $\quad v_g = -\dfrac{mv_b}{M}$

putting values $v_g = -\dfrac{0.008\,kg \times 715\,m/s}{4\,kg}$

or $v_g = -\dfrac{5.72\,kgm/s}{4\,kg}$

therefore $v_g = -1.43\,m/s$ — Answer

The minus sign indicates that the Ak47 rifle's recoil is to the left. The recoil speed is 1.43 m/s.

EXTENSION EXERCISE 3.2

Will you want to fire with a rifle of mass 0.008 kg having bullet of 4 kg, ejecting with a muzzle speed of 715 m/s?

Assignment 3.6 CANNON RECOIL

A 200-kg cannon at rest contains a 10-kg cannon ball. When fired, the cannon ball leaves the cannon with a speed of 90 m/s. What is the recoil speed of the cannon?

before firing

After firing

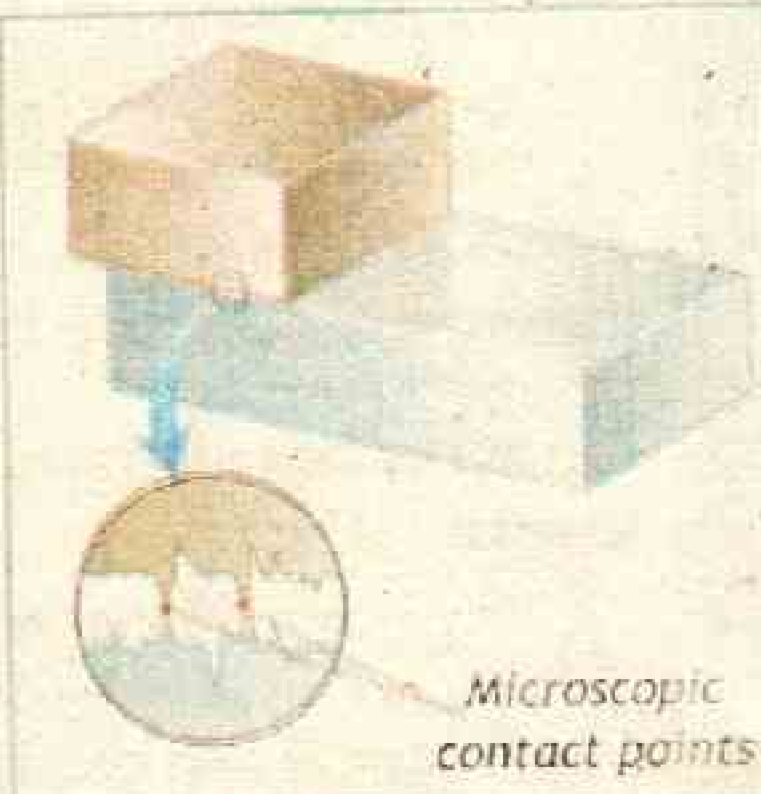
ROCKET PROPULSION AND THRUST

A phenomenon similar to muzzle velocity occurs in rocket propulsion. The rocket ejects gases from its tail at a high velocity, just as a rifle ejects bullets or cannon fires a shell from its barrel. A rocket's mass isn't constant because the fuel it contains is constantly decreasing. Thus giving acceleration to the rocket called thrust. Any space vehicle is maneuvered in empty space by firing its rockets in the direction opposite to that in which it needs to accelerate. When the rocket pushes on the gases in one direction, the gases push back on the rocket in the opposite direction.

3.5 FRICTION

Friction is a force that opposes relative motion or attempted motion between systems in contact. Friction is denoted by letter f, since it is a force therefore it is a vector quantity and has unit as newton (N). Frictional force is around us all the time that opposes motion of one body over another body in contact. When we rub (slide) our hand on a table top, we can feel the friction opposing this motion. We need it to both start and stop a bicycle and a car.

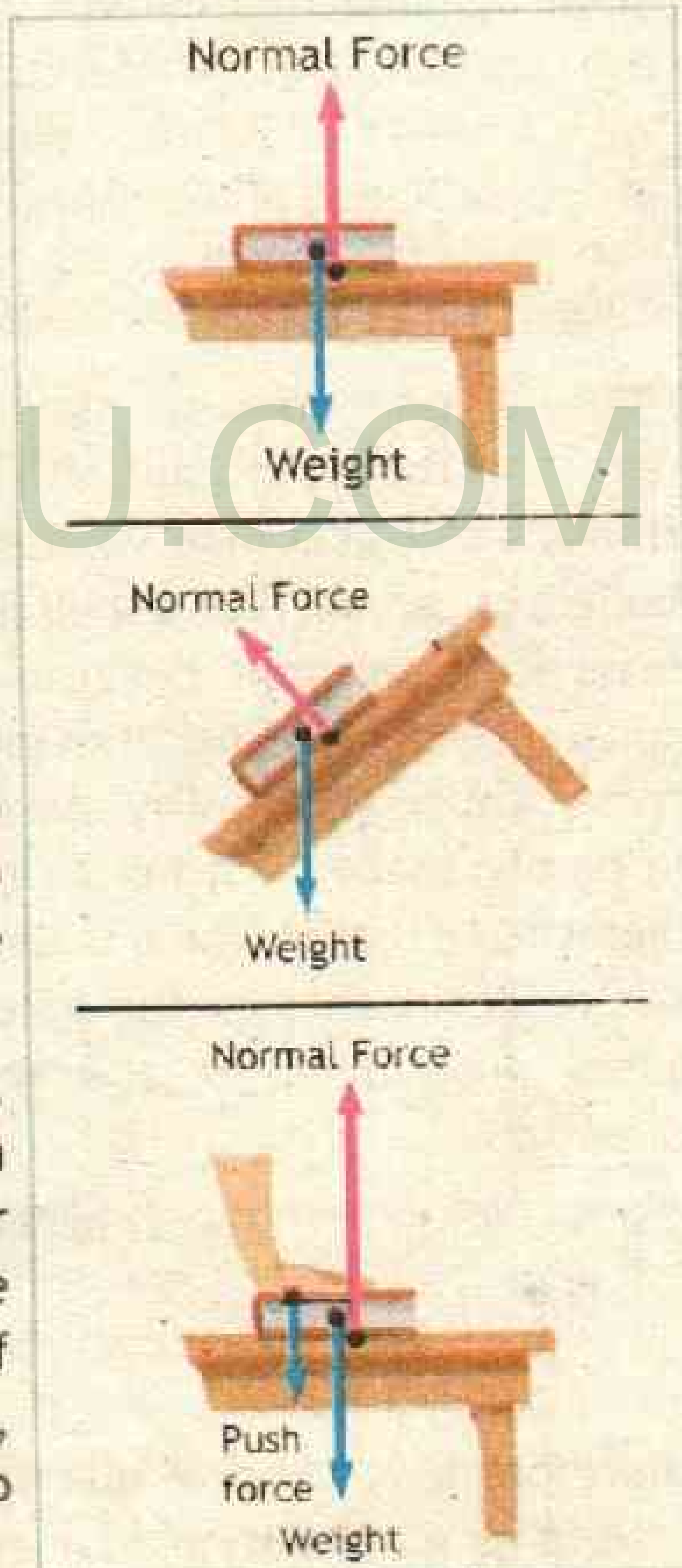
3.5.1 MICROSCOPIC DESCRIPTION OF FRICTION



Every surface is rough, even surfaces that appear to be highly polished can actually look quite rough when examined under a microscope. Some surfaces are more rough than others. Therefore when one surface slide over another, these irregularities bump into one another which gives rise to frictional force. Secondly at these contact points the molecules of the different bodies are close enough to exert strong attractive intermolecular forces on each other, thus opposing motion and result in friction.

NORMAL FORCE

A contact force perpendicular to the contact surface that prevents two objects from passing through one another is called the normal force F_N. (In geometry, normal means perpendicular.)



Consider a book resting on a horizontal table's surface. By Newton's third law the book exert the force on the table due to its weight and as a reaction table exert force on the book, which in this case is a normal force. The normal force due to the table must have just the right magnitude to keep the book from falling through the table. If no other vertical forces act, the normal force on the book is equal in magnitude to the book's weight.

If the surface of the table is not horizontal, the normal force is not vertical and is not equal in magnitude to the weight of the book. Remember that the normal force is perpendicular to the contact surface. Even on a horizontal surface, if there are other vertical forces acting on the book, then the normal force is not equal in magnitude to the book's weight as shown in figure.

3.5.2 TYPES OF FRICTIONAL FORCES:

There are two types of frictional force.

A) Static friction:

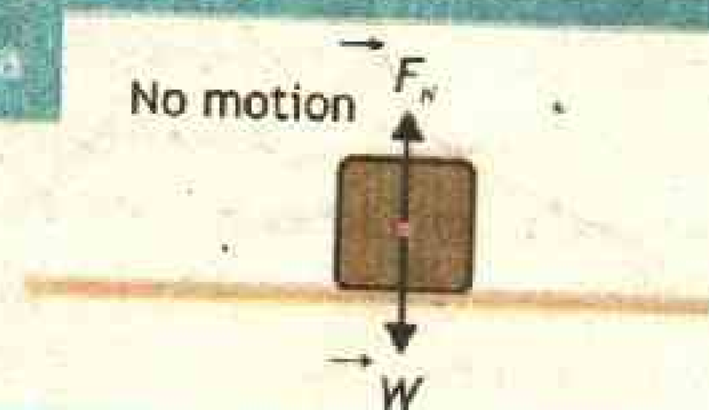
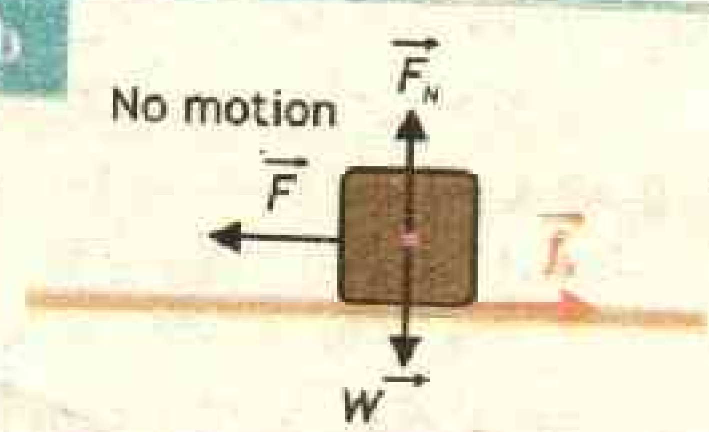
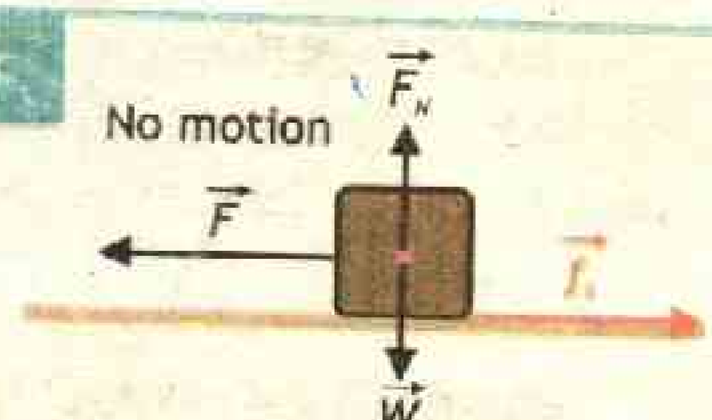
The frictional force that tends to prevent a stationary object from starting to move is called static friction denoted by f_s. For example, when we push horizontally on a heavy crate. The crate does not move. It means that a second force act on the crate to oppose our force, and this force must be directed opposite to our applied force and have the same magnitude to balance our push. That second force is a frictional force. When we push even harder. The crate still does not move. It means that the frictional force can change in magnitude so that the two forces still balance. Now if we push with more strength, the crate begins to slide. So we can say that, there is a maximum magnitude of the frictional force. When we exceeded that maximum magnitude, the crate started to move.

B) Kinetic friction:

The frictional force that acts against during motion of an object in a direction opposite to the direction of motion denoted by f_k.

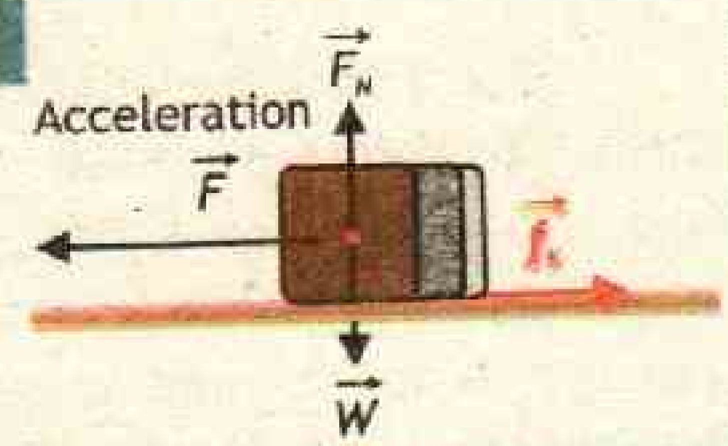
For example, when heavy crate starts motion, kinetic friction f_k now replaces static friction f_s. If we are applying same force the heavy crate after it has started moving it accelerates, means that kinetic friction is less than static friction ($f_k < f_s$). In order to drag the heavy crate with constant velocity we have to reduce the force to make it equal to kinetic friction. Table 3.2 shows a similar situation.

TABLE 3.2 DESCRIPTION OF FRICTION

A block rests on a tabletop, with the weight W balanced by a normal force F_N. *There is no attempt of sliding. Thus, no friction and no motion.*	a	
We exert a force F on the block, attempting to pull it to the left. In response, a frictional force f_s is directed to the right, exactly balancing our force. The force is called the static frictional force. The block does not move.	b	
As we increase the magnitude of our applied force, the magnitude of the static frictional force f_s also increases and the block remains at rest.	c	

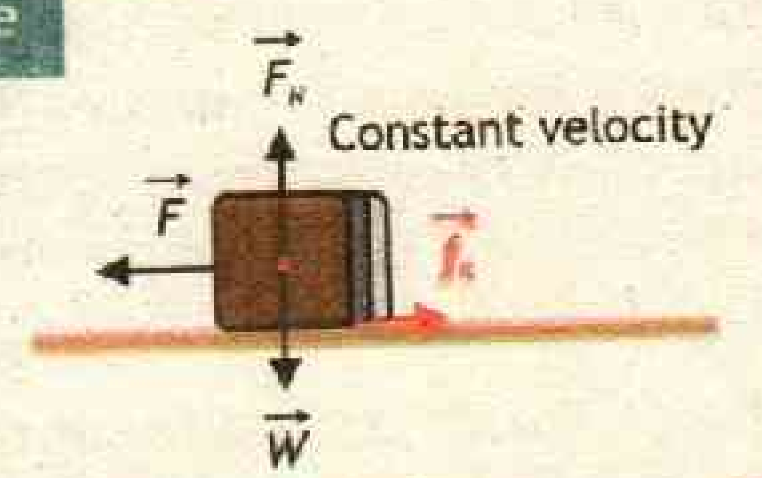
When the applied force reaches a certain level, the block "breaks away" from its contact with the tabletop and accelerates leftward. The frictional force that opposes the motion is now called the kinetic frictional force fk.

d



Usually, the magnitude of the kinetic frictional force is less than the maximum magnitude of the static frictional force. Thus, if we wish the block to move across the surface with a constant speed, we usually decrease the magnitude of the applied force once the block begins to move.

e



3.5.3 COEFFICIENT OF FRICTION

The maximum static frictional force $f_{s,max}$ between a pair of surfaces has two main characteristics.

- It is independent of the area of contact between the objects, provided that the surfaces are hard or non-deformable.
- Its magnitude is proportional to the magnitude of the normal force F_N.

$$f_{s,max} \propto F_N \qquad \text{or} \qquad f_{s,max} = \mu_s F_N$$

Where μ_s is a constant of proportionality known as the coefficient of static friction and depends on the nature of surfaces in contact before sliding. Coefficient of static friction μ_s is

$$\mu_s = \frac{f_{s,max}}{F_N} \quad \text{——— 3.10}$$

The magnitude of the force of kinetic friction f_k is assumed to be proportional to the normal force and independent of speed

$$f_k \propto F_N \qquad \text{or} \qquad f_k = \mu_k F_N$$

Where μ_k is a constant of proportionality known as the coefficient of kinetic friction and depends on the nature of surfaces in contact during sliding. Coefficient of static friction μ_k is

$$\mu_k = \frac{f_k}{F_N} \quad \text{——— 3.11}$$

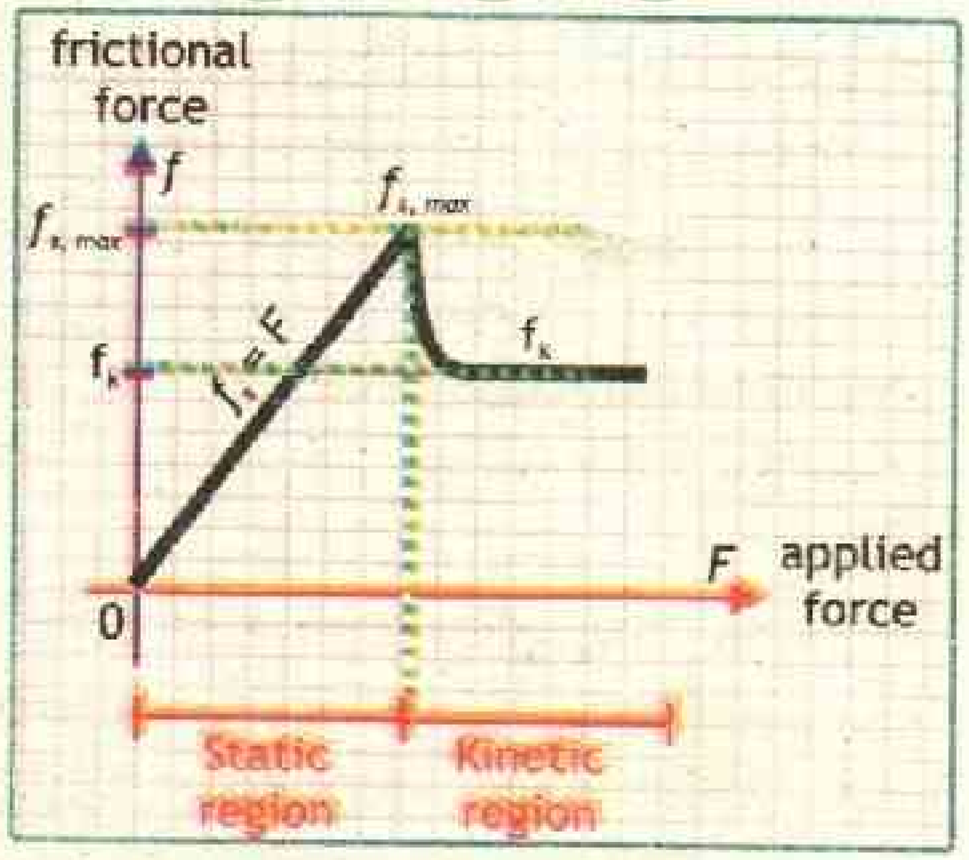
As μ is the ratio of forces, therefore, it has no units. Coefficient of friction is constant for a given pair of surfaces. For a different pair it has a different value. Values for friction of some pair of surfaces (both Static friction and kinetic friction) are given in table 3.3.

TABLE 3.3 APPROXIMATE VALUES OF COEFFICIENTS OF FRICTION

Surfaces	Coefficient of Static Friction, μ_s	Coefficient of Kinetic Friction, μ_k
Glass on glass	0.94	0.4
Ice on ice	0.1	0.02
Rubber on dry concrete	1.0	0.8
Steel on ice	0.1	0.05
Steel on steel	0.78	0.42
Wood on leather	0.6	0.3
Wood on wood	0.35	0.3

Friction is not restricted to solids sliding or tending to slide over one another. Friction occurs also in liquids and gases (both of which are called *fluids*). Fluid friction occurs as an object pushes aside the fluid it is moving through.

Graphical interpretation of Friction:



The graph is drawn between applied force F and friction f it shows that by increasing the applied force static friction f_s also increases until it reaches a certain maximum value called limiting friction $f_{s,max}$.

At this point the object starts moving and frictional force rapidly decreases to a smaller kinetic friction f_k value, which nearly remains constant.

Advantages of friction:

Friction is desirable in many cases, for example

i) Our ability to walk depends on friction between the soles of our shoes (or feet) and the ground.

ii) Friction holds the screw and nails in wood.

iii) The lighting of a match stick is another useful application of friction.

Disadvantages of friction:

Friction can sometime be a hindrance. for example

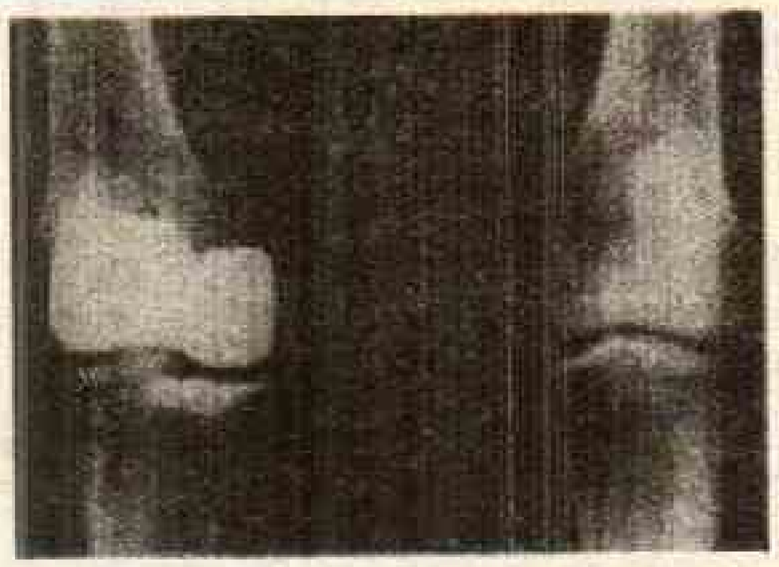
I) It slows down moving objects and causes heating of moving parts in machinery.

ii) Energy is wasted to overcome friction in machinery.

iii) Produce wear and tear.

We Have Internal Mechanism To Reduce Friction

Many parts of the body, especially the joints, have very small coefficients of friction. A joint is formed by the ends of two bones, which are connected by thick tissues. The knee joint is formed by the lower leg bone (the tibia) and the thighbone (the femur). The ends of the bones in the joint are covered by cartilage, which provides a smooth, almost glassy surface. The joints also produce a fluid (synovial fluid) that reduces friction and wear. A damaged or arthritic joint can be replaced by an artificial joint (shown in lower image). These replacements can be made of metals (stainless steel or titanium) or plastic (polyethylene), also with very small coefficients of friction.



ACTIVITY ROLLING REDUCE FRICTION

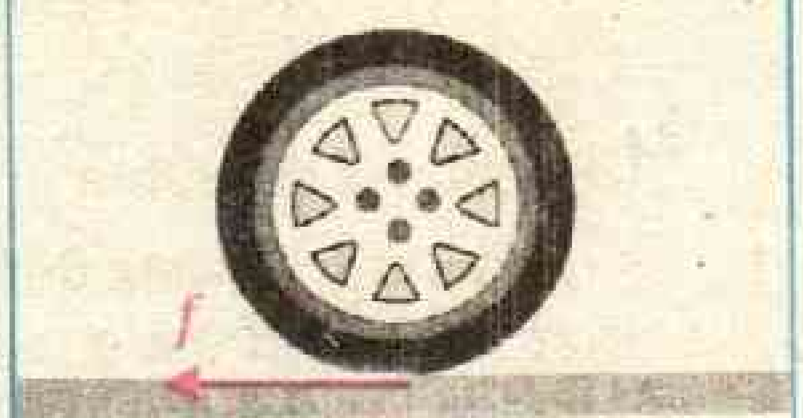
Take the book and slide it on the table now place book on few pencils and roll it you will see that less effort is required.

3.5.4 ROLLING FRICTION

If we set a heavy spherical ball rolling, it experiences an opposing force called rolling friction. ***When a body rolls over a surface, the force of friction is called rolling friction.***

It is a matter of common observation that a body with wheels move easily as compared to a body of the same size without wheels. This is due to the fact that rolling friction overcome the problem of friction by changing contact.

Figure 3.9



Friction resists sliding

METHODS OF REDUCING FRICTION

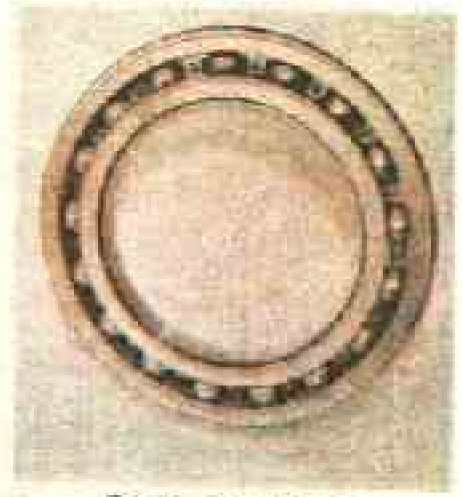
Some methods of reducing friction are given below

(i) **By polishing:**

If we polish the rough surfaces, they become smooth and friction is reduced.

(ii) **By applying Lubricants (oil or Grease) to surfaces:**

Friction of certain liquids is less than that of solid surfaces, therefore, oil or grease is applied between the parts of machinery.



Ball Bearing

(iii) **By using Ball Bearing:**

This method converts the sliding friction is converted into rolling friction by use of ball bearings.

FUTURE LUBRICANTS

Research into lubricants continues to try to find ways to reduce the coefficient of kinetic friction, μ_k, to a value as close to zero as possible. Modern lubricants include buckyballs – molecules consisting of 60 carbon atoms arranged in the shape of a soccer ball, which were discovered in 1985. These molecules act like microscopic ball bearings.

APPLICATIONS — PHYSICS OF CAR TYRES

A) The friction between the car tyres and the road is static friction, because the bottom of the tyre is deformed and comes in static contact with the road.

At contact point tyre is deformed and is momentarily at rest

B) **Static friction is more than kinetic friction, therefore we need the tyres of the car to be rolling than sliding to have grip on the road:** The friction during sliding is less than the friction that builds up before sliding takes place. When we slam on breaks the tyres lock, they slide, providing less friction than if they are made to roll to a stop. A rolling tyre does not slide along the road surface, and the friction is static friction, with more grab than sliding friction. But once the tyres start to slide, the frictional force is reduced. Modern cars have an antilock brake system keeps the tyres below the threshold of breaking loose into a slide.

C) **Kinetic friction does not depend upon speed:** It's also interesting that the force of friction does not depend on speed. A car skidding at low speed has approximately the same friction as the same car skidding at high speed. If the friction force on a tyre is 100 newtons at low speed, to a close approximation it is 100 newtons at a higher speed. The friction force may be greater when the tyre is at rest and on the verge of sliding, but, once sliding, the friction force remains approximately the same.

D) **Friction does not depend on the area of contact.** For a narrower tyre the same weight is concentrated on a smaller area with no change in the amount of friction. So those extra wide tyres you see on some cars provide no more friction than narrower tyres. The wider tyre simply spreads the weight of the car over more surface area to reduce heating and wear. Similarly, the friction between a truck and the ground is the same whether the truck has four ty res or eighteen! More tyres spread the load over more ground area and reduce the pressure per tyre. The stopping distance when brakes are applied is not affected by the number of tyres.

INFORMATION

The brakes of a bicycle use friction to enable the cyclist to control the speed.

E) **Tyres have treads not to increase friction but to displace and redirect water from between the road surface and the underside of the tyre:** Many racing cars use tires without treads because they race on dry days.

Example 3.7 WOODEN PACKAGE ON WOOD FRICTION

Ayesha pushes a newly bought deep-freezer of mass 120 kg packed in wood across a wooden floor. **(a)** She applies a 400 N force to set it moving, what is the coefficient of static friction? **(b)** Then she makes it move with constant speed by applying force of 350 N, what is the coefficient of kinetic friction?

SOLUTION

GIVEN:

mass = 120 kg

Normal force $F_N = W = mg$

$= 120\ kg \times 9.8\ ms^{-2}$

Normal force $F_N = 1176\ N$

REQUIRED:

(a) coefficient of static friction $\mu_s = ?$

(b) coefficient of kinetic friction $\mu_k = ?$

(a) Applied force to set the package moving is equal static frictional force, therefore $f_{s,max} = 400\ N$, by the relation for coefficient of static friction μ_s

$$\mu_s = \frac{f_{s,max}}{F_N} \quad \text{putting values} \quad \mu_s = \frac{400\,N}{1176\,N}$$

or $\mu_s = 0.340$ — **Answer**

(b) Applied force to keep it moving at constant speed is equal to kinetic frictional force, therefore $f_k = 350\ N$, by equation for coefficient of kinetic friction μ_k

$$\mu_k = \frac{f_k}{F_N} \quad \text{putting values} \quad \mu_k = \frac{350\,N}{1176\,N}$$

or $\mu_k = 0.29$ —— **Answer**

These values are close to the approximate values given in the table for the coefficient of friction between wood and wood.

Assignment 3.7 LEATHER AND WOOD FRICTION

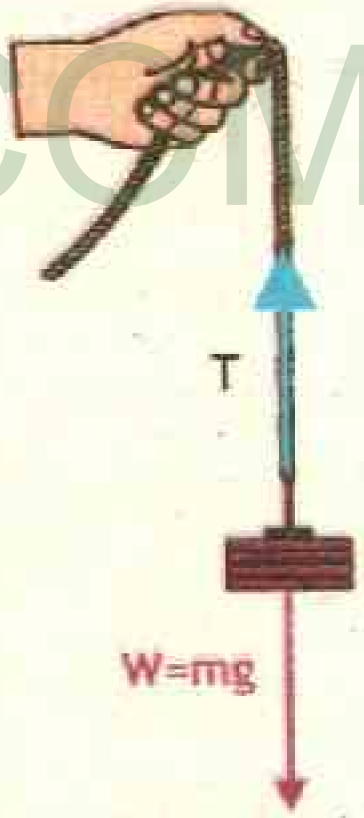
A 5 kg heavy leather bag is placed on a horizontal wooden plank. How much force is required to set it in motion if the coefficient of friction between the plank and bag is 0.1.

LAB WORK

- Investigate the relationship between force of limiting friction and normal reaction to find the co-efficient of sliding friction between a wooden block and horizontal surface.
- Measure the force of limiting friction by rolling a roller on a horizontal plane.

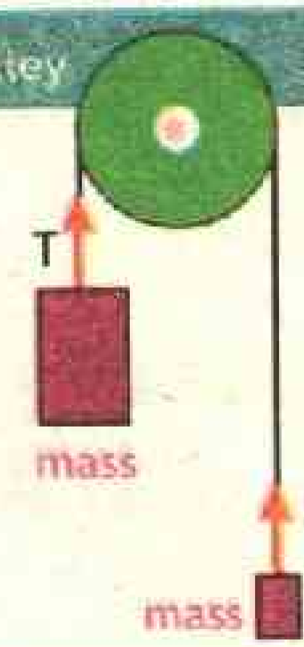
TENSION

The pulling force exerted by a stretched rope, string, cable or cord on an object to which it's attached is called a tension force. Tension is always a pull force. Hence, the direction of a tension force is always the direction in which one would pull the object with a string or rope.



Suppose a person is holding an object of mass 'm' at rest with the help of a string, the object exerts a force on the hand through the string in the downward direction due its weight. By Newton's third law the force which is exerted by the string on the hand is called the tension in the string and it is usually denoted by T. As the object is at rest the magnitude of tension is equal to that of weight of the object as shown in figure.

ATWOOD MACHINE



Pulleys are often used to redirect a force exerted by a string, as indicated in the figure. In the ideal case, a pulley has no mass and no friction in its bearings. Thus, an ideal pulley simply changes the direction of the tension in a string, without changing its magnitude. **When two objects of unequal mass are hung vertically over a frictionless pulley of negligible mass, the arrangement is called an Atwood's machine.**

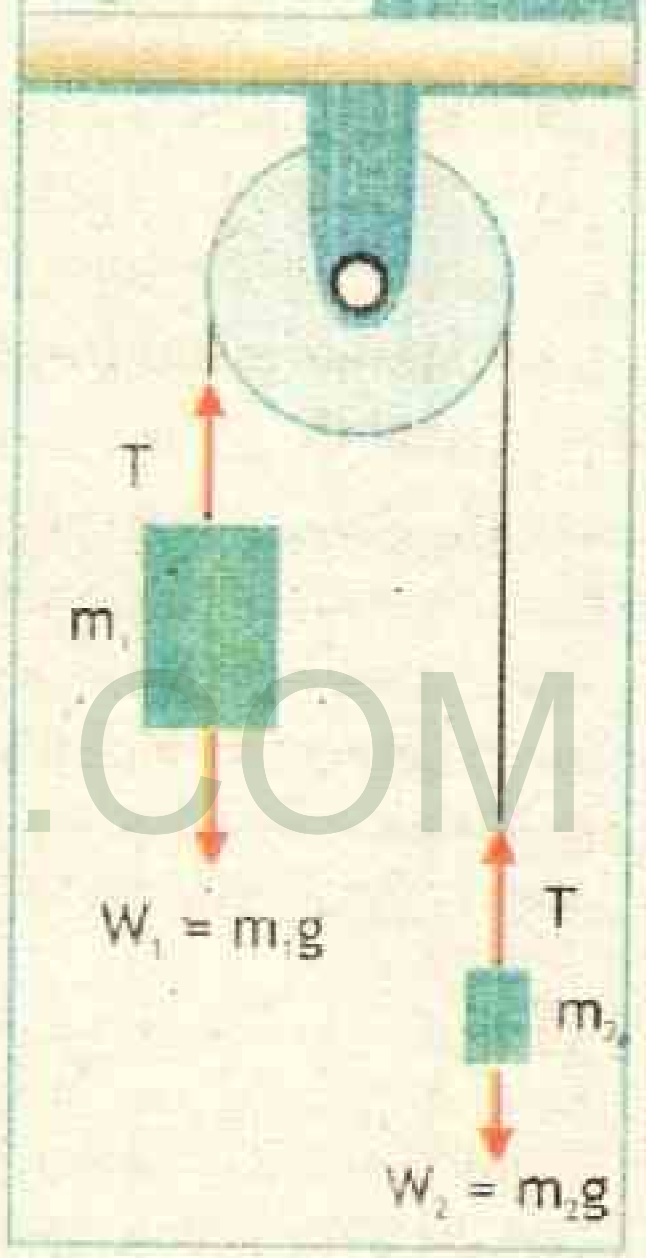
3.6 CONNECTED BODIES

When two objects are connected by a string, applying a force on one of the objects will cause both objects to accelerate at the same rate.

3.6.1 ACCELERATION AND TENSION IN ATWOOD's MACHINE

Consider motion of two objects having masses m_1 and m_2 (with m_1 greater than m_2) suspended by an inextensible string which passes over a frictionless pulley forming an Atwood's machine. In such an arrangement m_1 will move downward under the action of gravity and m_2 will move upward. Tension T and acceleration a will be same for both bodies.

Figure 3.10



Two forces are acting on mass m_1:

i) Its weight $W_1 = m_1g$, acting downward

ii) Tension of string T, acting upward.

As m_1 is moving downward, the net force F_{net1} acting on it is downward due to which acceleration 'a' is produced in it. Hence,

$$\vec{F}_{net1} = W_1 - T$$

or $$m_1 a = m_1 g - T$$

rearranging $$T = m_1 g - m_1 a \quad \text{--- (1)}$$

Similarly two forces are acting on mass m_2:

- Its weight $W_2 = m_2g$, acting downward
- Tension of string T, acting upward.

As m_2 is moving upward, the net force F_{net2} acting on it is upward due to which acceleration 'a' is produced in it. Hence,

$$\vec{F}_{net2} = T - W_2$$

or $$m_2 a = T - m_2 g$$

rearranging $$T = m_2 a + m_2 g \quad \text{--- (2)}$$

Since both equation 1 and equation 2 equal to T, therefore we can write

$$m_2 a + m_2 g = m_1 g - m_1 a$$

rearranging $m_1 a + m_2 a = m_1 g - m_2 g$

taking common $(m_1 + m_2)a = (m_1 - m_2)g$

dividing both sides by $m_1 + m_2$ $\frac{(m_1 + m_2)a}{(m_1 + m_2)} = \frac{(m_1 - m_2)g}{(m_1 + m_2)}$

therefore $a = \frac{(m_1 - m_2)}{(m_1 + m_2)} g$ —— 3.12

This is the value of acceleration at which both masses are moving.

ELEVATORS AND ATWOOD's MACHINE

Figure 3.11

The supporting cable in elevators passes up over a pulley and then back down to a heavy, movable counterweight, as shown in Figure 3.11. Gravitational forces acting downward on the counterweight create tension in the cable. The cable then exerts an upward force on the elevator cage. Most of the weight of the elevator and passengers is balanced by the counterweight. Only small additional forces from the elevator motors are needed to raise and lower the elevator and its counterweight. Although the elevator and counterweight move in different directions, they are connected by a cable, so they accelerate at the same rate. Elevators are only one of many examples of machines that have large masses connected by a cable that runs over a pulley.

To find tension T, we can put the value of a in either equation 1 or 2

for equation 1 $T = m_1 g - m_1 \times \frac{(m_1 - m_2)}{(m_1 + m_2)} g$

taking $m_1 + m_2$ as LCM $T = \frac{m_1 g \times (m_1 + m_2) - m_1 g \times (m_1 - m_2)}{(m_1 + m_2)}$

or $T = \frac{m_1^2 g + m_1 m_2 g - m_1^2 g + m_1 m_2 g}{(m_1 + m_2)}$

therefore $T = \frac{2m_1 m_2}{(m_1 + m_2)} g$ —— 3.13

Example 3.8 ELEVATOR (AS ATWOOD MACHINE)

Let the elevator is going up with mass of counter weight as 1200 kg Assume the mass of the elevator when carrying passengers is 1000 kg. Calculate a. the acceleration of the elevator and b. the tension in the cable.

SOLUTION

GIVEN:

mass of counter weight m_1 = 1200 kg
mass of elevator m_2 = 1000 kg
acceleration due to gravity g = 9.8 ms^{-2}

REQUIRED:

acceleration a = ?
tension T = ?

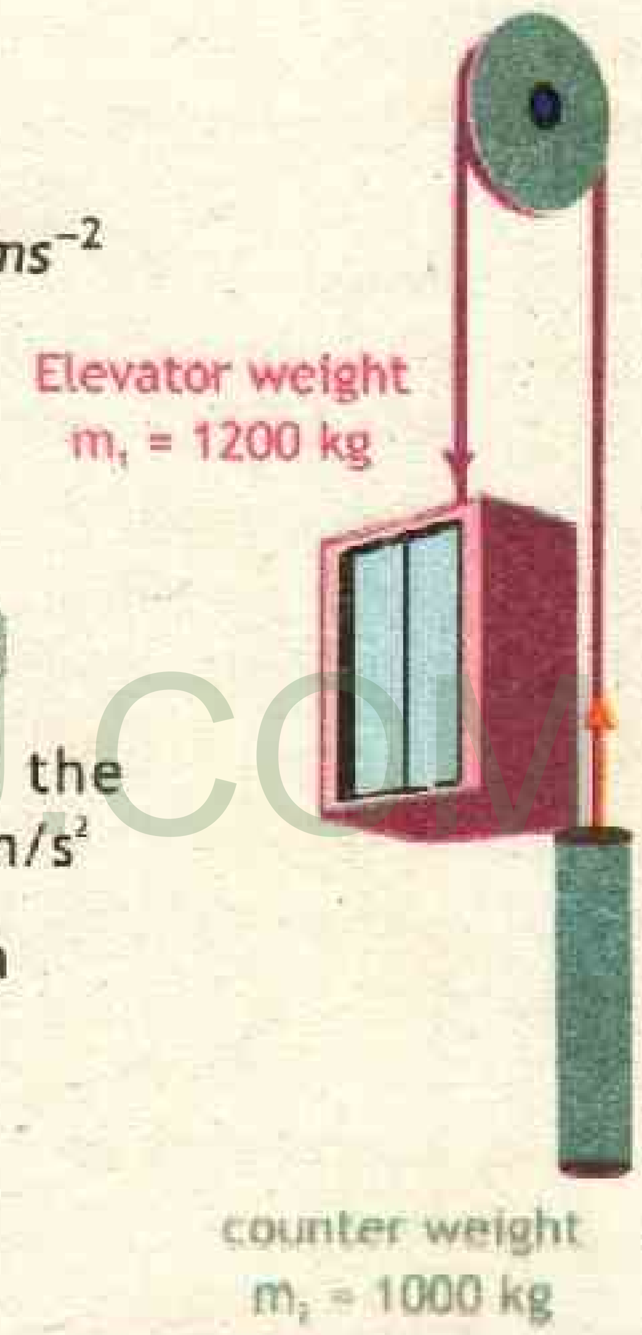
a) From Atwood's machine equation for acceleration

$$a = \frac{(m_1 - m_2)}{(m_1 + m_2)} g$$

putting values $$a = \frac{(1200\,kg - 1000\,kg)}{(1200\,kg + 1000\,kg)} \times 9.8\,ms^{-2}$$

or $$a = \frac{200\,kg}{2200\,kg} \times 9.8\,ms^{-2}$$

therefore $$a = 0.89\,ms^{-2}$$ — Answer



The elevator accelerates downward (and the counterweight upward) at an acceleration of 0.89 m/s^2

b) From Atwood's machine equation for tension

$$T = \frac{2m_1m_2}{(m_1 + m_2)} g$$

putting values $$T = \frac{2 \times 1200kg \times 1000kg}{(1200kg + 1000kg)} \times 9.8\,ms^{-2}$$

or $$T = \frac{2400000kg^2}{2200kg} \times 9.8\,ms^{-2}$$

or $$T = 10691\ kgms^{-2} \quad \text{as} \quad N = kgms^{-2}$$

therefore $$T = 10691\,N$$ — Answer

The tension in the elevator cable is 10691 N

EXTENSION EXERCISE 3.3

If both mass of elevator cabin and counter weight are equal as 1000 kg. What is the acceleration and tension in the cable.

Assignment 3.8 SIMPLE ATWOOD MACHINE

Two bodies of mass 3.5 kg and 1.5 kg are tied to ends of string which passes over a pulley. Find **a.** the acceleration of bodies and **b.** the tension in string.

LAB WORK

To determine the value of "g" by the Atwood's machine.

3.7 UNIFORM CIRCULAR MOTION

When a body moves in a circle we call it circular motion, for example, a famous amusement ride is Ferris wheel (shown in picture) which makes us move in a circle. Circular motion is of two types - uniform circular motion and non-uniform circular motion. **When the speed of the moving object does not change as it travels in the circular path, it is called uniform circular motion.** However when there are variations in speed, for an object moving in circular path we call it non-uniform circular motion.

3.7.1 CENTRIPETAL ACCELERATION

Acceleration can be produced in a body either by increasing or decreasing its magnitude of velocity (known as speed) or by changing direction of velocity. When an object moves in a circle, it continuously changes its direction. This means that, the object moves at a tangent to the circular path in which it travels. The velocity vector is also directed along the tangent. We can demonstrate this with a simple experiment.

Tie a ball to a string, and rotate it around head by holding one end of the string so that the stone travels in a circle.

If you let go of the string, the ball will travel in a straight line. This shows that velocity vector is directed along tangent. The same phenomena is used in hammer throw game, when athlete whirl and let the hammer go it travels a straight distance.

However, as there is a continuous change in the direction, an object moving in a circle is always accelerating. This acceleration is directed inwards, towards the center of the circular path, and is known as **centripetal acceleration.** For an object of mass m moving with velocity v, in the

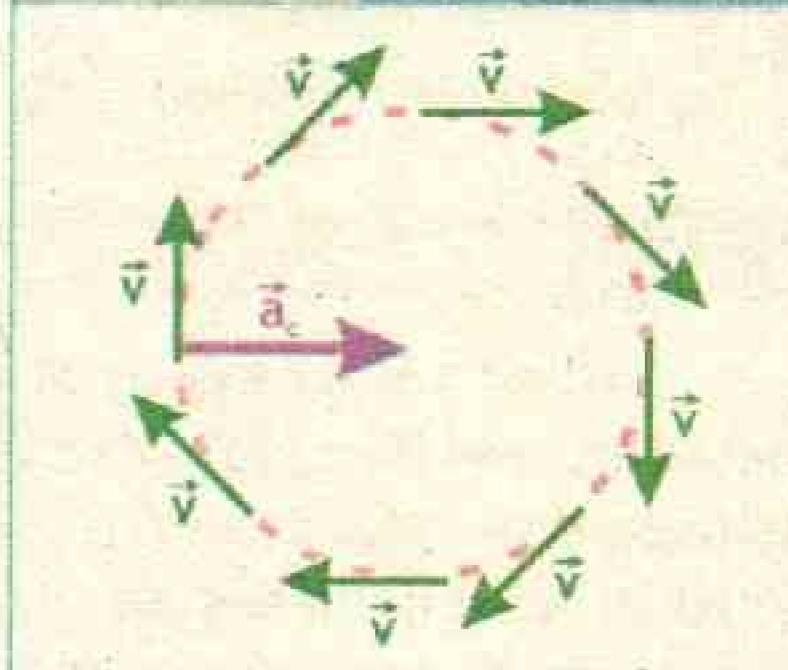
acceleration

circle of radius r, the centripetal acceleration a_c is

$$a_c = -\frac{v^2}{r} \qquad (3.14)$$

The negative sign shows that acceleration is directed towards the center.

Figure 3.12



When a particle moves in uniform circular motion its velocity vector changes direction at every point resulting in centripetal acceleration a_c.

3.7.2 CENTRIPETAL FORCE

To produce an acceleration, a net force has to act on the system. The net force is directed perpendicular to the velocity vector, towards the center of the circular path. This force is called the centripetal force. In the absence of the centripetal force, the object will travel in a straight line. Hence, the effect of the centripetal force is to continuously change the direction of the moving object, forcing it to move in a circle. The centripetal force F_c by Newton's second law of motion can be written as

$$F_c = ma_c$$

putting value from equation 3.14 , we get

$$F_c = \frac{mv^2}{r} \qquad (3.15)$$

3.7.3 APPLICATIONS OF CENTRIPETAL FORCE

The following are some daily life application of centripetal force.

A) Banking of Road:

When a car moves along a curve, centripetal force is required. In the absence of this force, the car will skid off the road. The force of friction between the tyre and the road provides this centripetal force and keeps the car moving on the curved path. However if the tyres are worn out or the road is slippery due to some rain, snow or oil spill, the friction will be not be enough to provide necessary centripetal force.

For extra protection level of the outer edge of a round track is kept slightly higher than that of the inner edge known as banking of road. In this case the normal component of the vehicle increase friction to provide necessary centripetal force for safe turning around the circular track.

That is, roads must be steeply banked for high speeds and sharp curves. Since the race car tracks are designed for high speeds, every turn has its own limiting speeds to pass, depending upon banking provided.

TID-BITS'

Race car coming towards a curve. From the tire marks we see that most cars experienced friction force to give them the needed centripetal acceleration for rounding the curve safely. But, we also see tire tracks of cars on which there was not sufficient force and which unfortunately followed more nearly straight-line paths.

B) Centrifuge:

A centrifuge is a device that separates substances suspended in a liquid by spinning a sample of liquid very quickly around an axle. Any small denser particles found in the liquid travel in a straight line inside the test tube, obeying Newton's first law. The liquid in the test tube applies a centripetal force on these particles to keep them moving in a circle. After running the centrifuge at high speed for a period of time, the particles become clumped together at the bottom of the test tube, which can be collected and the sample is analyzed.

The same Centrifuge principle can be used in these commonly used devices.

(i) Separator:

A separator is a Centrifugal device that separates milk into cream and skimmed milk. In this machine milk is whirled rapidly. Since milk is a mixture of light and heavy particles, when it is rotated the light particles gather near the axis of rotation whereas the heavy particles go away and hence cream can easily be separated from milk.

(ii) Washing Machine dryer:

Washing machine dryer is a kind of centrifuge. The dryer consists of a long cylinder with small holes on its walls. Wet clothes are placed in this cylinder, and then rotated rapidly. Water moves outward to the wall of the cylinder and is drained out through the holes. In this way clothes become dry quickly.

Example 3.9 BUG ON DISK

Suppose this bug has a mass m = 5.0 g and sits on the edge of a compact disc of radius 6.0 cm that is spinning such that the bug velocity is 1.2 m/s. Find **a.** the centripetal acceleration of the bug and **b.** the total force on the bug

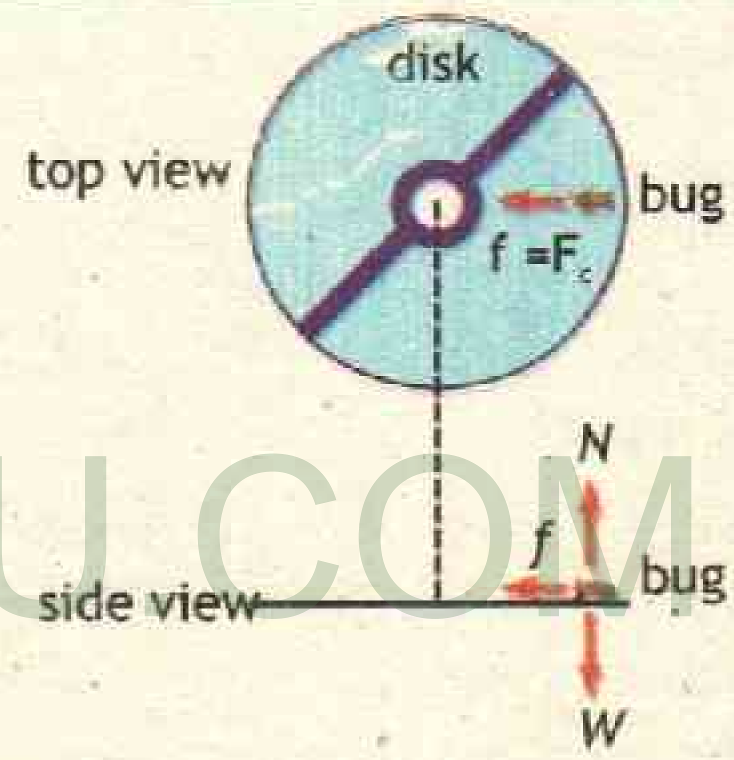
SOLUTION

Given

mass m = 5 g = 0.005 kg

velocity v = 1.2 m/s

radius r = 6 cm = 0.06 m



REQUIRED:

(a) centripetal acceleration a_c = ?

(b) centripetal force F_c = ?

The centripetal acceleration of bug is

$$a_c = -\frac{v^2}{r} \quad \text{putting values} \quad a_c = -\frac{(1.2\,ms^{-1})^2}{0.06\,m}$$

$$\text{or} \quad a_c = -\frac{1.44\,m^2s^{-2}}{0.06\,m}$$

$$\text{therefore} \quad a_c = -24\,ms^{-2}$$ — **Answer**

The centripetal force on bug is $F_c = m a_c$

putting values $F_c = 0.005\,kg \times 24\,ms^{-2}$ or $F_c = 0.12\,N$ — **Answer**

Assignment 3.9 MASS OF PLANE

A pilot is flying a small plane at 56.6 m/s in a circular path with a radius of 188.5 m. The centripetal force needed to maintain the plane's circular motion is 1.89×10^{4} N. What is the plane's mass?

KEY POINTS

Dynamics: The branch of mechanics in which we discuss the motion of bodies along with causes of motion of bodies.

Force: Force is a physical quantity which moves or tends to move a body, stops or tends to stop a moving body or which tends to change the speed and direction of a moving body.

Newton 1st Law of Motion: This law states that every body continues in its state of rest or uniform motion in a straight line unless an external net force acts upon it.

Newton Second Law of Motion: This law states that whenever a net force acts on a body, it produces acceleration in the direction of the net force. The acceleration is directly proportional to the net force and inversely proportional to the mass of the body.

Newton Third Law of Motion: This law states that to every action there is an equal and opposite reaction.

Mass: The quantity of matter in a body is called its mass.

Weight: The downward force with which the earth pulls a body towards its center is called weight of the body.

Momentum: The product of mass and velocity is called momentum. It is a vector quantity.

Law of Conservation of Momentum: This law states that if there is no external force applied to a system, the momentum of that system remains constant.

Force of Friction: The force which opposes the motion of an object while in contact with its surroundings is called the force of friction.

Uniform Circular Motion: If a body moves in a circular path with a uniform speed, it is said to be in a uniform circular motion.

Centripetal Force: The force which compels a body to move in a circular path is called centripetal force.

PROJECTS

GROUP - A

ROLLER COASTER: Many amusement-park rides utilize centripetal acceleration to create thrills for the park's customers. Choose two rides that involve circular motion and to explain the physics of circular motion creates the sensations for the riders. Prepare a presentation to be presented in physics class.

PROJECTS

GROUP - B

TYRES IN PAKISTAN, ARE PEOPLE AWARE?: Research tyre types used in Pakistan, What type of tyres are better in hot and dry conditions, cold and snowy regions and in wet weather? Interview few people who drive and gather information whether they know the advantages and disadvantages of wide tyres and treads on tyre .

Photograph different types of tyre treads found on cars in your school parking or a local tyre store, Think, to which of the tyres you photographed provides the shortest stopping distance on dry roads, snow, and ice. Use Internet , electronic and print resources to collect data on the stopping distances for the tyres you have chosen. Compare these results to your predictions. Make a catalogue of your research and place it in school library for reference.

GROUP - C

ROAD BARRIERS: Design an experiment that uses a dynamics cart with other easily found equipment to test whether it is safer to crash into a steel railing or into a container filled with sand. How can you measure the forces applied to the cart as it crashes into the barrier? If your teacher approves your plan, perform the experiment. Write how your research will prove to produce more effective highway barriers.

GROUP - D

CONVEYER BELTS: What are conveyer belts. Research different conveyer belts and their uses. In terms of static and kinetic friction analyze the fabric of different conveyer belts, used in industry. Prepare a presentation, charts and models for conveyer belt.

GROUP - E

GUN TEST: An inventor is testing his new rifles during the target-shooting segment of an event. The new 0.75 kg guns shoot 25.0 g bullets at 615 m/s. The shooting team coach has hired you to advise him about how these guns could affect the accuracy. Prepare figures to justify your answer, display them on chart. Be ready to defend your position.

EXERCISE

MULTIPLE CHOICE QUESTIONS

1. A 30 kg object is supported from rope, such that tension in the rope is equal to its weight. the weight of the object is

   A. 30 kg B. 30 N C. 294 N D. 9.8 N/kg

2. Force needed to produce an acceleration of 10 ms^{-2} in a ball of mass 0.5kg is

   A. 20 N B. 10.5 N C. 9.5 N D. 5 N

3. Ball A collide with ball B which is at rest, after the collision which of the following condition is not possible

   A. ball A comes to rest and ball B start moving
   B. both balls move in same direction
   C. both balls move in opposite directions
   D. both balls are at rest

4. What is the mass of a car that is traveling with a velocity of 20 m/s[W] and a momentum of 22000 kg m/s[W]

   A. 440000 kg B. 21980 kg C. 22020 kg D. 1100 kg

5. An object at earth and taken to moon should have

   A. less mass/less weight B. same mass/more weight
   C. same mass/less weight D. less mass/same weight

6. The unit of coefficient of friction is

   A. N B. kg C. μ D. it has no units

7. The centripetal acceleration for an object of mass 1 kg moving with 6 m/s in a circle of radius 3 m is.

   A. 18 ms^{-2} B. 12 ms^{-2} C. 10 ms^{-2} D. 2 ms^{-2}

8. How many times the centripetal force will increase if the mass of a body moving with uniform speed in a circle is doubled?

   A. Six time B. Two times C. Four times D. Eight times

9. Which of the following forces can act as a centripetal force

   A. tension B. friction C. gravitational force D. All of these

10. An empty suitcase is placed in the middle of bus on its floor traveling at high speed. When the bus brake suddenly, the suitcase slide
    A. backwards B. forward C. jumps up D. remains in place
11. In Newton's third law the action reaction pair does not neutralize each other, because they
    A. act on same body B. act on different bodies
    C. act on third body D. produce friction

CONCEPTUAL QUESTIONS

Give a brief response to the following questions.

1. Why does dust fly off, when a hanging carpet is beaten with a stick?
2. If your hands are wet and no towel is handy, you can remove some of the excess water by shaking them. Why does this work?
3. Why a balloon filled with air move forward, when its air is released?
4. Why does a hose pipe tend to move, backward when the fireman directs a powerful stream of water towards fire?
5. Your car is stuck in wet mud. Some students on their way to class see your predicament and help out by sitting on the trunk of your car to increase its traction. Why does this help?
6. How does friction help you walk? Is it kinetic friction or static friction?
7. The parking brake on a car causes the rear wheels to lock up. What would be the likely consequence of applying the parking brake in a car that is in rapid motion?
8. Why is the surface of a conveyor belt made rough?
9. Why does a boatman tie his boat to a pillar before allowing the passengers to step on the river bank?
10. In uniform circular motion, is the velocity constant? Is the acceleration constant? Explain.
11. You tie a brick to the end of a rope and whirl the brick around you in a horizontal circle. Describe the path of the brick after you suddenly let go of the rope.
12. Why is the posted speed for a turn lower than the speed limit on most highways?

COMPREHENSIVE QUESTIONS

Give an extended response to the following questions.

1. What is force? What are its unit. Distinguish between contact and non-contact forces?
2. State and explain Newton's three laws of motion. Give one example of each.
3. What is weight? Differentiate between mass and weight.
4. Define momentum. Relate force to change in momentum.
5. Define isolated system. Explain the law of conservation of momentum.
6. Define collision and explosion. Explain change in momentum in terms of collision and explosion.
7. What is friction. What are microscopic basis of friction? What is normal force, how it affects friction.
8. Differentiate between static and kinetic friction by giving an example. Find the expression for the coefficient of kinetic and static friction.
9. What are advantages and disadvantages of friction. Also give methods to reduce and improve friction.
10. What is tension? If two connected bodies of masses m_1 and m_2 are hanging from the ends of a string which is passing over a pulley, find the values of tension and acceleration in it.
11. What is uniform circular motion. What are the factors on which magnitude of acceleration (centripetal acceleration) in uniform circular motion depends.
12. What is centripetal force? Explain how centripetal force is used in banking of roads and centrifugation.

NUMERICAL QUESTIONS

1. 1580-kg car is traveling with a speed of 15.0 m/s. What is the magnitude of the horizontal net force that is required to bring the car to a halt in a distance of 50.0 m?

2. A bullet of mass 10 g is fired with a rifle. The bullet takes 0.003 s to move through barrel and leaves with a velocity of 300 ms^{-1}. What is the force exerted on the bullet by the rifle?

3. A 2200-kg vehicle traveling at 94 km/h (26 m/s) can be stopped in 21s by gently applying the brakes. It can be stopped in 3.8 s if the driver slams on the brakes. What average force is exerted on the vehicle in both of these stops?

4. You want to move a 500-N crate across a level floor. To start the crate moving, you have to pull with a 230-N horizontal force. Once the crate "breaks loose" and starts to move, you can keep it moving at constant velocity with only 200 N. What are the co-efficients of static and kinetic friction?

5. Two bodies of masses 3 kg and 5 kg are tied to string which is passed over a pulley. If the pulley has no friction, find the acceleration of the bodies and tension in the string.

6. Determine the magnitude of the centripetal force exerted by the rim of a car's wheel on a 45.0-kg tyre. The tyre has a 0.480-m radius and is rotating at a speed of 30.0 m/s.

7. A motorcyclist is moving along a circular wooden track of a circus (death well) of radius 5 m at a speed of 10 ms^{-1}. If the total mass of motorcycle and the rider is 150 kg find the magnitude of the centripetal force acting on him?

8. A car of mass 1000 kg is running on a circular motor way interchange near Swabi with a velocity of 80 ms^{-1} the radius of the circular motor way interchange is 800 m. How much centripetal force is required?

WEB LINKS

https://faraday.physics.utoronto.ca/PVB/Harrison/Flash/

http://howthingsfly.si.edu/flight-dynamics/newton%E2%80%99s-laws-motion

http://www.school-for-champions.com/science/force.htm#.WlhodryWbIU

Unit 4

TURNING EFFECT OF FORCES

CHECK LIST

After studying this unit you should be able to:

- ✓define like and unlike parallel forces.
- ✓state head to tail rule of vector addition of forces/vectors.
- ✓describe how a force is resolved into its perpendicular components.
- ✓determine the magnitude and direction of a force from its perpendicular components.
- ✓define moment of force or torque as moment = force x perpendicular distance from pivot to the line of action of force.
- ✓explain the turning effect of force by relating it to everyday life.
- ✓state the principle of moments.
- ✓define the centre of mass and centre of gravity of a body.
- ✓define couple as a pair of forces tending to produce rotation.
- ✓prove that the couple has the same moments about all points.
- ✓define equilibrium and classify its types by quoting examples from everyday life.
- ✓state the two conditions for equilibrium of a body.
- ✓solve problems on simple balanced systems when bodies are supported by one pivot only.
- ✓describe the states of equilibrium and classify them with common examples.
- ✓explain effect of the position of the centre of mass on the stability of simple objects.

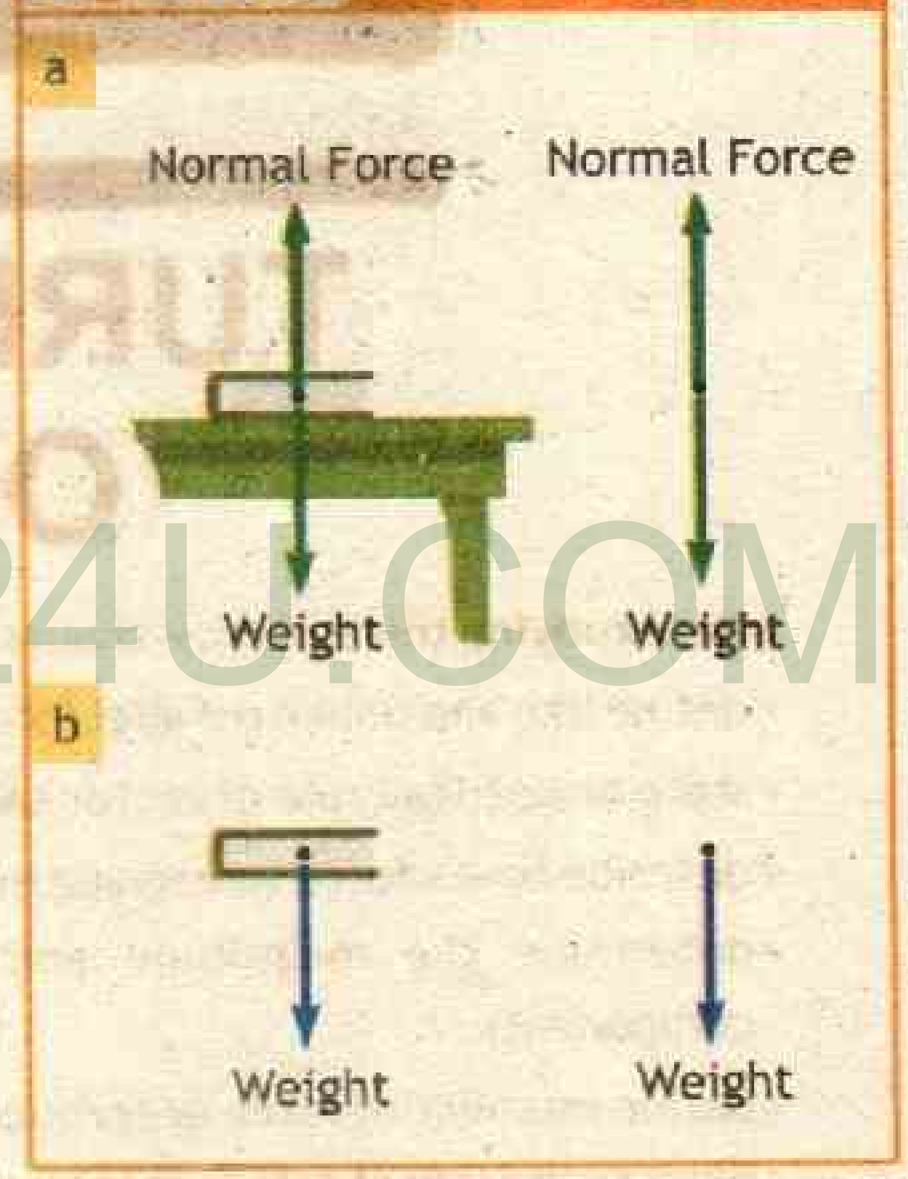
Until now, we have been concerned mainly with translational motion. We discussed the kinematics and dynamics of translational motion (the role of force). In this Chapter we will deal with rotational motion. We will discuss the kinematics and dynamics of rotational motion (involving torque). Our understanding of the world around us will be increased significantly and there may be a few surprises.

We will consider mainly the rotation of rigid objects about a fixed axis. A rigid object is an object with a definite shape that doesn't change, so that the particles composing it stay in fixed positions relative to one another.

2.1 FORCE DIAGRAMS

To study the effects of forces acting on any object, we can apply the skill of drawing force diagrams. Since force is a vector quantity it can be represented by an arrow. Force diagrams are very useful conceptual tools for physics students because they help examine the forces acting on an object. In force diagrams the object on which forces are shown is reduced to a dot at its center and the forces acting on the object are represented by arrows pointing away from it.

Figure 4.1 Force Diagrams



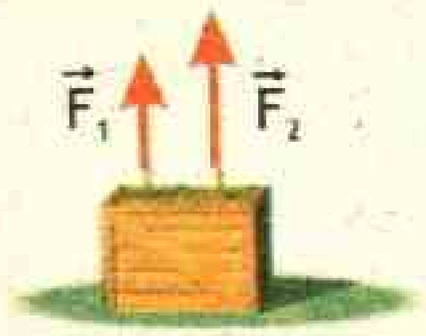
For example, if we were to draw a force diagram of this textbook placed at rest on table, we would reduce textbook to a dot, and draw two arrows representing forces acting on it, as shown in Figure 4.1 a. One of the forces is the weight of the book, pulling it downward. The other force is the normal force due to the bench pushing the book upward. The forces in Figure 4.1 a are equal and opposite; that is, the magnitude of the gravitational force is equal to the magnitude of the upward force due to the table. These two forces are an example of balanced forces. When an object is acted on by balanced forces, the forces cancel each other out and the object behaves as though no force is acting on it.

Figure 4.1 b is a force diagram of a textbook in free fall. Assuming negligible air resistance, the only force acting on the book is the force of gravity downward; there is no balancing upward force. As a result, the force due to gravity on the book is unbalanced, and the book accelerates downwards.

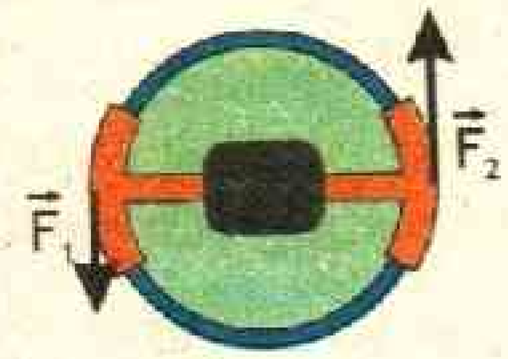
Figure 4.2 Parallel Forces

"If the directions of forces are parallel to each other, even if they are in opposite direction, those forces are called **parallel forces**. If they are in the same direction they are called **'Like parallel forces'** and if they are in the opposite direction they will be known as **'Unlike parallel forces'**.

Like parallel forces: For example when we lift a box with double support we are applying like parallel forces from each support, the force from one support may be greater than the other as shown in the figure.



Unlike parallel forces: For example when we apply force with our both hands on steering wheel of a car to turn it the force from one hand may be greater than the other as shown in figure. we are applying unlike parallel forces.



4.2 ADDITION OF FORCES

Addition of forces is a process of obtaining a single force which produces the same effect as produced by a number of forces acting together.

Forces are vectors and may be added geometrically by drawing them to a common scale (Recall chapter 2: Kinematics, representation of vectors) and placing them head to tail. Joining the tail of the first force vector with the head of the last will give another force vector which is the sum of these forces called **resultant force** (or **net force**, as you are already familiar with this from last chapter, Newton's Laws). These two terms resultant force and the net force can be used interchangeably.

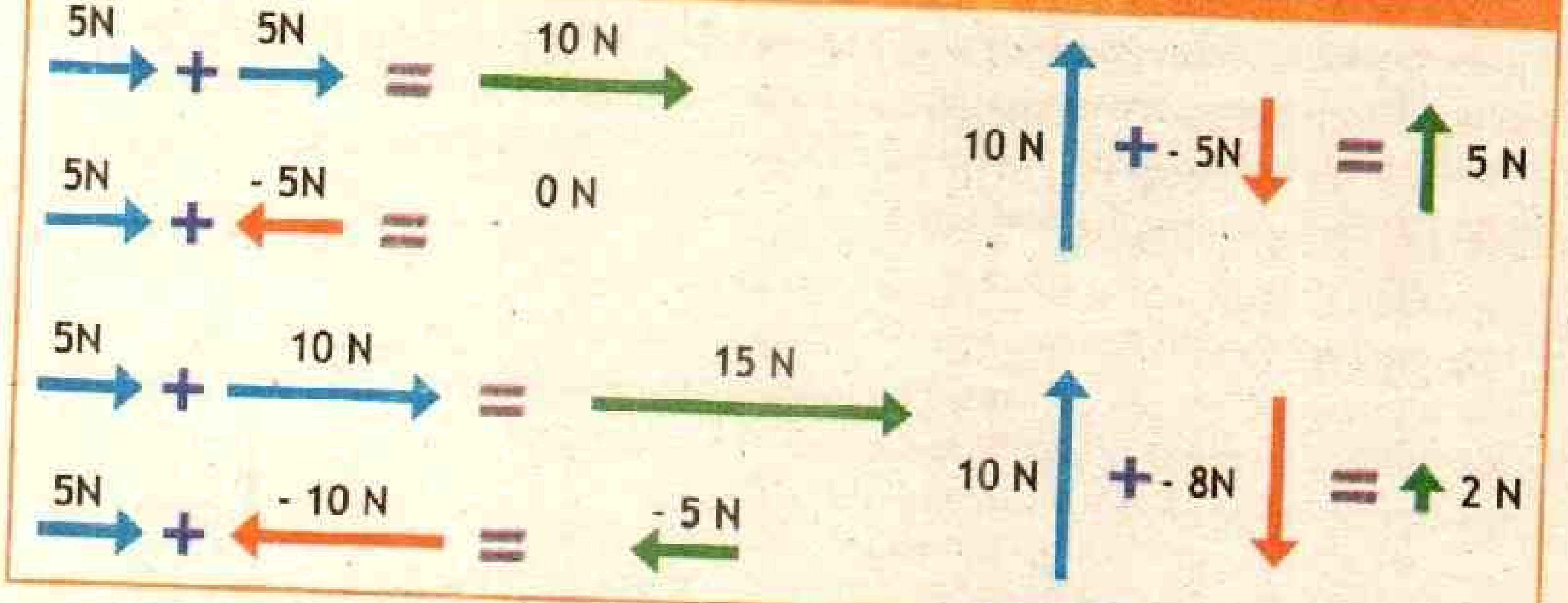
The situation of addition of forces is simple for like and unlike parallel forces i.e.

Add the magnitudes of vectors in case of like parallel forces.

Subtract the magnitudes of vectors in case of unlike parallel forces.

Few examples are shown in the figure 4.3.

Figure 4.3 Addition Of Parallel Forces



But things get complicated when the forces being added are not an angle to each other (neither parallel nor anti parallel). In such cases we will not make free vectors as above but we would have to draw vectors on a coordinate axis.

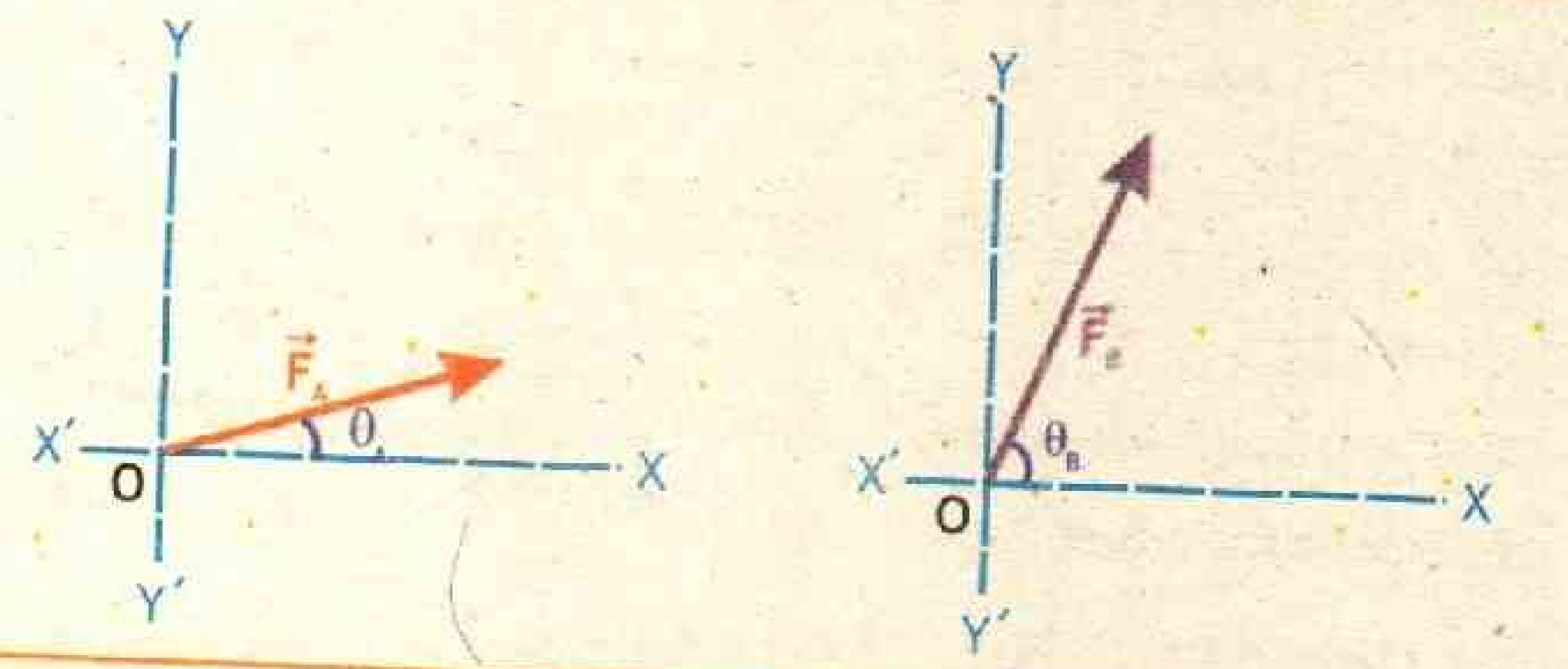
As an example consider two persons pulling a cart such that their force vectors are drawn to same scale. Draw F_A making angle θ_A with the x-axis and F_B making angle θ_B with the x-axis, as shown in the figure 4.4.

The following steps must now be followed to add the vectors by head to tail rule.

i. Sketch first force vector F_A using same scale according to selected scale in a given direction.

ii. Now place the tail of the second force vector F_B on the head of the first force vector F_A in the given direction.

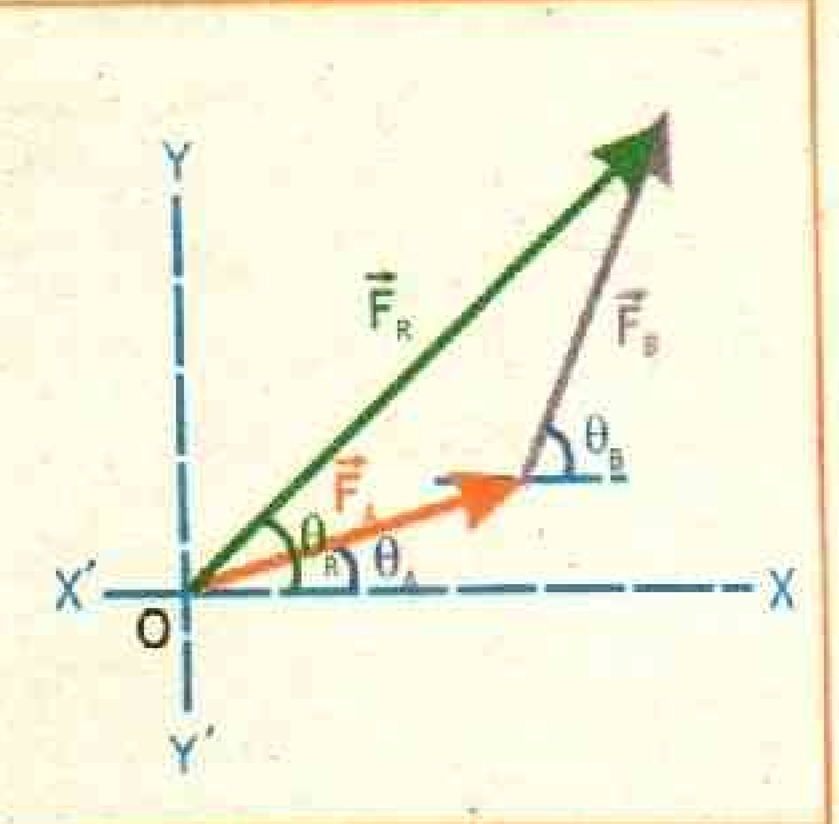
Figure 4.4 Addition Of Forces Making An Angle



iii. Now the net force, resultant force F_R can be obtained by joining the tail of the first force vector F_A to the head of the second force vector F_B, putting an arrow on the line pointing away from the origin gives the resultant vector F_R as shown in figure 4.5.

iv. To determine the magnitude of resultant measure the length of F_R and convert it back according to given scale. To determine the direction of the resultant measure the angle of resultant θ_R with x-axis.

Figure 4.5 Resultant Force



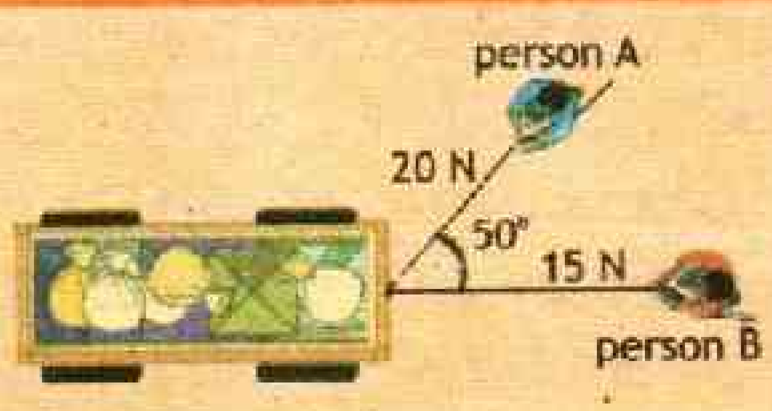
$$\vec{F}_R = \vec{F}_A + \vec{F}_B \quad (4.1)$$

Addition of More than two Vectors:

This rule for vector addition can be extended to any number of forces.

Example 4.1 PULLING TRASH IN DIFFERENT DIRECTIONS

Two people, A and B, are pulling a trash cart with two ropes. Person A applies a force 20 N [50° with x-axis] on one rope. Person B applies a force of 15 N [0° with x-axis] on the other rope. Calculate the magnitude of net force on the trash cart.



SOLUTION

Scale:

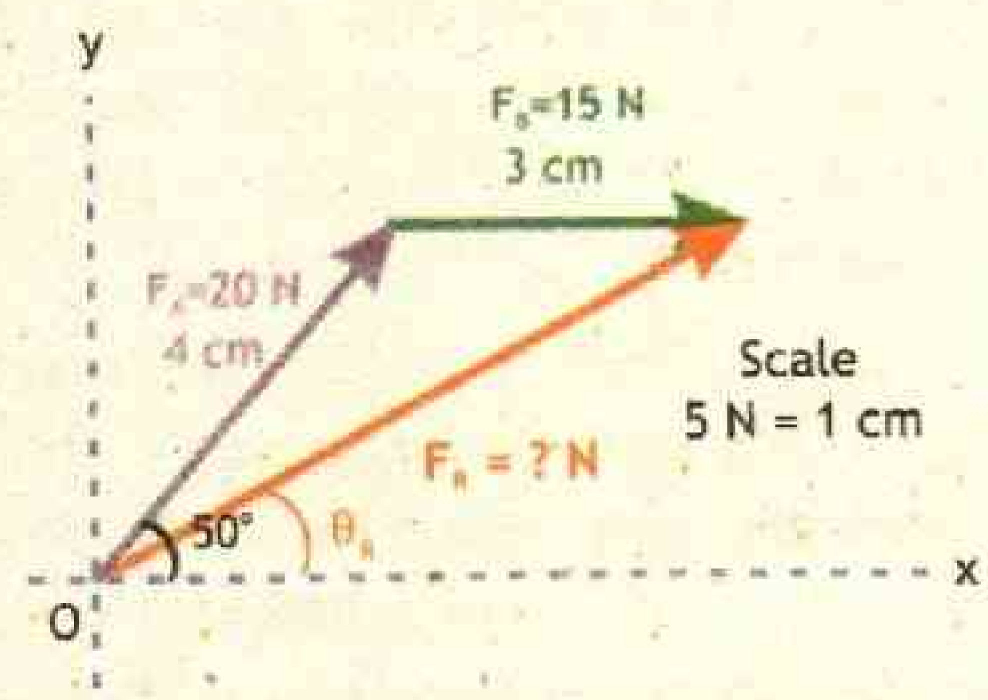
Let 5N = Km

F_A = 20 N = 4 cm

θ_A = 50° with the x-axis

F_B = 15 N = 3 cm

θ_B. 0° with the x-axis



Finding the resultant:

We joined the tail of the first to the head of the second vector to get the resultant F_R. We then measured the length of vector F_R which was about 6.2 cm ($6.2 \times 5 = 31$ N), and with the protector we measure the angle $\theta = 30^\circ$ with x-axis.

$F_R = 31$ N, 30° with x-axis — **Answer**

EXTENSION EXERCISE 4.1

Will it make any difference if you first draw F_B and then F_A to find the resultant?

Assignment 4.1 HEAD TO TAIL RULE

Two forces are applied *one force is 25 N [20° with x-axis] and the other force is 10 N [60° with x-axis], find the net resultant force.*

4.3 RESOLUTION OF FORCES

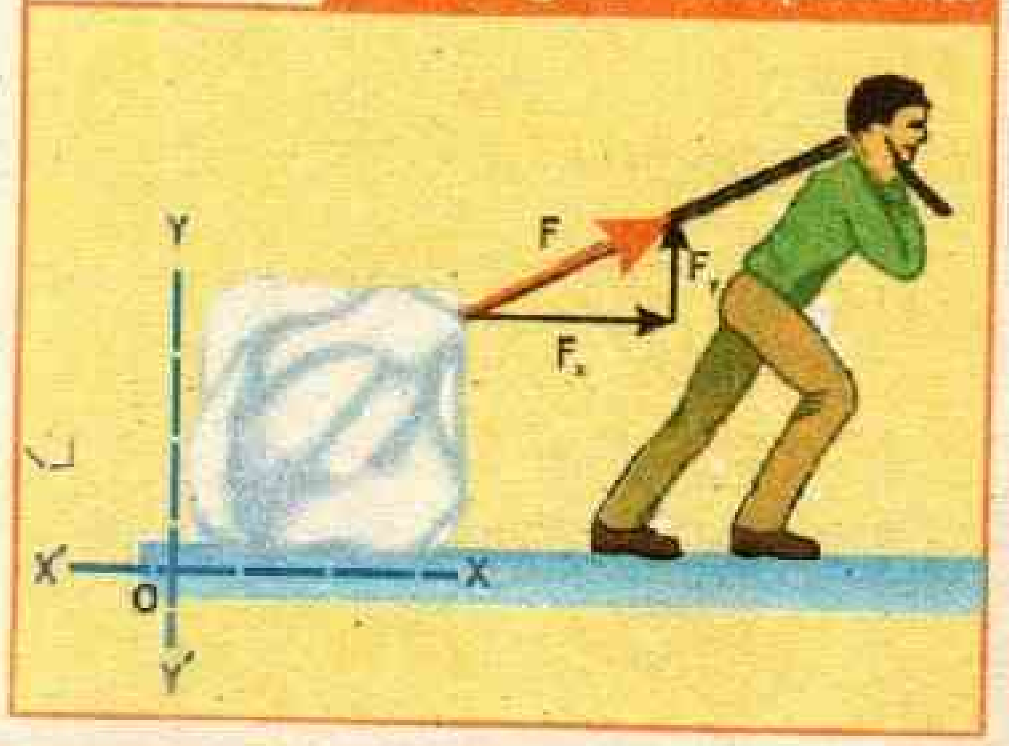
The process of splitting a force vector into two or more force vectors is called resolution of forces. The force vectors so obtained are called components.

POINT TO PONDER

Is vector addition of more than two forces possible, by head to tail rule?

This process is opposite of addition of vectors, in principle force being a vector can be resolved into as many components as we wish. However If these components in to which a force vector is split are perpendicular to each other then such components are called **rectangular components of vector**. Resolving forces into rectangular components help us to analytically add forces rather than needing a ruler or/and protector. Part of the graphical technique is retained, because vectors are still represented by arrows for easy visualization.

Figure 4.6 Rectangular Components



Analytical methods are more concise, accurate, and precise than graphical methods, which are limited by the accuracy with which a drawing can be made. Therefore, in physics, very often we need to separate a vector into rectangular components. For example a ice block is being pulled by a boy using rope. We can think of force as tension in the rope. This single force F can be resolved into two components - one directed upwards rightwards along x-axis (F_x) and the other directed upwards along y-axis (F_y) as shown in fig 4.6.

Consider a force F in the Cartesian coordinate System, represented by the line OP, making an angle θ as shown in the figure. 4.7

Draw perpendiculars from point P on x-axis and y-axis which meets the axis at points Q and S respectively. Put arrow head from the direction of O towards Q and S such that they represent vectors as F_x (OQ & SP) and F_y (OS & QP), becomes the rectangular components of vector $\vec{F}$ (OP).

By head to tail rule of vector addition, we know that force $\vec{F}$ is the vector sum of $\vec{F}_x$ and $\vec{F}_y$, mathematically

$$\vec{F} = \vec{F}_x + \vec{F}_y \qquad (4.2)$$

Figure 4.7 Rectangular Components

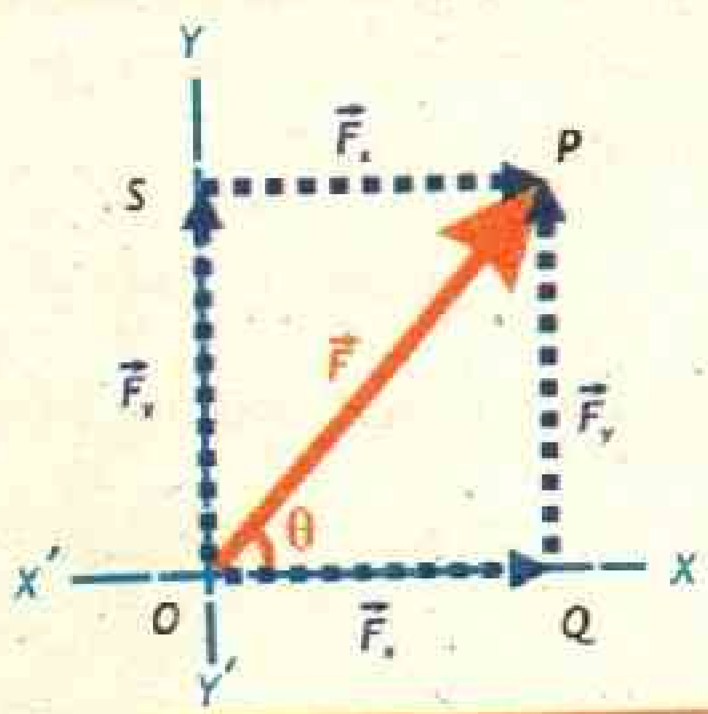


TABLE 4.1: ANGLE VALUES			
θ	sin θ	cos θ	tan θ
0°	0.000	1.000	0.000
30°	0.866	0.500	0.577
45°	0.707	0.707	1.000
60°	0.866	0.500	1.732
90°	1.000	0.000	infinite

Components represented in terms of force: Consider a triangle Δ OPQ, without taking the sides as vectors. This forms a right angle triangle for which we have.

$$\cos\theta = \frac{Base}{hyp} = \frac{OQ}{OP}$$

or $$\cos\theta = \frac{F_x}{F}$$

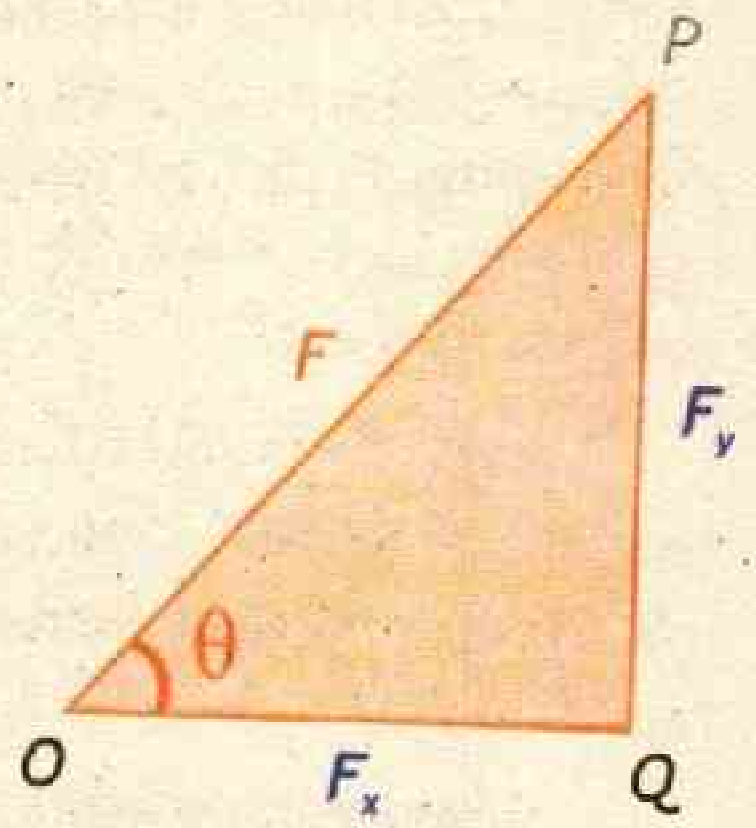
therefore $$F_x = F\cos\theta \qquad (4.3)$$

similarly $$\sin\theta = \frac{Perp}{hyp} = \frac{QP}{OP}$$

or $$\sin\theta = \frac{F_y}{F}$$

therefore $F_y = F\sin\theta$ —— 4.4

This means that we can calculate the components analytically juct by knowing the value of force and the angle.



Force represented in terms of its Components:

Since triangle Δ OPQ, from a right angle triangle, therefore we can use Pythagorus theorem, which states that

$$(hyp)^2 = (base)^2 + (perp)^2$$

taking square root on both sides $\sqrt{(hyp)^2} = \sqrt{(base)^2 + (perp)^2}$

such that $hyp = \sqrt{(base)^2 + (perp)^2}$

or $OP = \sqrt{(OQ)^2 + (QP)^2}$

therefore $F = \sqrt{F_x^2 + F_y^2}$ —— 4.5

The magnitude of vector can now be determined if the values of the magnitudes of components are known. To determine the direction in right angle triangle Δ OPQ, we have tan θ as

$$\tan\theta = \frac{perp}{base} = \frac{QP}{OQ}$$

or $\tan\theta = \frac{F_y}{F_x}$

therefore $\theta = \tan^{-1}\frac{F_y}{F_x}$ —— 4.6

Example 4.2 **PULLING A BOX ON FLOOR**

Divia is pulling a box on the floor with a force of 20 N making an angle of 60° with th horizontal. Find the horizontal and vertical components of this force.

GIVEN

Force F = 20.0 N

Angle θ = 60°

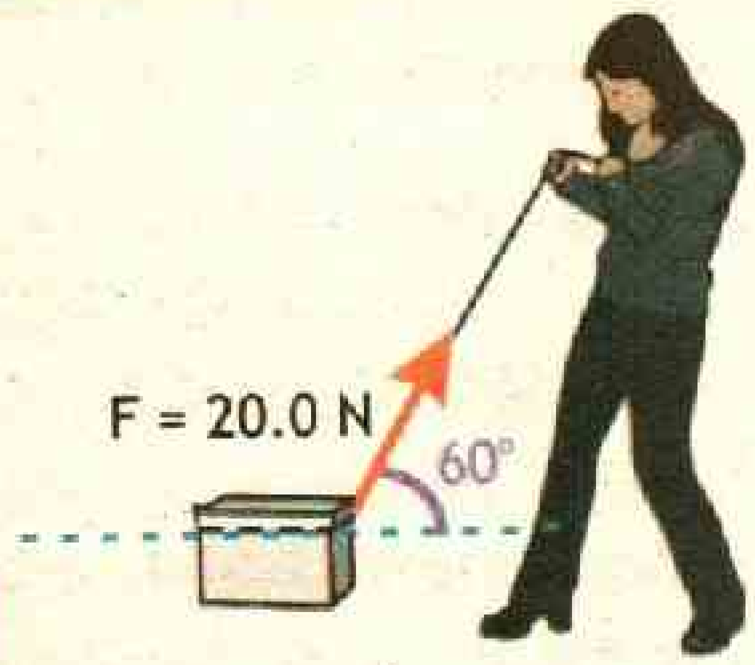
REQUIRED:

(a) Horizontal component of force F_x = ?

(b) Vertical component of force F_y = ?

SOLUTION

(a) Horizontal component of force F_x is the force that is involve in moving the box along the floor, Using equation 4.3



$F_x = F\cos\theta$

putting values $F_x = 20N\cos 60^o$

therefore $F_x = 10N$ — Answer

(a) For vertical component of force F_y we will use equation 4.4

$F_y = F\sin\theta$

putting values $F_y = 20N\sin 60^o$

therefore $F_y = 17.3N$ — Answer

To check the answer, we can convert the components back into magnitude and direction.

$F = \sqrt{F_x^2 + F_y^2}$

putting values $F = \sqrt{(10)^2 + (17.3)^2}$

or $F = \sqrt{100 + 299.3}$

therefore $F = 19.9N = 20N$

The magnitude is nearly equal to 20 N, therefore our calculations are correct, now to check the angle

$\theta = \tan^{-1}\frac{F_y}{F_x}$

putting values $\theta = \tan^{-1}\frac{17.3}{10}$

or $\theta = \tan^{-1}1.73$

therefore $\theta = 60^o$

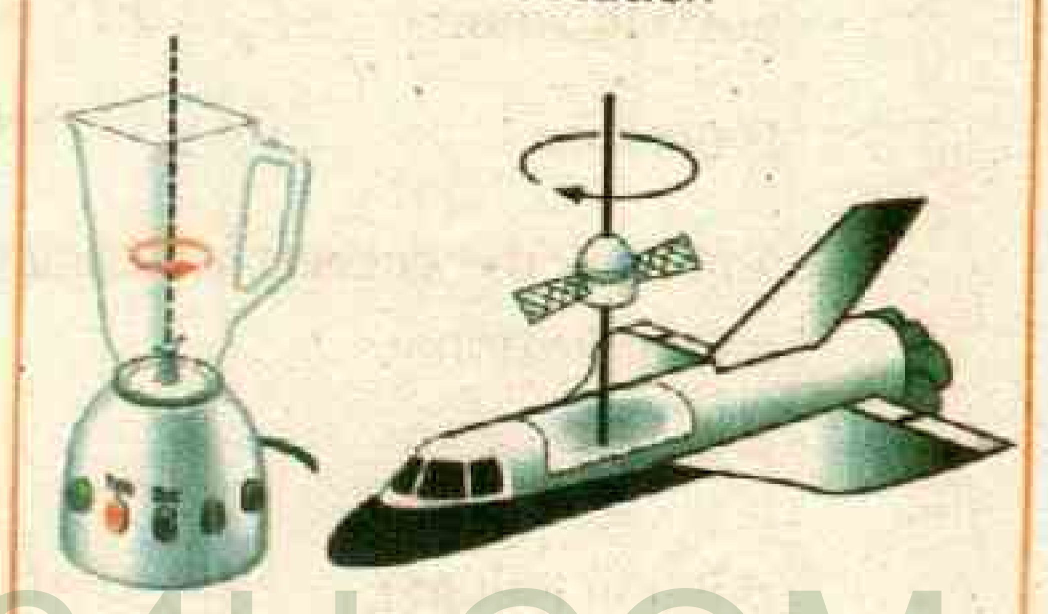
As the angle is equal to 60°, therefore our calculations are correct.

Assignment 4.2 TILLING GARDEN

While tilling your garden, you exert a force on the handles of the tiller that has components F_x = 85 N and F_y = 13 N. The x-axis is horizontal and the y-axis points up. What are the magnitude and direction of this force?

ROTATIONAL MOTION:

Motion where all points of an object moves about single fixed axis (which can be external is called rotational motion). In force diagrams we have seen that extended object (an object that occupies non zero space) forces can be shown by reducing object to a dot at its center. But there are some situations for which we need to consider an extended object—a system of particles for which the size and shape do make a difference and cannot be neglected. The following terms will be used in our study of rotational dynamics in this chapter.



Rigid objects:

Rigid objects are objects of fixed form that do not distort or deform (change shape) as they move. The study of rotational dynamics becomes easier if we consider the objects to be rigid.

Axis of Rotation:

For rotational motion we have to consider an axis of rotation. **Axis of rotation is a line about which rotation takes place.** This line remain stationary during rotational motion of the extended object, while the other points of the body move in circles about this line, it may be a pivot, hinges or any other support.

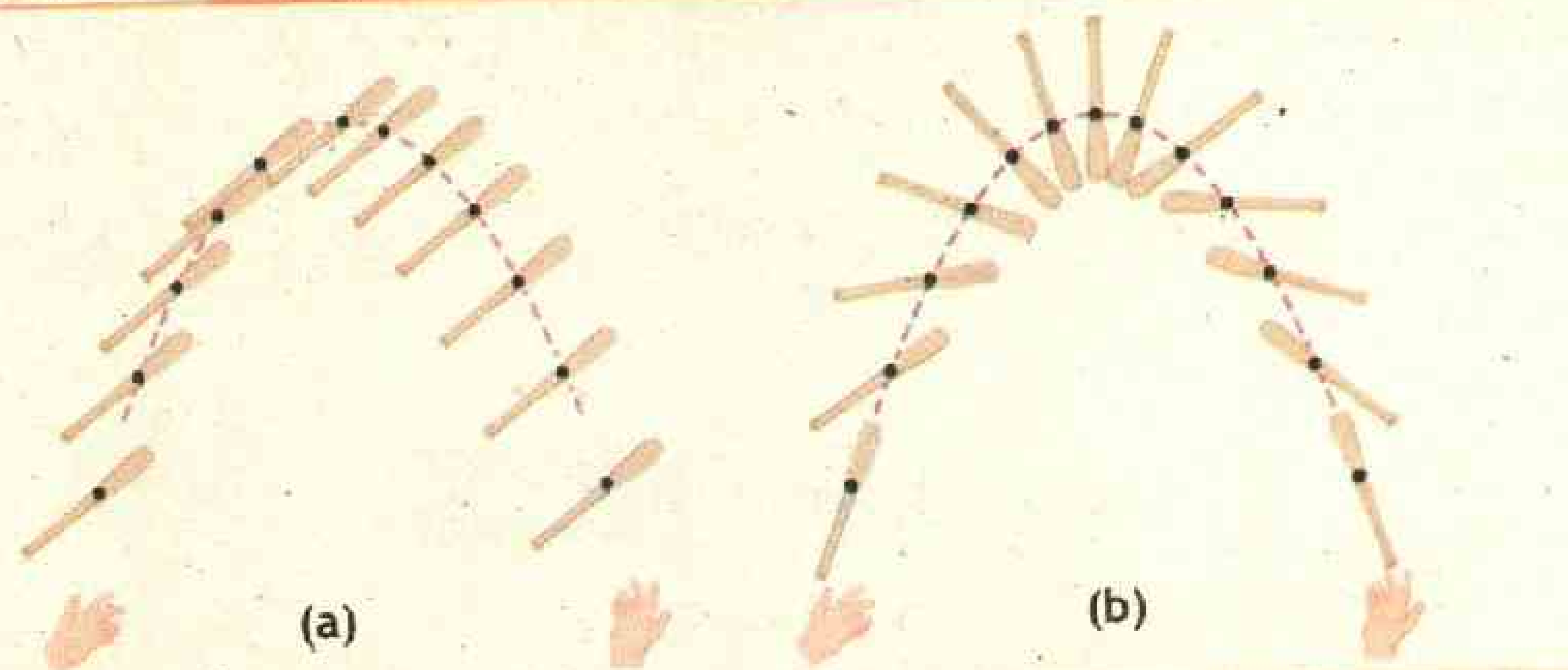
4.4 CENTER OF MASS

An extended rigid body is made of large number of small interconnected particles. The masses of all particles together make the mass of the body. **The center of mass of the body is the point about which mass is equally distributed in all directions.**

In force diagrams we have seen that extended object (that is, an object that has size) forces can be shown by reducing object to a dot at its center. The most suitable location of this point is center of mass.

Observations indicate that even if an object rotates, or several parts of a system of objects move relative to one another, there is one point that moves in the same path that a particle would move if subjected to the same net force. This point is called the center of mass (abbreviated CM). The general motion of an extended object (or system of objects) can be considered as the sum of the translational motion of the CM, plus rotational, vibrational, or other types of motion about the CM.

Figure 4.8 MOTION OF BASEBALL BAT



As an example, consider the motion of the center of mass of the base ball bat thrown in Fig. 4.8 a; the CM follows a parabolic path even when the base ball bat rotates, as shown in Fig. 4.8 b. Other points in the rotating base ball bat follow more complicated paths.

The center of mass is the point at which we can imagine all the mass of an object to be concentrated. Thus, the center of mass is also the point at which we can imagine the force of gravity acting on the entire object to be acting. If we can imagine all of the mass to be concentrated at this point when calculating the force due to gravity, it is legitimate to call this point the center of gravity, a term that can often be used interchangeably with center of mass.

The point where whole weight of the body appear to act is called center of gravity. In most physics problems, one of the forces acting on the body is its weight. The weight doesn't act at a single point; it is distributed over the entire body. But we can always assume that the entire force of gravity (weight) is concentrated at a point called the center of gravity (abbreviated 'CG').

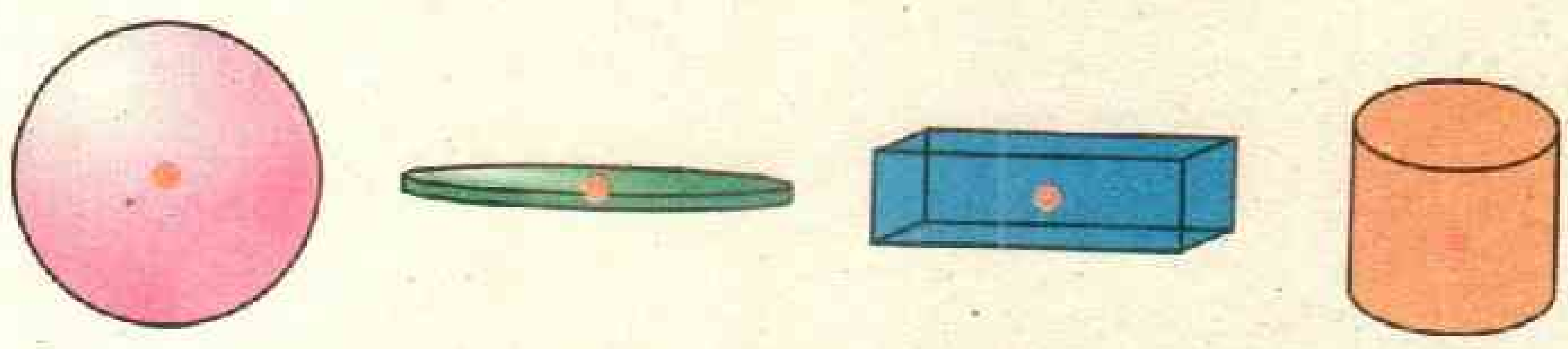
Difference between Center of Gravity (CG) and Center of Mass (CM):

The acceleration due to gravity decreases with altitude; but for small objects this variation is negligible, the body's center of gravity is for most of the time same as its center of mass.

Center of Gravity (CG) and Center of Mass (CM) for symmetric objects with uniform density:

The center of gravity of a homogeneous (having same density throughout) sphere, cube, circular disk, or rectangular plate is at its geometric center. The center of gravity of a right circular cylinder or cone is on the axis of symmetry, and so on.

Figure 4.9 Center Of Mass For Symmetric Object



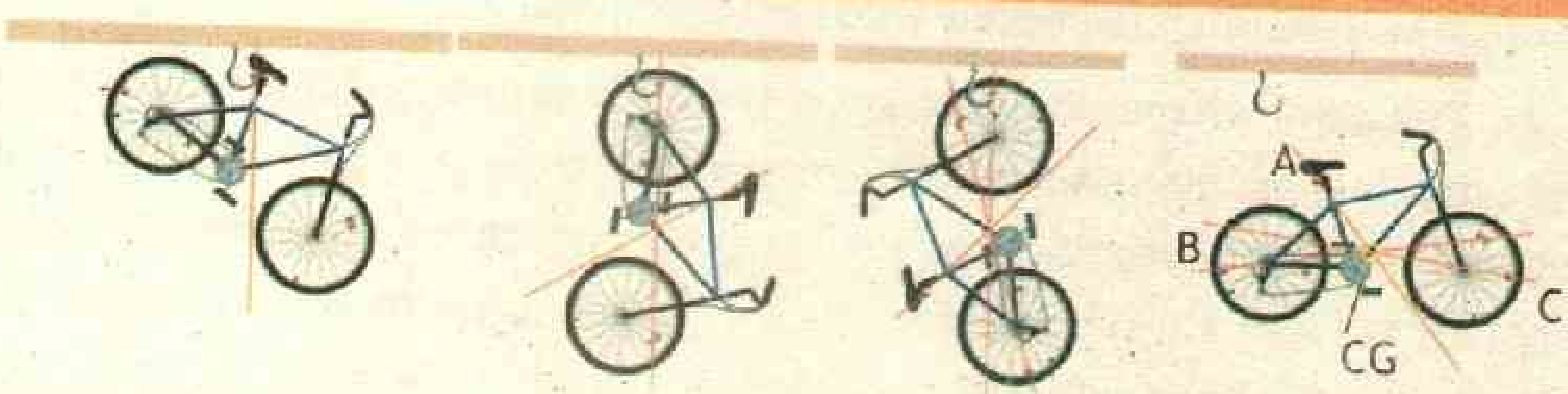
(a) (b) (c) (d)

Center of mass/gravity (CM/CG) is obvious by inspection and located at the center of symmetric object

Center of Gravity (CG) and Center of Mass (CM) for irregular objects:

As the centre of mass of a uniform wooden rod is at its mid-point, but when massive metal is attached to light wooden rod, the CM/CG is now non-uniform and we can find CM/CG by hanging this object from various locations.

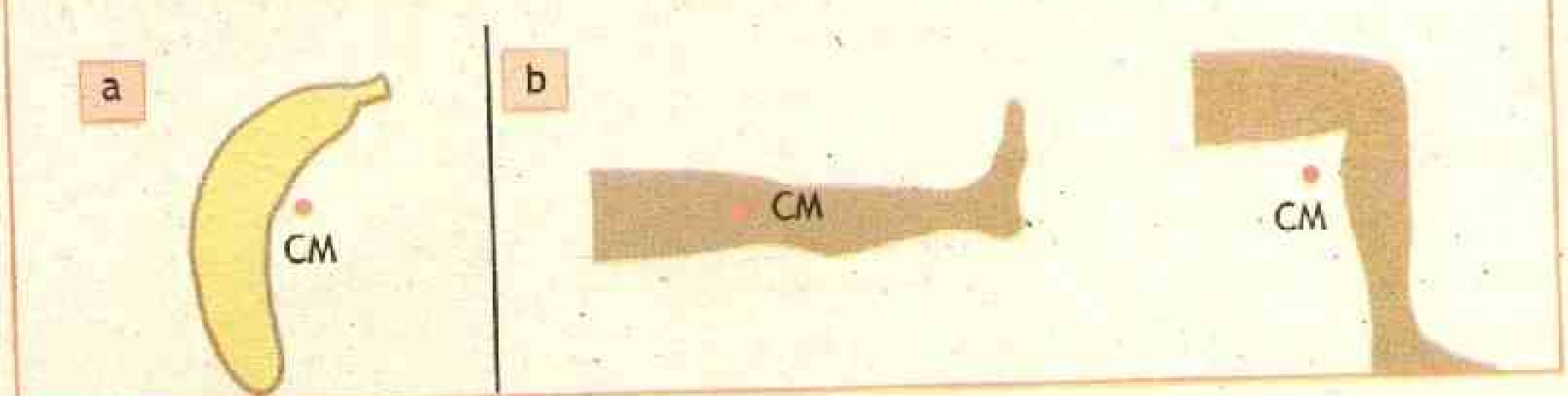
Figure 4.10 Irregular Object Center Of Mass



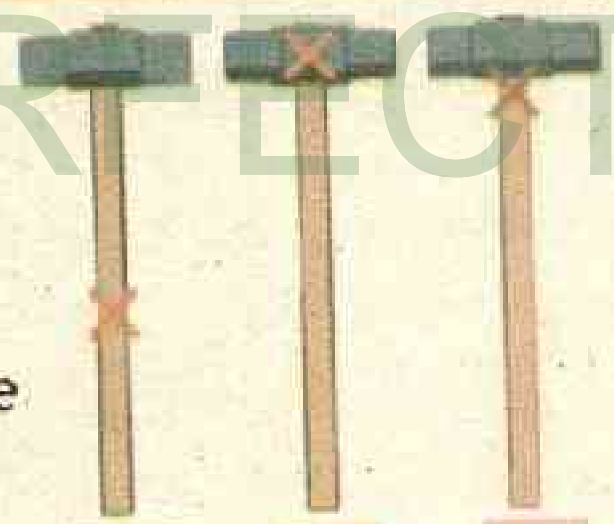
One way to determine the balance point of a three-dimensional object (such as bicycle) is to hang it randomly from at least three different points, as shown in Figure. The point of intersection of all three plumb lines is the bicycle's centre of gravity. This point is also the object's centre of mass.

The CM/CG may or may not lie inside the mass, some times the CM/CG is outside the distribution of mass. For example Banana in the figure 4.11 a has center of gravity outside the mass distribution. Also the center of mass may change its location depending upon the orientation of the object. If parts of an object change position relative to each other the location of CM/CG will change. For example, leg shown in figure 4.11(b). When leg is starched the mass is inside the body, but when the leg is bent the change in mass distribution changes CM/CG and is shifted outside the body.

Figure 4.11 CENTER OF MASS OUTSIDE MASS DISTRIBUTION



SELF ASSESSMENT



A sledgehammer has a massive metal head attached to a much lighter wooden handle. Which location is most likely to be the sledgehammer's center of mass?

POINT TO PONDER

The figures show a high jumper using different techniques to get over the crossbar. Which technique would allow the jumper to clear the highest setting of the bar? ☐

LAB WORK

- To find the tension in the strings by balancing a metre rod on the stands.
- To find the weight of an unknown object by using vector addition of forces.

4.5 TORQUE OR MOMENT OF FORCE

Force can be used to produce rotation in an object, for example in opening a door or tightening a nut with spanner or wrench. **Turning effect produced in a body about a fixed point due to applied force is called torque or moment of force.** Physicists usually use the term "torque," while engineers usually use "moment".

Torque is the cause of changes in rotational motion and is similar to force, which causes changes in translational motion. This means that torque play the same role in rotation as force in translation.

Quantitatively Torque = force applied × perpendicular distance from the axis of rotation. This perpendicular distance from the axis of rotation to the line of action of force is called moment arm (or lever arm) 'd'.

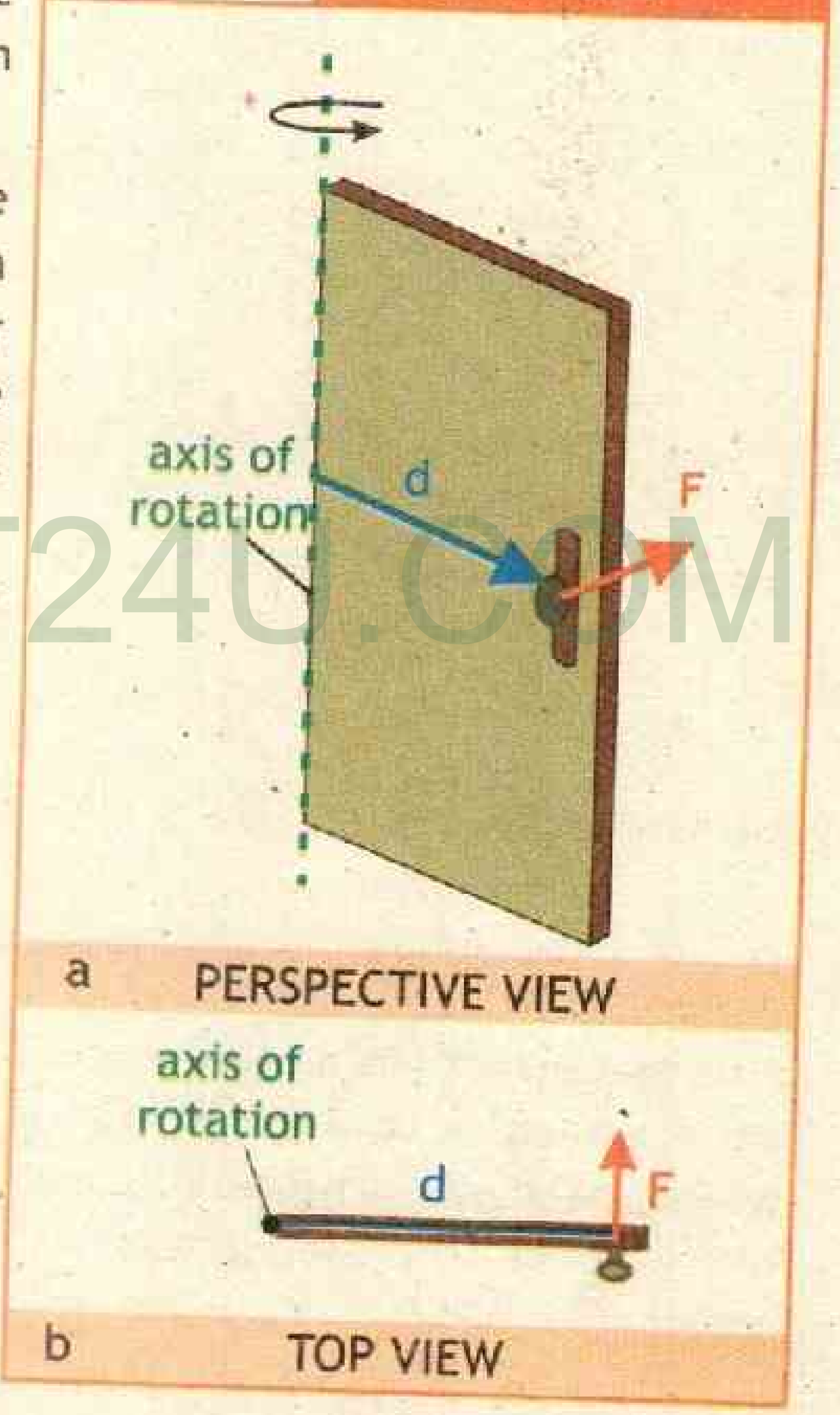
Thus torque 'τ' will be the product of applied force 'F' and moment arm 'd'.

$$\tau = F \times d \qquad (4.7)$$

The SI unit of torque is "newton metre" (Nm).

For example, to open the door force 'F' is applied at perpendicular distance 'd' from the axis of rotation as shown in the figure 4.12. Increasing the applied force 'F' or the moment arm 'd' increases the torque 'τ'. Reducing applied force 'F' or moment arm 'd' decreases torque 'τ'.For example if we apply more force we will forcefully produce rotation in the door and small force at the same distance from the axis of rotation will produce less torque. Similarly as we move away from the hinges (where there is axis of rotation) moment arm 'd'

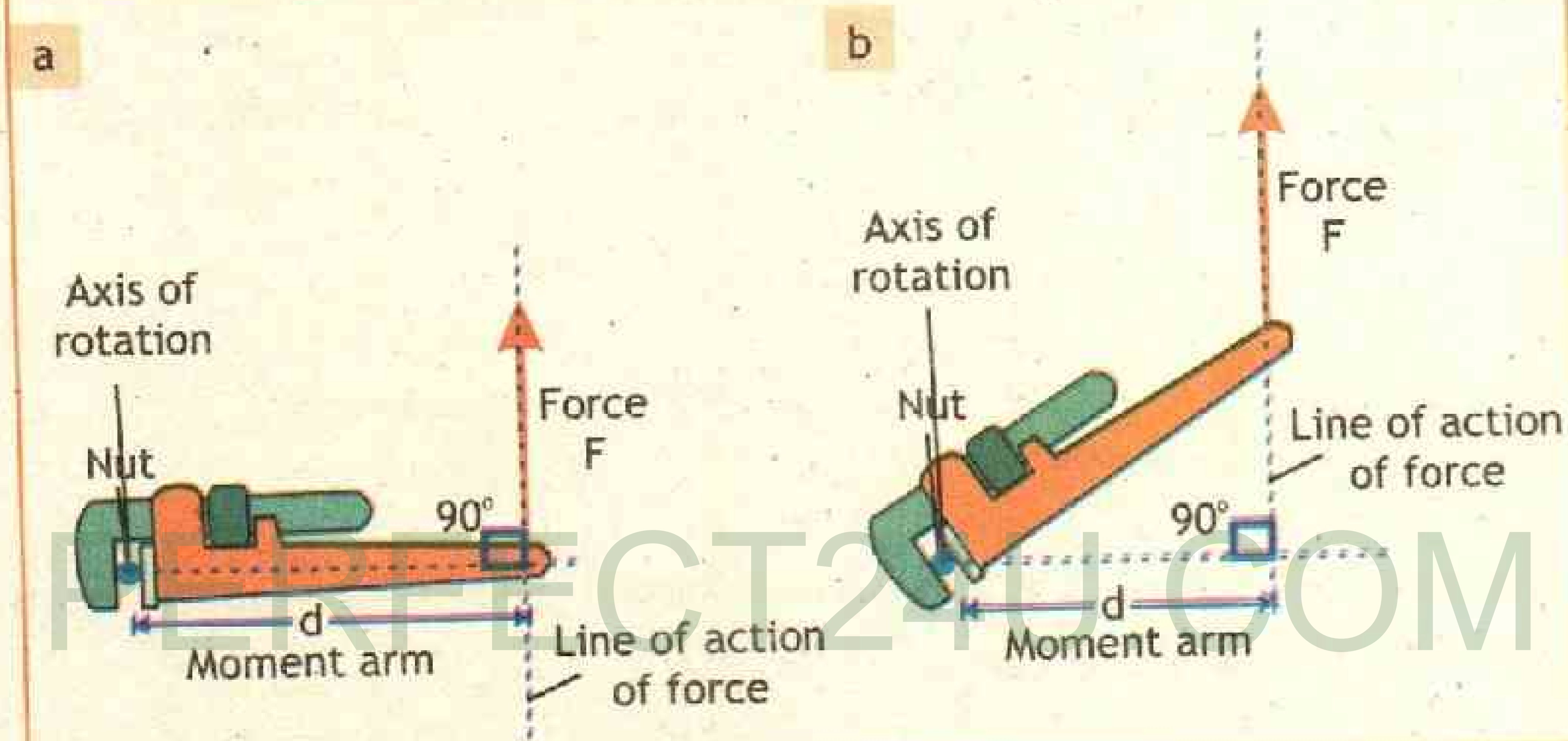
Figure 4.12 DOOR PHYSICS



increases and torque also increases for same applied force. Furthermore, if there is no force no torque will be produced, similarly a force applied at the pivot point will cause no torque since the moment arm would be zero (d = 0).

However force is not always applied perpendicularly, in this situation we have to extend the line of action of force applied 'F' and take the moment arm 'd' as perpendicular distance from the axis of rotation to the line of action of force.

Figure 4.13 MOMENT ARM



For example consider a wrench which is used to open a nut as shown in figure 4.13 (a) the torque is produced. However if we continue to apply the same force in the same direction, after the nut has rotated as in figure 4.13 (b), our definition of moment arm will reduce it in magnitude and torque will decrease.

Moment arm is key to the operation of the lever, pulley, gear, and many other simple machines.

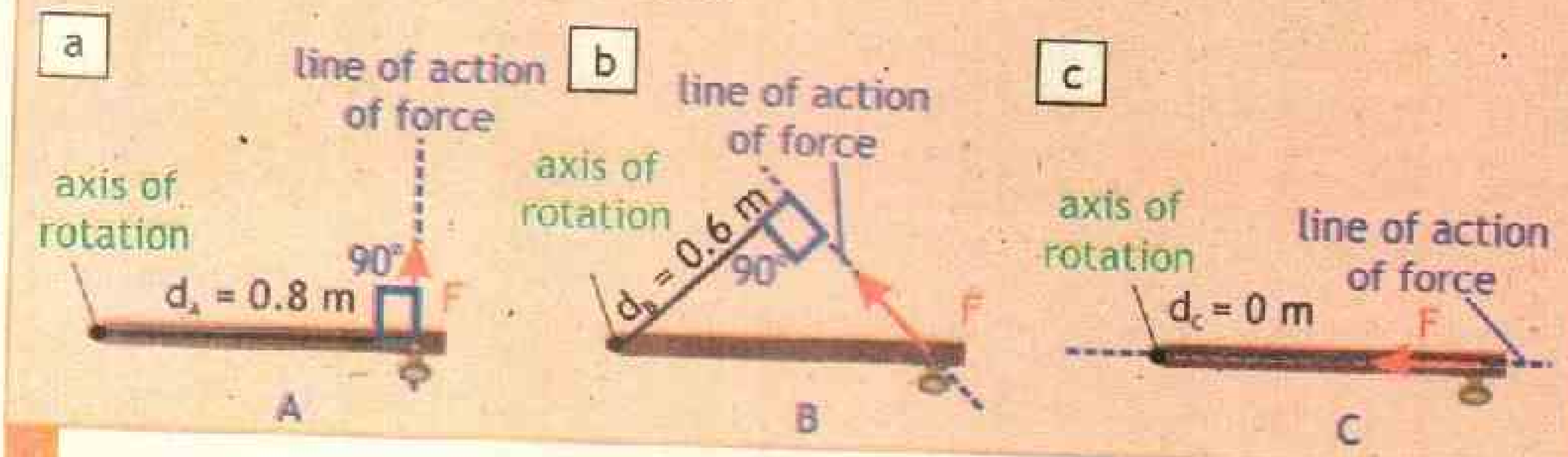
There are two senses of rotation. If the force is capable of rotating the body in clockwise direction, the torque is known as **clockwise torque.**

Similarly, the force is capable of producing rotation in the anti-clockwise direction, the torque is known as **anti-clockwise torque.**

Conventionally, **clockwise torque** is taken as **negative,** whereas **anticlockwise torque is taken as positive.**

Example 4.3 OPENING A DOOR

In Figure a force (magnitude 55 N) is applied to a door. However, the arms are different in the three parts of the drawing: (a) $d_A = 0.80$ m, (b) $d_B = 0.60$ m, and (c) $d_C = 0$ m. Find the torque in each case.



SOLUTION

GIVEN:

Force F = 55 N

Moment arm $d_A = 0.80$ m

Moment arm $d_B = 0.60$ m

Moment arm $d_C = 0.00$ m

REQUIRED:

(a) torque $\tau_A = ?$

(b) torque $\tau_B = ?$

(c) torque $\tau_C = ?$

In each case the lever arm is the perpendicular distance between the axis of rotation and the line of action of the force.

(a) Using the definition of torque, the equation 4.7 can be written as

$$\tau_A = F \times d_A$$

putting values $\tau_A = 55\,N \times 0.80\,m$

therefore $\tau_A = 44\,Nm$ — Answer

(b) Using the definition of torque, the equation 4.7 can be written as

$$\tau_B = F \times d_B$$

putting values $\tau_B = 55\,N \times 0.60\,m$

therefore $\tau_B = 33\,Nm$ — Answer

(c) Using the definition of torque, the equation 4.7 can be written as

$$\tau_C = F \times d_C$$

putting values $\tau_C = 55\,N \times 0.00\,m$

therefore $\tau_C = 0\,Nm$ — Answer

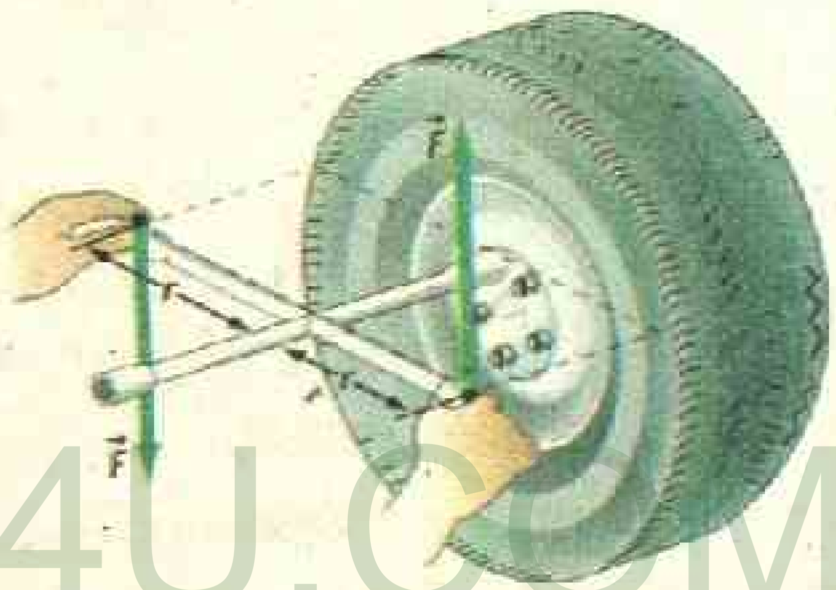
Because the lever arm is different in each case, the torque is different, even though the magnitude of the applied force is the same. In parts a and b the torques are positive, since the forces tend to produce a counter clockwise rotation of the door. In part c the line of action of passes through the axis of rotation (the hinge). Hence, the lever arm is zero, and the torque is zero.

Assignment 4.3 FORCE ON BOTTLE OPENER

20 Nm torque is required to open a soda bottle. A boy with a bottle opener apply a force perpendicularly at 0.1 m, what is the magnitude of force required.

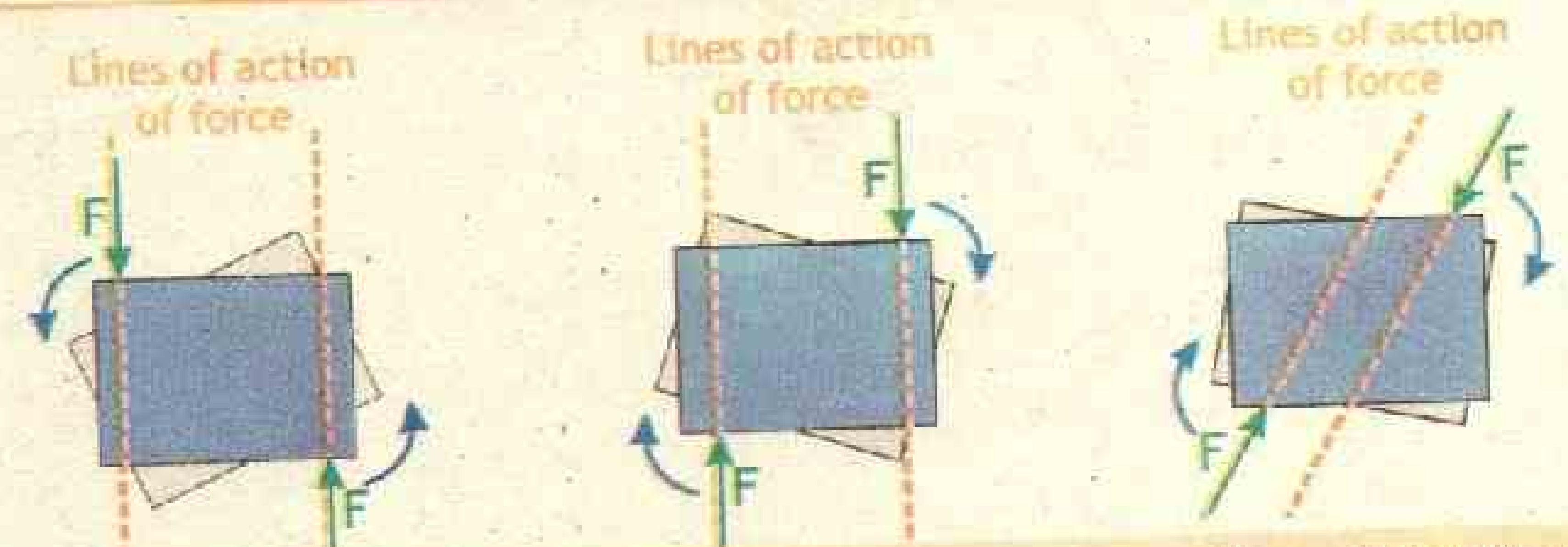
4.6 COUPLE

A special case of moments is a couple. **Two equal and opposite parallel forces acting along different lines on a body constitute a couple.** It does not produce any translation, but only rotation. The resultant force of a couple is zero, but, the resultant of a couple is not zero; it is a pure moment. The shortest distance between two couple forces is called **couple arm.**



Example of couple is shown in the figure, also the forces that two hands apply to turn a steering wheel are often a couple. Each hand grips the wheel at points on opposite sides of the shaft. When they apply a force that is equal in magnitude yet opposite in direction the wheel rotates.

Figure 4.14 Couple Acting On Book



For example apply forces on this physics textbook with your fingers such that the line of action is different. No matter how you apply these forces the book will turn.

Similarly in our day-to-day life, we come across many objects which work on the principle of couple. For example Exerting force on bycycle pedals, winding up the spring of a toy car, opening and closing the cap of a bottle and turning of a water tap etc.

4.7 EQUILIBRIUM

We know that forces tend to cause either translational or rotational motion, depending on the direction and position of the force applied with respect to the centre of mass. Now we turn our attention to one specific effect of an application of force: static equilibrium. To achieve true static equilibrium, two conditions must be met. First, to avoid translation (moving from place to place), the net force directed through the centre of mass of the object must be zero. Second, to avoid rotation, the net torque on the object must also be zero. The study of objects in equilibrium is called STATICS. Equilirium is defined as

"The state of a body in which under the action of several forces acting together there is no change in translational motion as well as rotational motion is called equilibrium".

Therefore for complete equilibrium two conditions must be met.

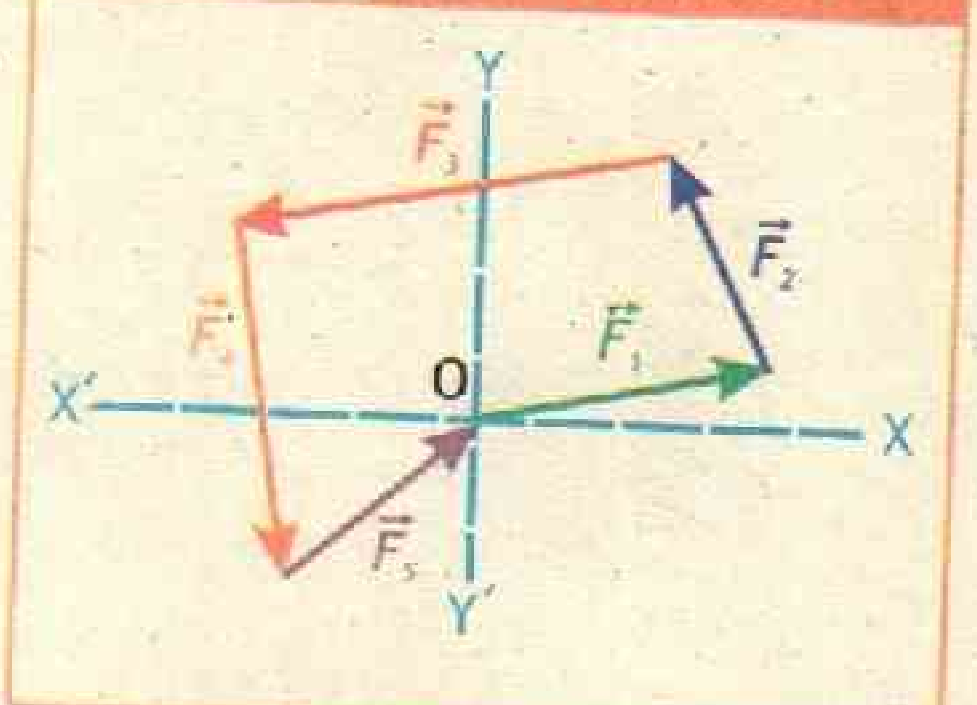
A) First Condition of Equilibrium:

When the vector sum of all the forces acting on the body is ZERO then the first condition of equilibrium is satisfied. Mathematically if $\vec{F}_{net}$ is the sum of forces $\vec{F}_1$, $\vec{F}_2$, $\vec{F}_3$, ... , $\vec{F}_n$ then

$$\vec{F}_{net} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \ldots\ldots + \vec{F}_n = 0$$

or $$\vec{F}_{net} = \sum_{i=1}^{i=n} \vec{F}_i = 0 \qquad (4.8)$$

Figure 4.15 First Condition



For an object to satisfy the first condition of equilibrium the condition is that force polygon must close. Mathematically if $\vec{F}_{net}$ is the sum of forces $\vec{F}_1$, $\vec{F}_2$, $\vec{F}_3$, $\vec{F}_4$ & $\vec{F}_5$ by head to tail rule it must be ZERO as shown in figure 4.15.

B) Second Condition of equilibrium:

When the vector sum of all the Torques acting on the body is ZERO then the second condition of equilibrium is satisfied. If τ_{net} is the sum of torques τ_1, τ_2, τ_3, ..., τ_n then mathematically

$$\vec{\tau}_{net} = \vec{\tau}_1 + \vec{\tau}_2 + \vec{\tau}_3 + ... + \vec{\tau}_n = 0$$

or

$$\vec{\tau}_{net} = \sum_{i=1}^{i=n} \vec{\tau}_i = 0 \qquad (4.9)$$

For complete equilibrium both the first and second conditions of equilibrium must be satisfied. Consider the following example in which a wheel is acted upon by forces.

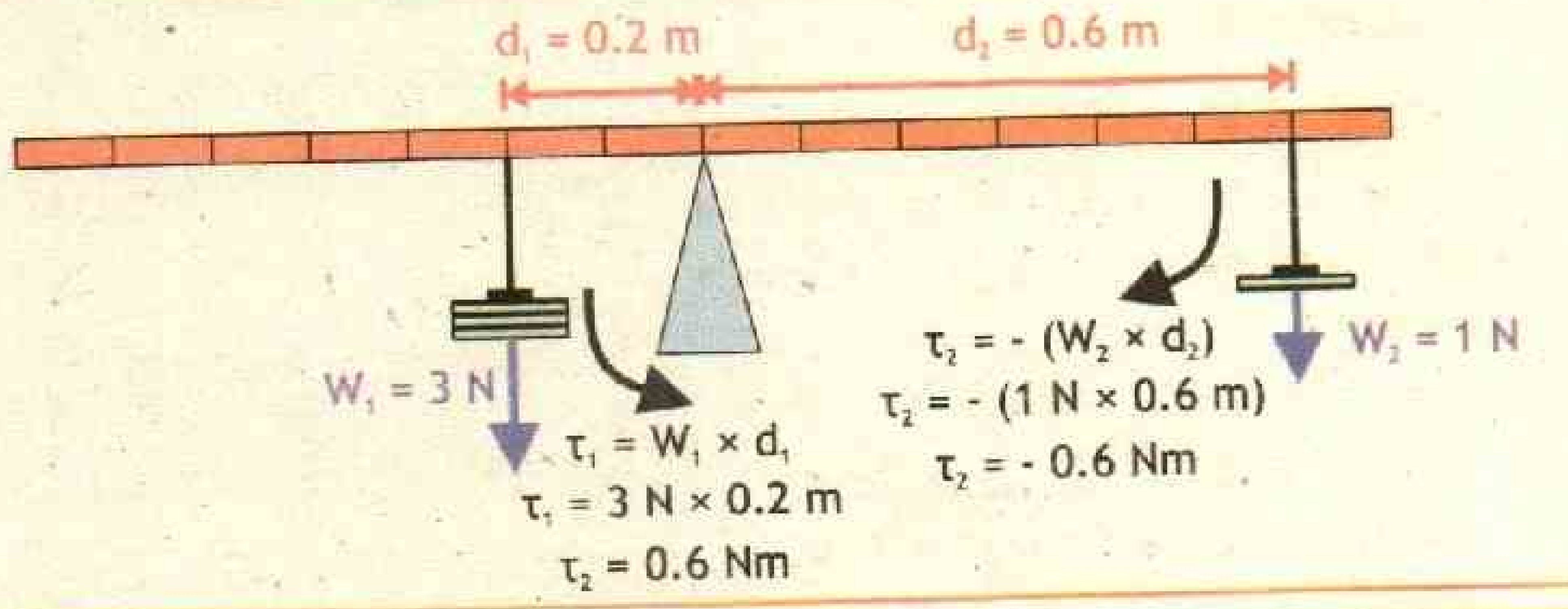
PRINCIPLE OF MOMENTS

Second condition of equilibrium can also be stated as the principle of moments, which states that

'For an object in equilibrium, the sum of the clockwise moments taken about the pivot must be equal to the sum of anti-clockwise moments taken about the same pivot'. To balance torques or moment of force, apart from force the perpendicular distance from the axis of rotation also play the key role.

For example, if we suspend weight of 3 N at 0.2 m from the pivot, it exerts the same torque as 1 N weight at 0.6 m from the fulcrum. A uniform meter stick will balance on pivot under

Figure 4.16 Principal Of Moments

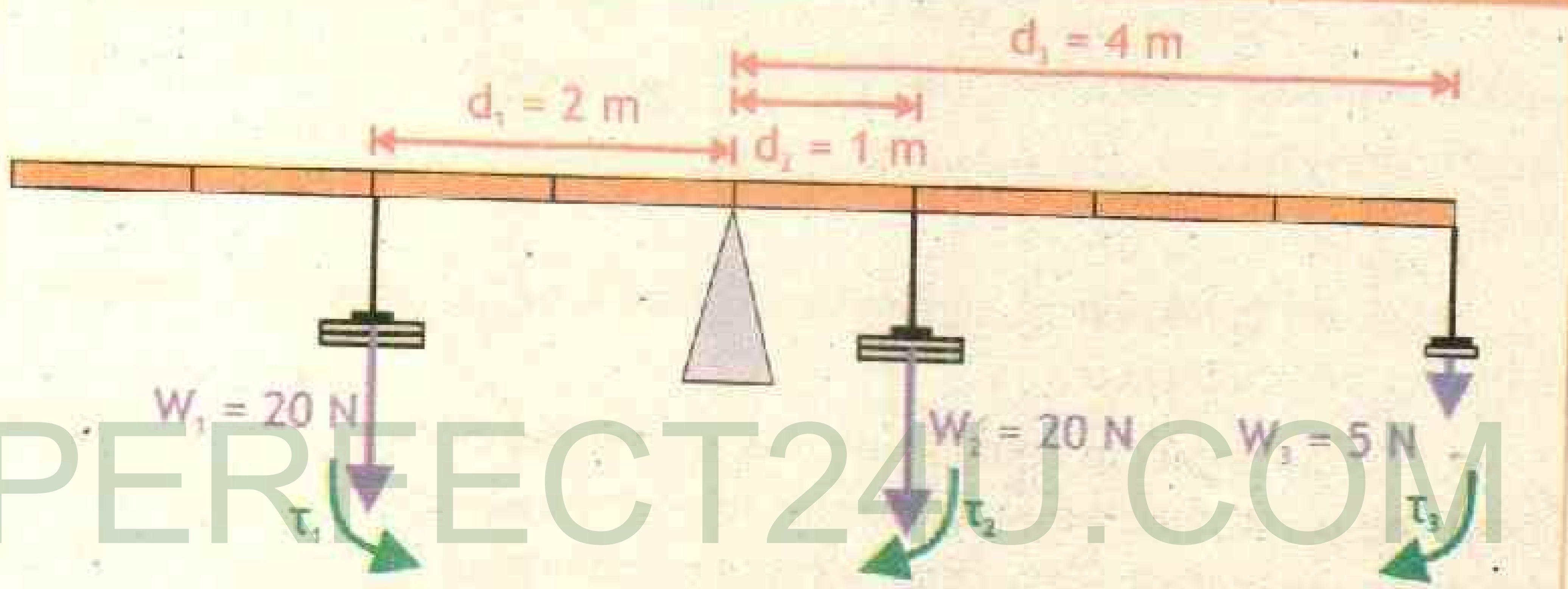


these conditions as shown in the figure 4.16. In the figure 4.16 anticlockwise torques are taken as negative, which leads to second condition of equilibrium that the sum of both these torques must be zero.

$$\tau_2 + \tau_2 = 0.6 \text{ Nm} - 0.6 \text{ Nm}$$
$$\tau_2 + \tau_2 = 0 \text{ Nm}$$

Similarly three or more torques around a pivot (as axis of rotation) can also balance each other. For example in figure 4.17, there is only one anticlock wise moment about the turning point, but two clockwise moments add up to balance it.

Figure 4.17 Principal Of Moments



$\tau_1 = W_1 \times d_1$ | $\tau_2 = -(W_2 \times d_2)$ | $\tau_3 = -(W_3 \times d_3)$

$\tau_1 = 20 \text{ N} \times 2 \text{ m}$ | $\tau_2 = -(20 \text{ N} \times 1 \text{ m})$ | $\tau_3 = -(5 \text{ N} \times 4 \text{ m})$

$\tau_1 = 40 \text{ Nm}$ | $\tau_2 = -20 \text{ Nm}$ | $\tau_3 = -20 \text{ Nm}$

Anticlockwise moment

$$\tau_1 = 40 \text{ Nm}$$

Clockwise moment

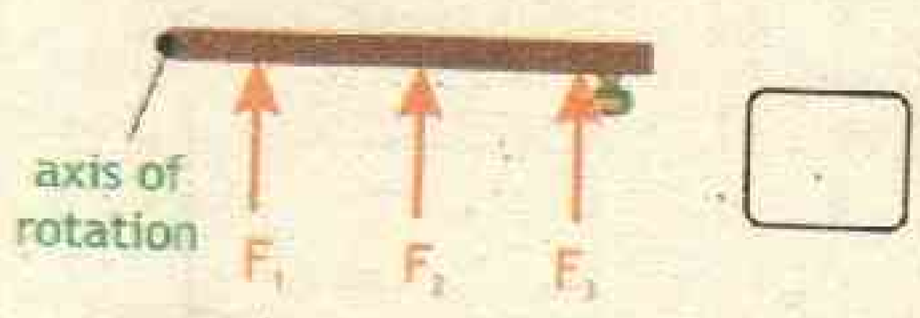
$$\tau_2 + \tau_3 = -20 \text{ Nm} - 20 \text{ Nm} = -40 \text{ Nm}$$

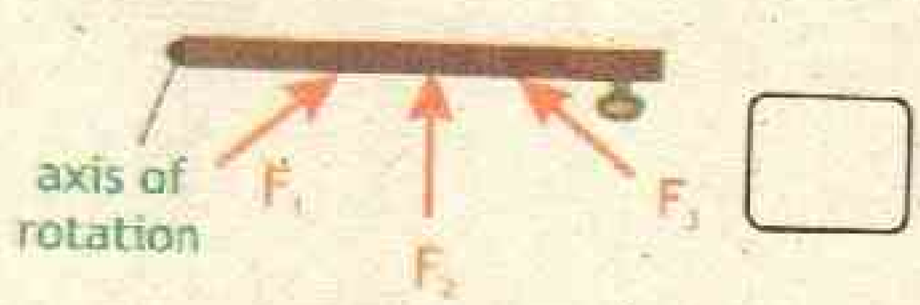
For second condition of equilibrium to be satisfied the sum of all these torques must be zero.

$$\tau_1 + \tau_2 + \tau_3 = 40 \text{ Nm} - 20 \text{ Nm} - 20 \text{ Nm} = 0 \text{ Nm}$$

CONCEPT TEST

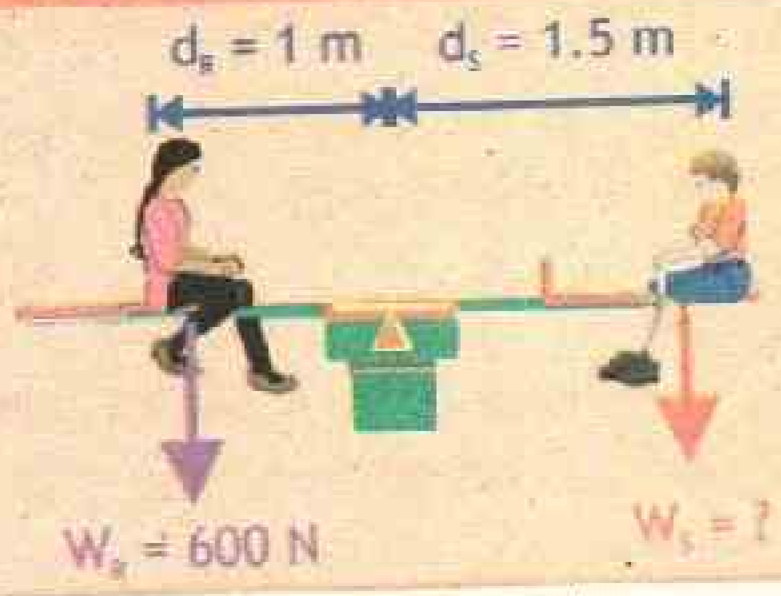
Which force of equal magnitude will produce larger torque?





Example 4.4 SEESAW BALANCE

Two Children Romiasa and Sanaan are sitting on a seesaw. The see-saw is balanced on a pivot as Romiasa is at 1 m and Sanaan at 1.5 m from the pivot (as shown in figure). If Romiasa weight is 600 N, what is the weight of Sanaan?



SOLUTION

GIVEN:

Romaisa's Weight W_R = 600 N

Romaisa's Moment arm = d_R = 1 m

Sanaan's Moment arm = d_S = 1.5 m

REQUIRED:

Sanaan's Weight W_S = ?

Here Romaisa is producing anticlockwise torque, while Sanaan is producing clockwise torque, Therefor by second condition of equilibrium

$$\tau_R - \tau_S = 0$$

As the see-saw is balanced, therefore we can write second condition of equilibrium as principle of moments 'The Sum of the clockwise moments = sum of the anticlockwise moments

$$\tau_R = \tau_S$$

or $$W_R d_R = W_S d_S$$

dividing both sides by d_S $$W_S = \frac{W_R d_R}{d_S}$$

putting values $$W_S = \frac{600\,N \times 1m}{1.5}$$

therefore $$W_S = 400\,N$$ Answer

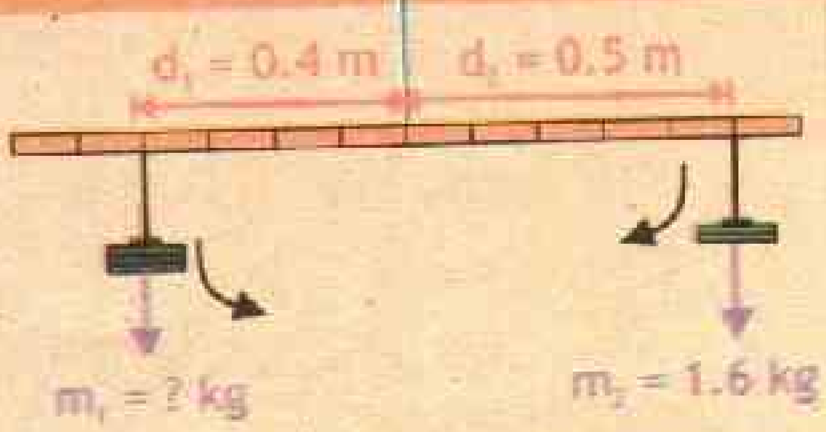
Hence the weight of Sanaan is 400 N.

EXTENSION EXERCISE 4.2

Find the mass of Sanaan and Romaisa.

Assignment 4.4 CALCULATING MASSES

With a beam two masses m_1 and m_2 are suspended at distance 0.4 m and 0.5 m respectively from suspension point as shown in the figure. Ignoring the weight of the balance, if m_2 = 1.6 kg, what is the mass m_1?



Types of Equilibrium:

The effect of force is to produce change in translational motion and effect of torque is to produce change in rotational motion. Thus the equilibrium is divided into two types.

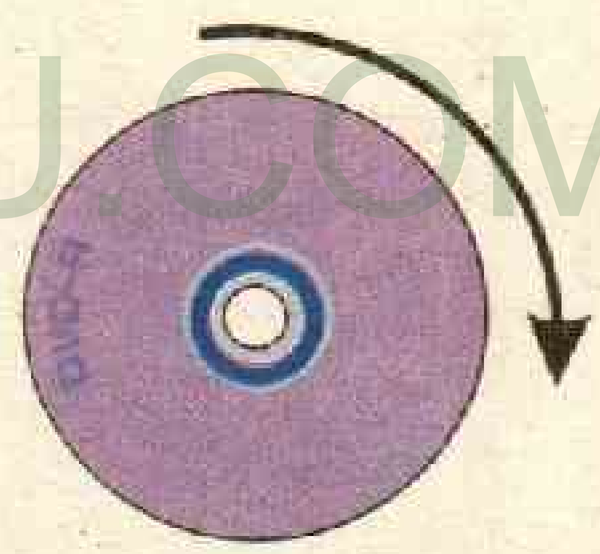
A) Static equilibrium:

When a body is at rest under the action of several forces acting together and several torques acting the body is said to be in static equilibrium. For example a book resting on the table is in static equilibrium, the weight mg of the book is balanced by a normal reaction force from the table surface.

B) Dynamic equilibrium:

When a body is moving at uniform velocity under the action of several forces acting together the body is said to be in dynamic equilibrium. It is further divided in to two types as shown in figure 4.18.

Figure 4.18 Types Of Dynamic Equilibrium



I) Dynamic Translational Equilibrium:

When a body is moving with uniform linear velocity the body is said to be in dynamic translational equilibrium. For example a paratrooper falling down with constant velocity is in dynamic translational equilibrium

II) Dynamic Rotational Equilibrium:

When a body is moving with uniform rotation the body is said to be in dynamic rotational equilibrium. For example a compact disk (CD) rotating in CD Player with constant angular velocity is in dynamic rotational equilibrium.

LAB WORK

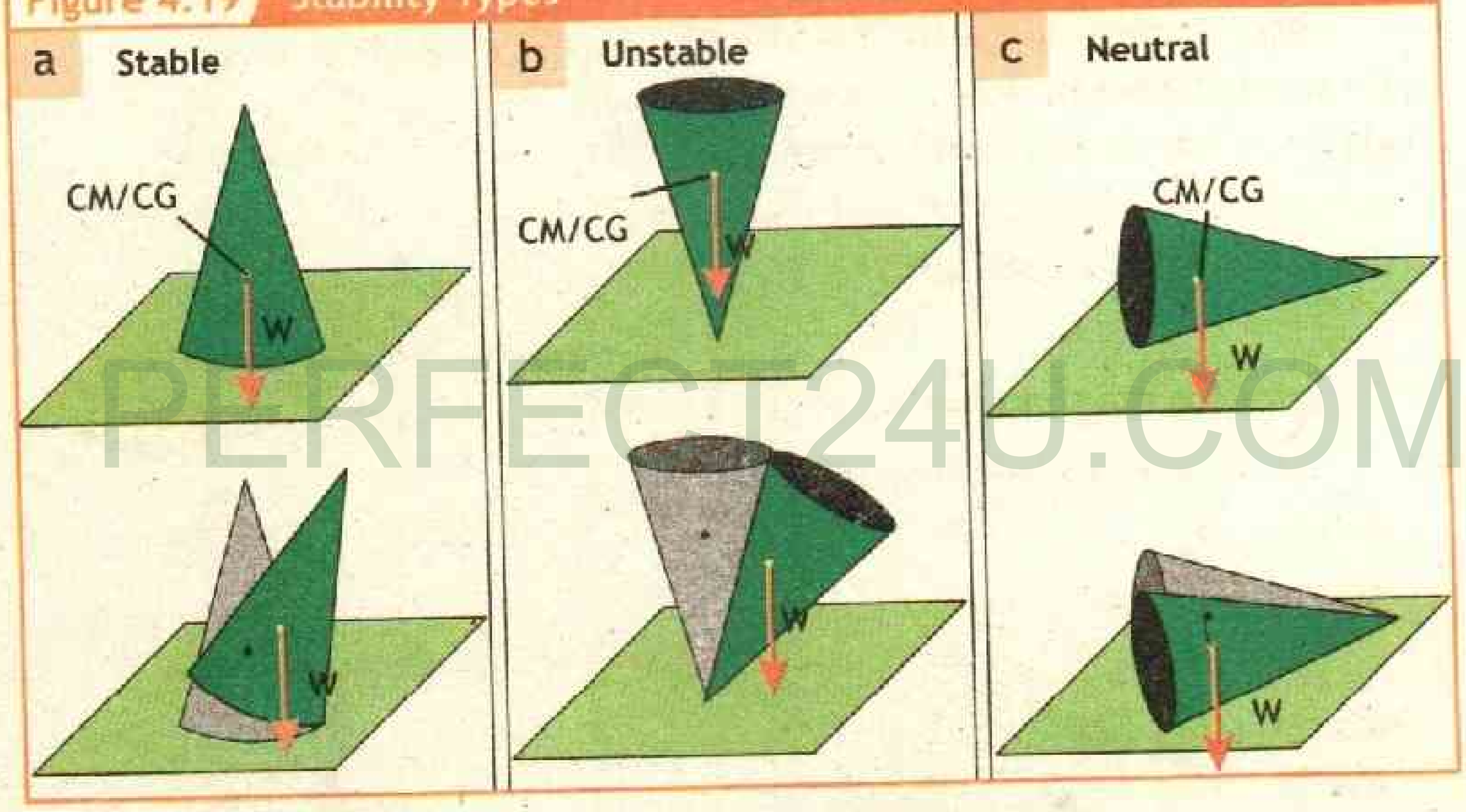
- To verify the principle of moments by using a metre rod balanced on a wedge.
- To find the weight of an unknown object by using principle of moments.

4.8 STABILITY

Stability is a measure of how hard it is to displace an object or system from EQUILIBRIUM. The conditions of equilibrium does not specify whether an object is stable or not. The stable object does not topple easily. The position of the centre of mass of a body affects whether or not it topples over easily. This is important in the design of such things as tall vehicles (which tend to overturn when rounding a corner), racing cars, reading lamps and even drinking glasses.

Three cases are studied in statics. They differ in the effect on the center of mass of a small displacement.

Figure 4.19 Stability Types



a) Stable equilibrium:

A body is in stable equilibrium if when slightly displaced and then released it returns to its previous position. As an example the cone in position a is stable as shown in figure 4.19 a. Its centre of mass rises when it is displaced. It regain its position back because its weight has a moment about the point of contact that acts to reduce the displacement.

b) Unstable equilibrium:

A body is in unstable equilibrium if it moves further away from its previous position when slightly displaced and released. As an example the cone in position b is unstable as shown in figure 4.19 b.

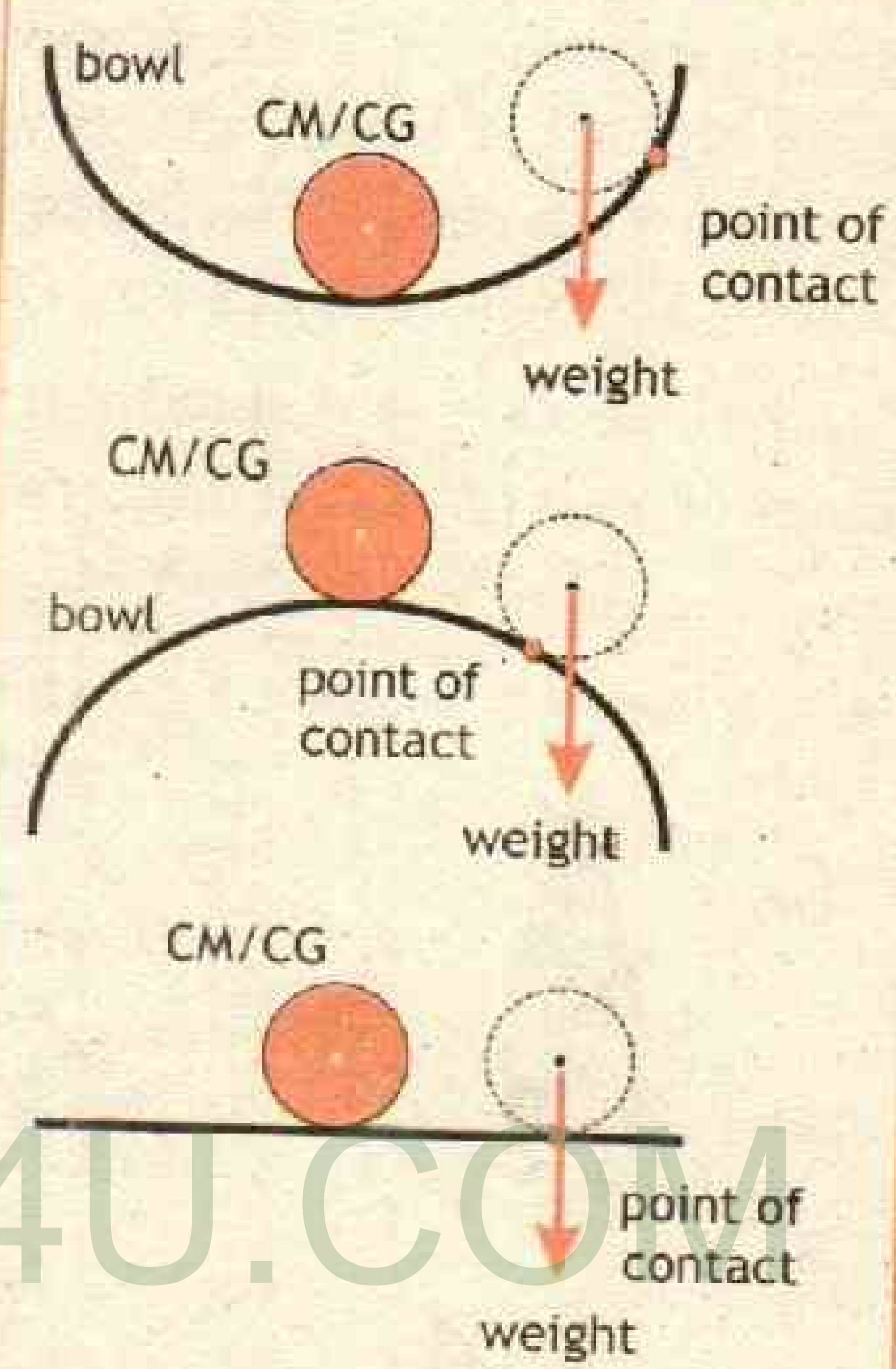
Its centre of mass falls when it is displaced, because there is a moment which increases the displacement.

c) Neutral equilibrium:

A body is in neutral equilibrium if it stays in its new position when displaced. As an example the cone in position B is neutral as shown in figure 4.19 c. Its centre of mass does not rise or fall because there is no moment to increase or decrease the displacement.

Similar demonstration for three cases of stability can be done by displacing a ball in a round bowl, as shown in figure 4.20. In each case tink about what will happen when the ball is displaced slightly?

Figure 4.20 Stability



An object's stability is improved by:

(a) lowering the center of mass; or

(b) increasing the area of support; or

(c) by both.

INTERESTING INFORMATION

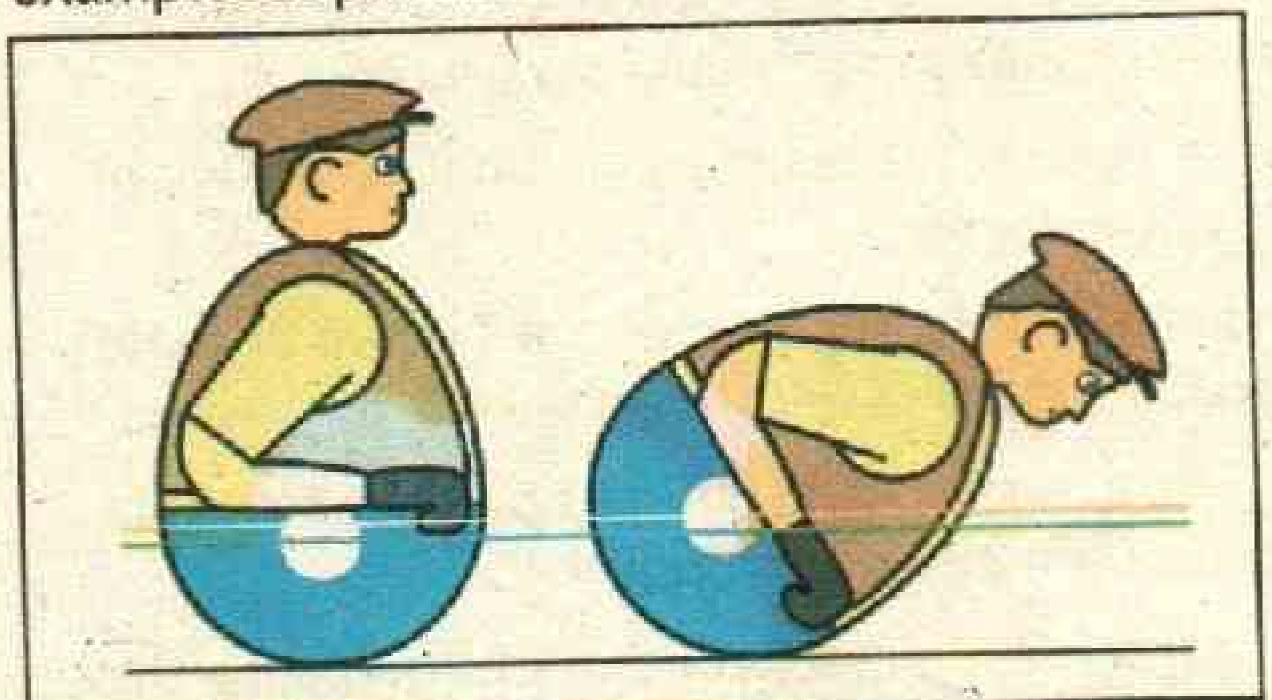
The CG/CM of race cars is kept low and tyres wide to decrease the chances for overturning of the car.

INTERESTING INFORMATION

The base of long glass and reading lamps is made heavy to lower CG/CM and large to increase area of support and thus to increase stability.

Equilibrium is stable as long as the vertical line from the centre of mass remains inside the area of the base of the body. If a disruption moves the vertical line from the centre of mass outside of the base, then the equilibrium is unstable. Neutral equilibrium exists when any disruptive force acts horizontally but the vertical height of the centre of mass remains unchanged. Taller people are generally less stable than shorter people because their higher centre of mass can be more easily pushed outside base of the structure, sometimes called the footprint. Some toys are more stable, then they look as they right by themselves if they are disturbed.

By making centre of mass vertically below the point of support makes state of the object a stable equilibrium. This mechanism is employed in various toys and equipments that restore themselves up when disturbed, few examples as pictures are shown.



TID-BITS

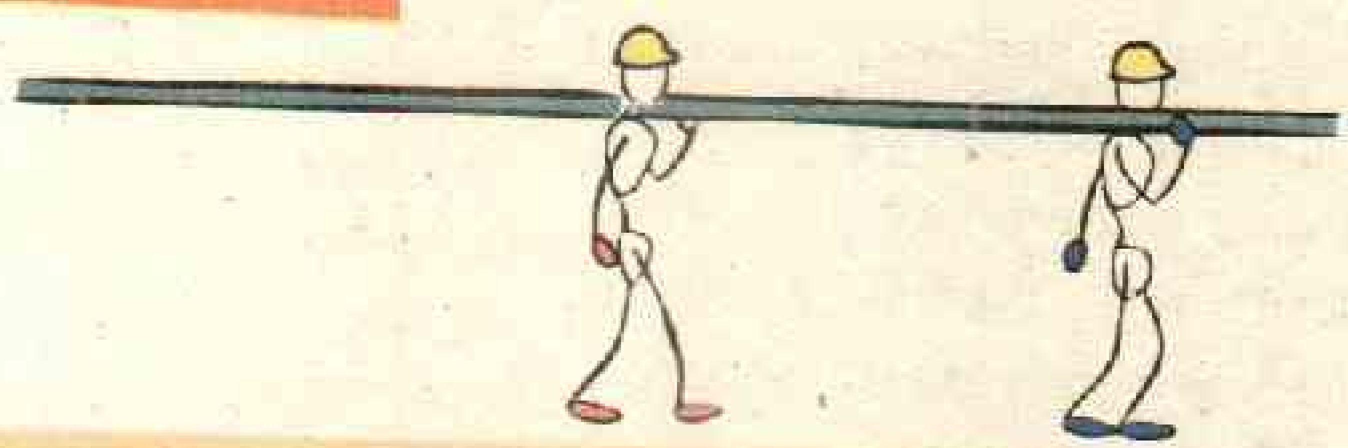
To stay balanced while walking the tightrope, this acrobat must keep her center of mass directly above the rope. If the center of mass shifts to one side, gravity will exert a torque on the acrobat, tending to cause a rotation about the rope and she will fall.

To stay balanced, the acrobat must create a counter-torque having equal magnitude and opposite sign. That is why tightrope walkers carry a long pole. Because the torque due to a force is the product of the magnitude of the force and the moment arm, the gravitational forces on the ends of the pole exert significant torques. Thus, the acrobat controls the net torque acting on her center of gravity by manipulating the pole. Also, the acrobat holds the pole low, moving her center of gravity closer to the rope.

ACTIVITY 4.1 RIDE A BUS

This is an experiment to perform while standing in a bus or a train. Stand facing sideways. How do you move your body to readjust the distribution of your mass as the bus accelerates and decelerates? Now stand facing forward. How do you move your body to readjust the distribution of your mass as the bus accelerates and decelerates? Why is it easier and safer to stand facing sideways rather than forward? Note: For your safety (and those around you), make sure you are holding onto something while you carry out this activity!

POINT TO PONDER



Two workers are carrying a long, heavy steel beam (Fig). Which one is exerting a larger force on the object? How can you tell?

KEY POINTS

Parallel Forces: The directions of forces are parallel to each other if they are in opposite direction, those forces are called parallel forces. If they are of same direction then they are called "like parallel forces" and if they are in the opposite direction they will be known as "Unlike parallel forces.

Addition of Vectors: Addition of vectors means the combination of two or more than two vectors to get a single vector.

Resolution of Vector: The process of splitting one vector by two or more than two vector components are called the resolution of vector.

Moment of a force or Torque: The measure of an object tendency to rotate about some point O is called torque or moment of force.

Moment of a force = force × perpendicular distance of the force to the pivot point.

The SI unit of the moment of a force is Nm.

Principle of moments: The principle of moments states that for an object in equilibrium, the sum of the clockwise moments taken about the pivot must be equal to the sum of the anti-clockwise moments taken about the same pivot.

KEY POINTS

Center of Mass: The center of mass of the body is the point about which mass is equally distributed in all directions.

Centre of Gravity: The centre of gravity is defined as a single point where the whole weight of an object appears to act.

Couple: A couple consists of two forces that are equal in magnitude, but opposite in direction.

Equilibrium: When a number of forces are simultaneously acting on a body and the body does not change its state of rest or of uniform motion, then the body is said to be in a state of equilibrium.

Stability: The stability of an object refers to the ability of the object to return to its original position when the force that changed its orientation is removed.

PROJECTS

GROUP - A

AUTOMOBILE ENGINES: Automobile engines are rated by the torque that they produce. Research and explain why torque is an important quantity to measure for automobile.

GROUP - B

BICYCLES TORQUES: Research different types of bicycles, describe exactly which measurements you would need to make in order to identify the torques at work during a ride on a specific bicycle. Suggest a considerations torque efficient design of bicycle ride. If possible design and construct a torque efficient bicycle model.

GROUP - C

SIMPLE MACHINES: Write a publication essay for school library on simple machines and explain how these machines use the principle of moments. Make a chart for display in the school laboratory.

GROUP - D

SELF RESTORE MECHANISM: Research different self restore mechanisms to design and build a toy from (e.g. trash toys in your home) that restore itself after it is displaced

GROUP - E

SEE SAW AS WEIGHING MACHINE: Make a see saw as weighing device from plank (wooden or any easily available thing) and discuss its limitations and donate it to the physics lab.

EXERCISE

MULTIPLE CHOICE QUESTIONS

1. Conventionally anti clock wise torque is taken as ________
   A. Negative B. positive C. parallel D. zero
2. A door requires a minimum torque of 80 Nm in order to open it. What is the minimum distance of the handle from the hinges, if the door is to be pulled with a force at the handle not greater than 100N?
   A. 0.6 m B. 1m C. 0.4 m D. 0.8 m
3. Two children are balanced on opposite sides of a seesaw. If one child leans inward toward the pivot point, her side will
   A. rise B. fall
   C. insufficient data D. neither rise nor fall
4. A body in equilibrium must not be
   A. at rest B. moving C. rotating D. accelerating
5. The torque in uniformly rotating fan having blade of length 0.5 m is
   A. 0.5 Nm B. 2 Nm C. - 0.5 Nm D. 0 Nm
6. A force of 100 N is applied perpendicularly at 0.5 m, to turn nut of wheel of a bus. The torque acting on nut is
   A. 500 Nm B. 50 Nm C. 5 Nm D. 0.005 Nm
7. The shortest distance between two couple forces is
   A. moment arm B. couple arm
   C. radius D. double moment
8. A girl pushes to open a door perpendicularly with a force of 25 N at 0.6 m from the hinge, the torque is
   A. 41.6 Nm B. 25.6 Nm C. 15 Nm D. 0 Nm
9. The angle at which x and y components of force are equal is
   A. 0° B. 30° C. 45° D. 60°
10. CM is different from CG, When we have nonuniform
    A. shape of object B. mass of object
    C. gravitational force D. none of these

CONCEPTUAL QUESTIONS

Give a brief response to the following questions.

1. Can the rectangular component of the vector be greater than the vector itself? Explain.
2. Explain why door handles are not put near hinges?
3. Can a small force ever exert a greater torque than a larger force? Explain.
4. Why it is better to use a long spanner rather than a short one to loosen a rusty nut ?
5. The gravitational force acting on a satellite is always directed towards the centre of the earth. Does this force exert torque on satellite?
6. Can we have situations in which an object is not in equilibrium, even though the net force on it is zero? Give two examples.
7. Why do tightrope walkers carry a long, narrow rod?
8. Why does wearing high-heeled shoes sometimes cause lower back pain?
9. Why is it more difficult to lean backwards. Explain?
10. Can a single force applied to a body change both its translational and rotational motion? Explain.
11. Two forces produce the same torque. Does it follow that they have the same magnitude? Explain.e. Describe the path of the brick after you suddenly let go of the rope.

COMPREHENSIVE QUESTIONS

Give an extended response to the following questions.

1. What are force diagrams? Define like and unlike parallel forces with example.
2. Explain the addition of forces, in connection with head to tail rule.
3. Define moment of a force. Give its mathematical description and elaborate the factors on which it depends?
4. What is resolution of forces? Explain with an example how forces can be resolved into rectangular components.
5. What is couple? explain with examples.

6. Define equilibrium. Explain its types and state the two conditions of equilibrium.
7. State and explain principle of moments with examples.
8. What is center of mass or center of garvity. Explain how CM/CG can be determined? Is there any difference between CM and CG?
9. Explain the stability of the objects with reference to position of center of mass.

NUMERICAL QUESTIONS

1. To open a door force of 15 N is applied at 30° to the horizontal, find the horizontal and vertical components of force.
2. A bolt on a car engine needs to be tightened with a torque of 40 Nm. You use a 25-cm-long wrench and pull on the end of the wrench perpendicularly. How much force do you have to exert?
3. Sana, whose mass is 43 kg, sits 1.8 m from the center of a seesaw. Faiz, whose mass is 52 kg, wants to balance Sana. How far from the center of the seesaw should Faiz sit?
4. Two kids of weighing 300 N and 350 N are sitting at the ends of 6 m long see-saw. The seesaw is pivoted at its centre. Where would a third kid sit so that the see-saw is in equilibrium in the horizontal position? The weight of third kid is 250 N. (Ignore the weight of see-saw)
5. Two children push on opposite sides of a door during play. Both push horizontally and perpendicular to the door. One child pushes with a force of 20 N at a distance of 0.60 m from the hinges, and the second child pushes at a distance of 0.50 m. What force must the second child exert to keep the door from moving? Assume friction is negligible.
6. A construction crane lifts building material of mass 1500 kg by moving its crane arm, calculate moment of force when moment arm is 20 m. After lifting the crane arm, which reduces moment arm to 12 m calculate moment.

WEB LINKS

http://www.learneasy.info/MDME/MEMmods/MEM30005A/add_forces/add_forces.html
https://courses.lumenlearning.com/boundless-physics/chapter/center-of-mass/
http://www.cyberphysics.co.uk/topics/forces/stability.htm

Unit 5 GRAVITATION

CHECK LIST

After studying this unit you should be able to:

- ✓ state Newton's law of gravitation.
- ✓ explain that the gravitational forces are consistent with Newton's third law.
- ✓ explain gravitational field as an example of field of force.
- ✓ define weight (as the force on an object due to a gravitational field.)
- ✓ calculate the mass of earth by using law of gravitation.
- ✓ solve problems using Newton's law of gravitation.
- ✓ explain that value of 'g' decreases with altitude from the surface of earth.
- ✓ discuss the importance of Newton's law of gravitation in understanding the
- ✓ motion of satellites.

The study of gravity has always been a central theme in physics, from Galileo's early experiments on free fall in the seventeenth century to Stephen Hawking's work on black holes in recent years. Perhaps the grandest milestone in this endeavor, was the discovery by Newton of the law for gravitation.

Our Milky Way galaxy is a disk-shaped collection of gas, dust, and billions of stars, including our Sun and solar system. Image shows how our galaxy would look if we could view it from outside. Earth is near the edge of the disk of the galaxy, about 26,000 light-years (2.5×10^{20} m) from its central bulge. Our galaxy is a member of the Local Group of galaxies, which includes the Andromeda galaxy at a distance of 2.5×10^{6} light-years.

The force that binds together these progressively larger structures, from moon all the way to galaxy clusters is known as the gravitational force. Gravity is action-at-a-distance force which acts even when the interacting objects are not in physical contact. This force not only holds us on Earth but also reaches out across intergalactic space and acts between galaxies. This force is our focus in this unit.

5.1 LAW OF UNIVERSAL GRAVITATION

Newton expressed the force of attraction between different bodies in the universe in the form of a law known as the law of universal gravitation; which is stated as follows

'Every body in the universe attracts every other body with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centres'.

Consider two spherical bodies of masses 'm_1' and 'm_2' separated by distance 'r' as shown in figure 5.1.

By definition of Newton's law of universal gravitation, the force of gravity F_g is

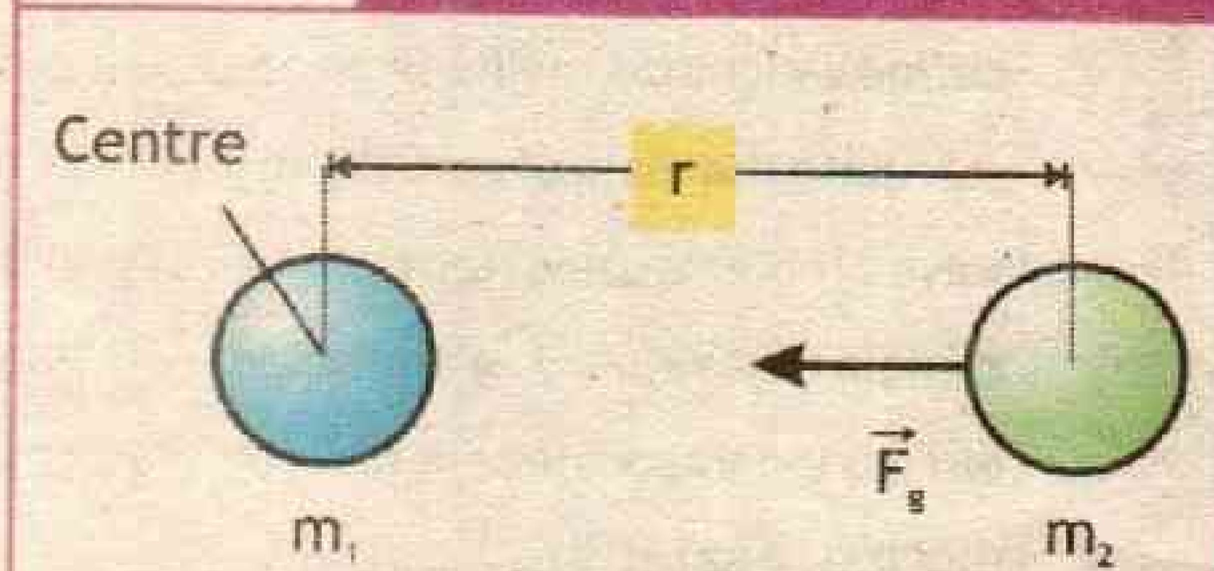
$$F_g \propto m_1 \times m_2 \quad \text{——— (1)}$$

and $$F_g \propto \frac{1}{r^2} \quad \text{——— (2)}$$

combining equation 1 and equation 2 we get

$$F_g \propto \frac{m_1 m_2}{r^2}$$

Figure 5.1 UNIVERSAL GRAVITATION

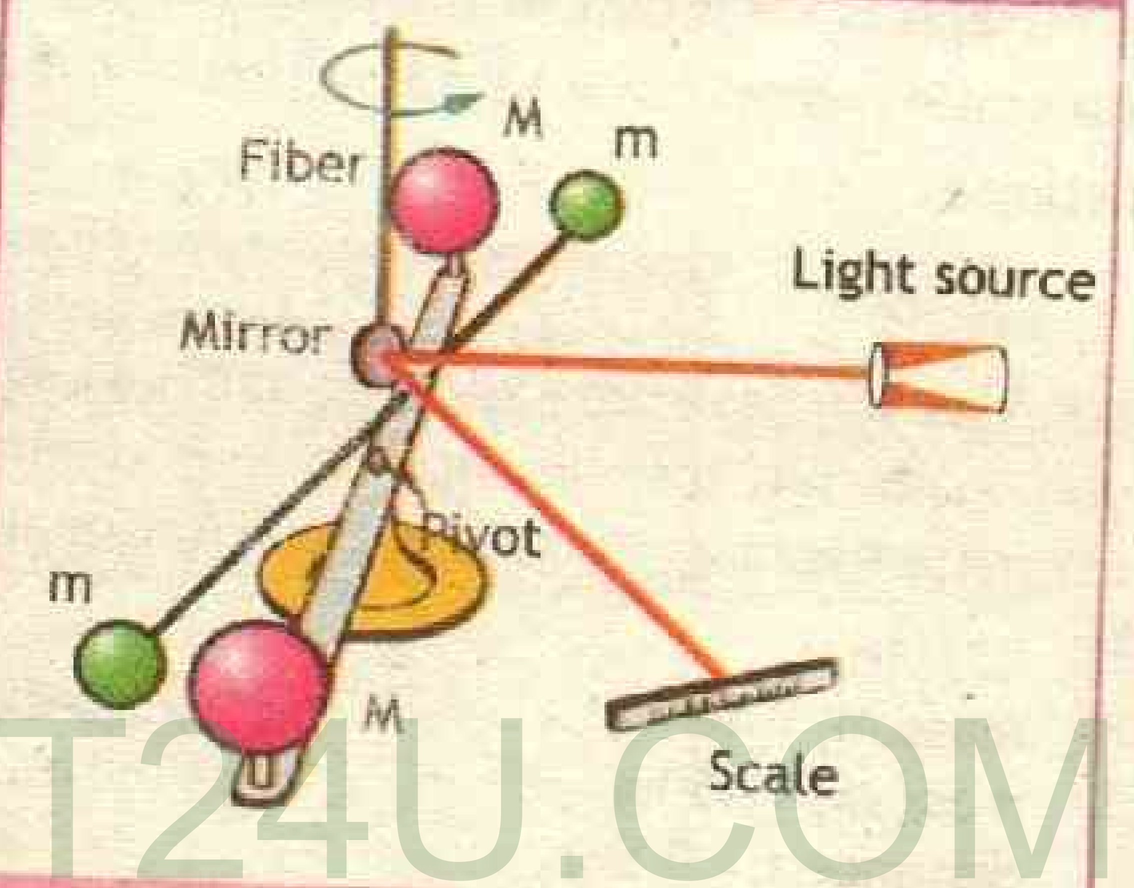


To change sign of proportionality into equality a constant is included

$$F_g = G\frac{m_1 m_2}{r^2} \quad \text{—— 5.1}$$

Where G is constant of proportionality and is known as gravitational constant. The value of gravitational constant (as determine by experiment) G = 6.67×10^{-11} $Nm^2 kg^{-2}$. It does not depend on the medium (vacuum, air, water, concrete etc.) between the two bodies. The above formula is a mathematical expression of Newton's law of universal gravitation.

Figure 5.2 TORSION BALANCE



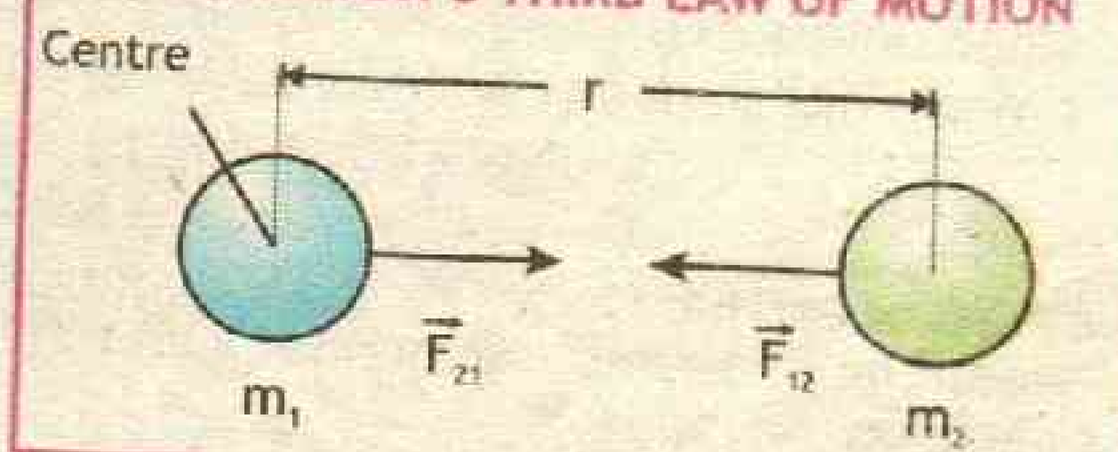
Cavendish used an apparatus like this to measure the gravitational attraction between the two suspended spheres (m) and the two on the stand (M) by observing the amount of torsion (twisting) created in the fiber. Distance between the masses can be varied to check the dependence of the force on distance. Modern experiments of this type continue to explore gravity.

Newton's Third Law of Motion and Universal Gravitation:

We can see that the force acting on mass m_2 due to mass m_1 is F_{12}. Also the force acting on mass m_1 due to mass m_2 is same force F_{21} both these forces are equal but opposite in direction. Therefore, we can say that the forces acting on two bodies due to gravitation force is the example of action and reaction forces.

$$\vec{F}_{12} = -\vec{F}_{12} \quad \text{—— 5.2}$$

Figure 5.3 UNIVERSAL GRAVITATION AND NEWTON'S THIRD LAW OF MOTION

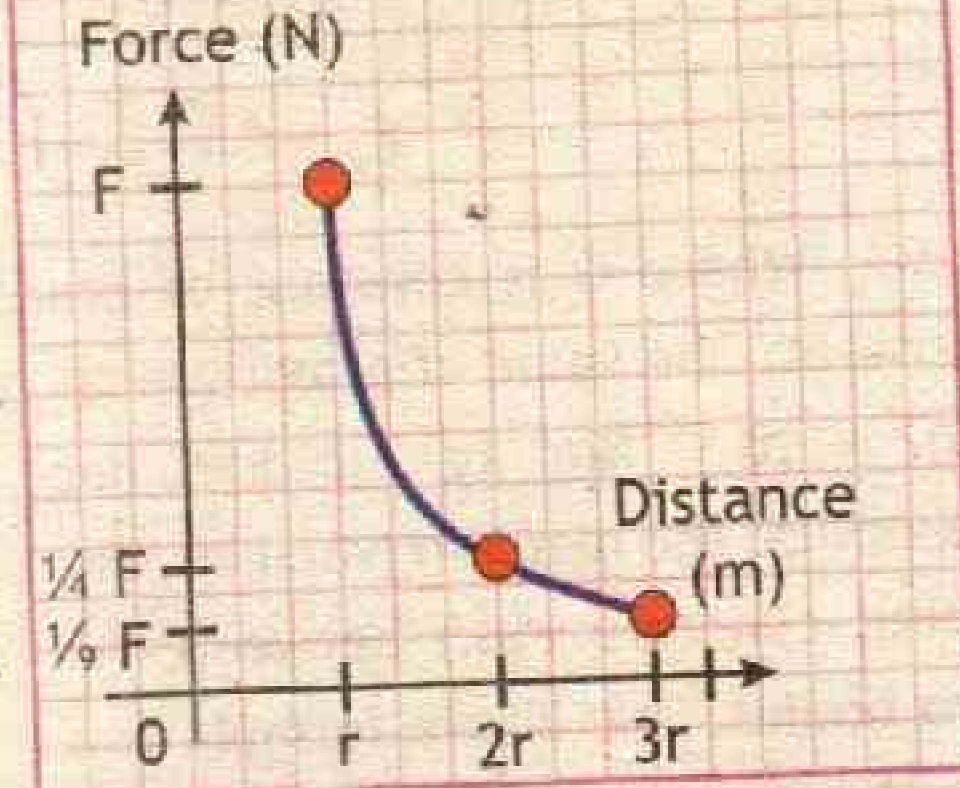


For example, Earth pulls on the Moon and the Moon pulls on Earth with a force of equal magnitude. At Earth's surface, Earth pulls down on a 1.0 kg mass with a force of magnitude 9.8 N, and the

1.0 kg mass pulls upward on Earth with a force of magnitude 9.8 N.

The gravitational force is an inverse-square force: it decreases by a factor of 4 when the distance increases by a factor of 2, it decreases by a factor of 9 when the distance increases by a factor of 3, and so on. Graph 5.1 is a plot of the magnitude of the gravitational force as a function of the distance.

Graph 5.1



Example 5.1 CAN YOU ATTRACT ANOTHER PERSON GRAVITATIONALLY

Suppose you have mass of 40 kg and a 45 kg person is sitting on a bench close to you, such that the distance between centers of you and the person is 0.5 m. Estimate the magnitude of the gravitational force you exert on that person.

SOLUTION

GIVEN:
mass m_1 = 40 kg
mass m_2 = 45 kg
distance r = 0.5 m
Gravitational Constant G = 6.673×10^{-11} Nm^2kg^{-2}

REQUIRED:
Gravitational force F_g = ?

By Newton's law of universal gravitation

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

putting values

$$F_g = 6.67 \times 10^{-11}\ Nm^2kg^{-2}\ \frac{40\,kg \times 45\,kg}{(0.5\,m)^2}$$

or

$$F_g = 6.67 \times 10^{-11}\ \frac{Nm^2}{kg^2}\ \frac{1800\,kg^2}{0.25\,m^2}$$

therefore

$$F_g = 4.8 \times 10^{-7}\ N$$ — Answer

This means we attract each other but a force of about 10^{-7} N is unnoticeably small unless extremely sensitive instruments are used. Even very large scale objects like ships and building have very small gravitational attraction.

Assignment 5.1 GRAVITATIONAL FORCE ON MOON

The mass of earth is 6×10^{24} kg and that of the moon is 7.4×10^{22} kg. If the distance between the earth and the moon is 3.84×10^5 km, calculate the force exerted by the earth on the moon.

INFORMATION

Light from distant stars and galaxies takes so long to reach us that we are actually seeing these objects as they appeared in the past. As we look up at the sky, we are really looking back in time. For example, the Sun's light takes almost 8.5 minutes to travel to Earth, so we see the Sun as it looked 8.5 minutes ago. The nearest star to us, Proxima Centauri, is 4.2 light-years away, so it appears as it was 4.2 years ago. The nearest galaxy is 2.5 million light-years away, and it looks as it did when our australopithecus hominid ancestors walked the planet. The farther away something is, the further back in time it appears.

5.2 MASS OF EARTH

The determination of gravitational constant helped scientists to calculate the mass of earth, sun and other celestial objects.

Let an object of mass 'm_0' be placed on the surface of the Earth. The distance between the center of the body and the earth is (nearly) equal to the radius of earth 'r_E'. If the mass of earth is 'm_E' then the force F_g with which the earth attracts the body towards its centre is given by law of gravitation.

$$F_g = G\frac{m_0 m_E}{r_E^2} \quad (1)$$

We know that the force of gravity is equal to the weight of the body.

$$F_g = W = m_0 g \quad (2)$$

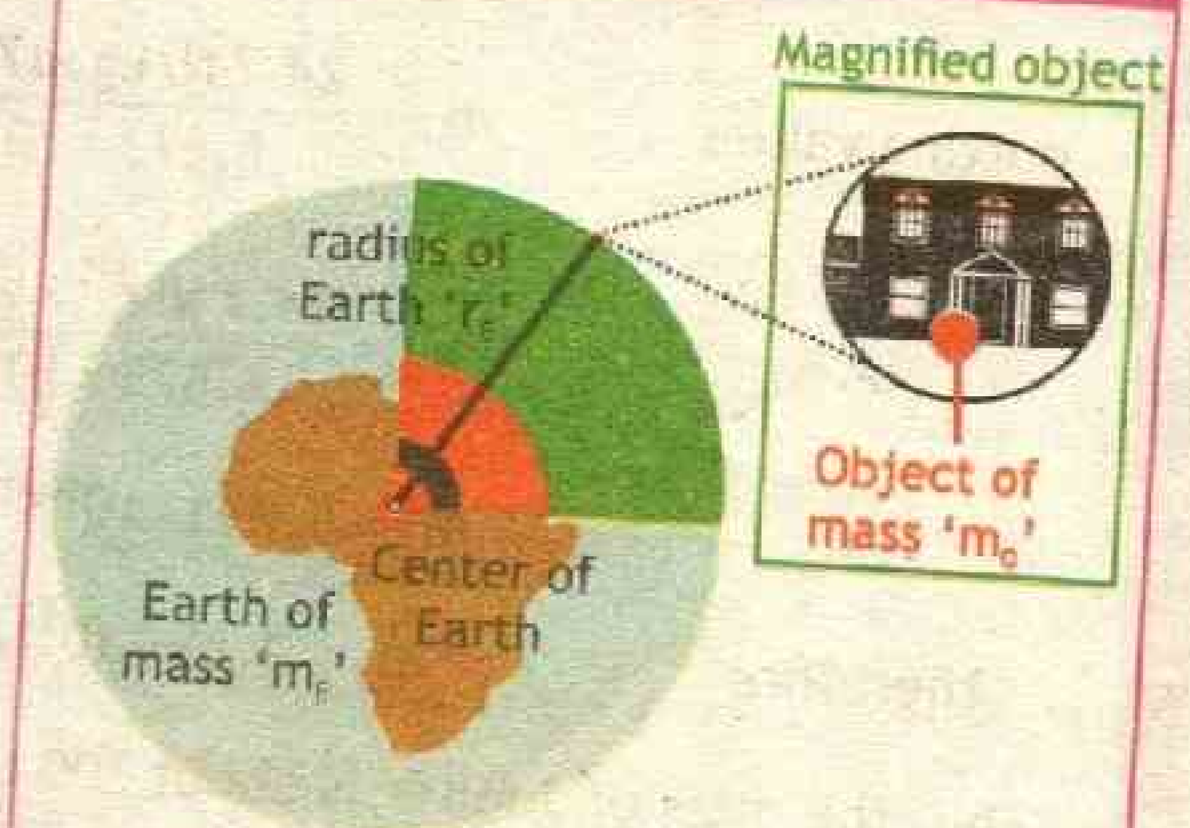
comparing equation 1 and equation 2 we get

$$m_0 g = G\frac{m_0 m_E}{r_E^2}$$

or $$g = G\frac{m_E}{r_E^2}$$

re-arranging $$m_E = \frac{g r_E^2}{G} \quad (5.3)$$

Figure 5.4 MASS OF EARTH



Since Gravitational Constant $G = 6.673 \times 10^{-11}\ Nm^2kg^{-2}$ for earth we have acceleration due to gravity $g = 9.8\ ms^{-2}$ ($9.8\ Nkg^{-1}$) and radius of Earth $r_E = 6.4 \times 10^6$ m. Putting these values in equation 5.3 we get

$$m_E = \frac{9.8\,Nkg^{-1}(6.4\times10^6\ m)^2}{6.67\times10^{-11}\ Nm^2\ kg^{-2}}$$

or $$m_E = \frac{9.8\,Nkg^{-1}\times4.1\times10^{13}\ m^2}{6.67\times10^{-11}\ Nm^2\ kg^{-2}}$$

therefore $$m_E = 6\times10^{24}\ kg$$

TIP $Nkg^{-1} = ms^{-2}$

Since $N = kg\ ms^{-2}$

Dividing both sides by kg

$N/kg = ms^{-2}$

or $N\ kg^{-1} = ms^{-2}$

Thus the mass of earth is approximately 6×10^{24} kg. This means that if we know acceleration due to gravity 'g' and radius 'r' of any planet or star we can calculate its mass.

Example 5.2 MASS OF JUPITER

Jupiter is the largest planet in the solar system. Radius of Jupiter is $r_J = 7.15\times10^7$ m, the acceleration due to gravity on Jupiter is 24.7 N/kg. Calculate the mass of Jupiter.

SOLUTION

GIVEN:

Radius of Jupiter $r_J = 7.15\times10^7$ m

Acceleration due to gravity at Jupiter $g_J = 24.7\ N/kg$

Gravitational Constant $G = 6.673\times10^{-11}\ Nm^2kg^{-2}$

REQUIRED:

Mass of Jupiter m_J = ?

The mass of a planet or star can be calculated by using equation 4.4

$$m_J = \frac{g_J r_J^2}{G}$$

putting values $$m_J = \frac{24.7\ N/kg\times(7.15\times10^7\ m)^2}{6.673\times10^{-11}\ Nm^2kg^{-2}}$$

or $$m_J = \frac{24.7\ Nkg^{-1}\times5.11\times10^{15}\ m^2}{6.673\times10^{-11}\ Nm^2kg^{-2}}$$

or $$m_J = 1.891\times10^{16+11}kg$$

therefore $$m_J = 1.89\times10^{27}\ kg$$ — Answer

Thus the mass of Jupiter is about 300 times the mass of the earth.

Assignment 5.2 MASS OF MOON

If the radius of the moon is 1.74×10^6 m and have acceleration due to gravity on its surface as $1.6\ ms^{-2}$. Calculate the mass of moon.

TIP REMEMBER THESE VALUES

Gravitational constant $G = 6.67 \times 10^{-11}\ N\ m^2\ kg^{-2}$

Radius of earth $r_E = 6.4 \times 10^6\ m$

TABLE 5.1: SELECTED DATA FOR THE SOLAR SYSTEM

Planet	Radius (km)	Mass (10^{24} kg)	g (m/s^2)	Orbital Period (yr)
Mercury	2,400	0.330	3.7	0.241
Venus	6,050	4.87	8.9	0.615
Earth	6,370	5.97	9.8	1
Mars	3,400	0.642	3.7	1.88
Jupiter	71,500	1890	24.7	11.9
Saturn	60,300	568	9.0	29.4
Uranus	25,600	86.8	8.7	83.8
Neptune	24,800	102	11.0	164
Sun	696,000	1,990,000	274	--

5.3 GRAVITATIONAL FIELD

Gravity is a field force:

Newton was not able to explain how objects can exert forces on one another without coming into contact. He developed a mathematical theory to describe gravity, but he did not had a physical explanation for how gravity works. Scientists later developed a theory of fields to explain how gravity and other forces operate.

According to this theory, masses create a gravitational field in space. (Similarly, charged objects generate an electric field and magnets develop a magnetic field.) A gravitational force is

INFORMATION

We have eight planets in our Solar System. However, outside of our Solar System there are thousands of other planets. The extra-solar planets or exo-planets are in orbit around another star. So far we have almost 3500 confirmed new worlds, with another 2000 awaiting confirmation.

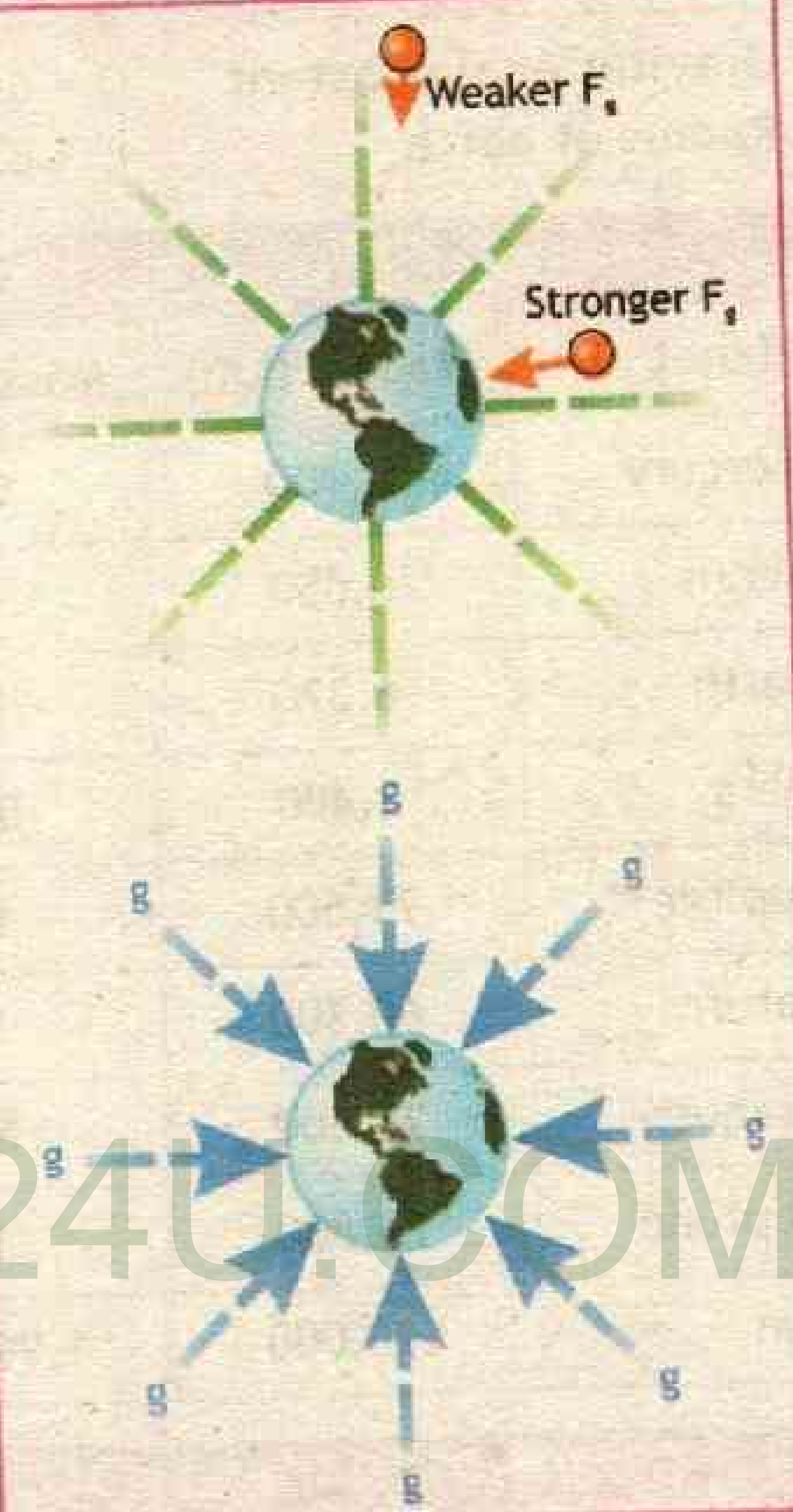
an interaction between a mass and the gravitational field created by other masses.

At any point, Earth's gravitational field can be described by the gravitational field strength, abbreviated as g. The value of 'g' is equal to the magnitude of the gravitational force exerted on a unit mass at that point,

or $g = F_g/m$.

The gravitational field (g) is a vector with a magnitude of 'g' that points in the direction of the gravitational force.

Figure 5.5 Gravitational Field



Gravitational field strength (free-fall acceleration) 'g':

Consider an object that is free to accelerate and is acted on only by gravitational force. According to Newton's second law, a = F/m. As seen earlier, g is defined as F_g/m, where F_g is gravitational force. Thus, the value of 'g' at any given point is equal to the acceleration due to gravity. For this reason, $g = 9.8\ m/s^2$ on Earth's surface. Although gravitational field strength and free-fall acceleration are equivalent, they are not the same thing. For instance, when you hang an object from a spring scale, you are measuring gravitational field strength. Because the mass is at rest (in a frame of reference fixed to Earth's surface), there is no measurable acceleration.

Figure 5.5 shows gravitational field vectors at different points around Earth. As shown in the figure, gravitational field strength rapidly decreases as the distance from Earth increases, as you would expect from the inverse-square nature of Newton's law of universal gravitation.

Weight changes with location:

In chapter 3 Dynamics, we learned that weight is the magnitude of the force due to gravity, which equals mass times free-fall acceleration. We can now refine our definition of weight as mass times gravitational field strength.

The two definitions are mathematically equivalent, but our new definition helps to explain why your weight changes with our location in the universe.

Newton's law of universal gravitation shows that the value of g depends on mass of all reacting bodies and distance to it.

For example, consider an object (e.g. tennis ball) of mass m_o placed on surface of earth. Let m_E be the mass of the earth and r_E is the distance between their centers. The gravitational force between the tennis ball and Earth is as follows:

$$F_g = G\frac{m_0 m_E}{r_E^2} \quad (1)$$

The gravitational field strength Fg by Newton's second law is

$$F_g = W = m_0 g \quad (2)$$

comparing equation 1 and equation 2 we get

$$m_0 g = G\frac{m_0 m_E}{r_E^2}$$

therefore $$g = G\frac{m_E}{r_E^2} \quad (5.4)$$

Inserting the known values of

$$m_E = 6 \times 10^{24}\,\text{kg}$$

and $$r_E = 6.4 \times 10^{6}\,\text{m}$$

along with $$G = 6.67 \times 10^{-11}\,\text{Nm}^2\text{kg}^{-2},$$

we find

$$g = 6.67 \times 10^{-11}\,\text{Nm}^2\text{kg}^{-2}\,\frac{6 \times 10^{24}\,\text{kg}}{(6.4 \times 10^{6}\,\text{m})^2}$$

therefore $$g = 9.77\,ms^{-2}$$

or $$g = 9.8\,ms^{-2}$$

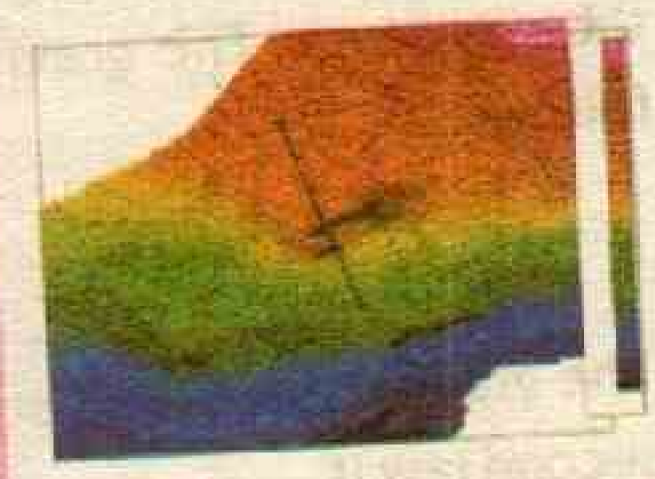
TID BITS

The hottest planet is not the closest planet to the Sun.
Even though Mercury is the closest planet to the Sun, it is not actually the hottest. Mercury does not have any atmosphere meaning that this planet is only hot in the daytime when it is directly facing the Sun. At this stage temperatures can rise to 425°C but at night the planet's temperature can drop down to a freezing -180°C. Venus (shown in picture) is the hottest planet. Its thick clouds trap the Sun's heat causing Venus to be a sizzling 500°C all of the time!

Equation 5.4 shows that the value of 'g' does not depend upon the mass of the body. This means that light and heavy bodies should fall towards the centre of the earth with the same acceleration. This equation also shows that gravitational field strength depends only on mass of earth 'm_E' and radius of earth 'r_E'. As earth is not a perfect sphere, and there are mountains and trenches so our distance from Earth's center varies as we change location, so our weight also varies. On the surface of any planet, the value of g, as well as our weight, will depend on the planet's mass and radius.

TECHNOLOGY

The variation in the value of 'g' on Earth is used to detect the presence of minerals and oil. Geophysicists use sensitive instruments, called gravimeters, to detect small variations in 'g' when they search for new deposits of ore or oil. Gold and silver deposits increase the value of 'g', while deposits of oil and natural gas decrease 'g'. Picture is an example of a map that shows different measured values of g as lines, where each line represents a specific value of g.



Example 5.3 VALUE OF 'g' AT SUN'S SURFACE

What is the free-fall acceleration at the surface of the sun? As mass of Sun is 1.99×10^{30} kg and having radius of 6.96×10^{8} m.

SOLUTION

GIVEN:

Radius of Sun $r_s = 6.96 \times 10^{8}$ m

Mass of Sun $m_s = 1.99 \times 10^{30}$ kg

Gravitational Constant $G = 6.67 \times 10^{-11}\ Nm^2kg^{-2}$

REQUIRED:

free-fall acceleration at Sun g_s - ?

The value of g at sun's surface can be calculated by equation 5.4 as

$$g = G\frac{m_S}{r_S^2}$$

$$g = 6.67 \times 10^{-11}\ Nm^2kg^{-2}\ \frac{1.99 \times 10^{30}\ kg}{(6.96 \times 10^{8}\ m)^2}$$

therefore $g = 274\ ms^{-2}$ — **Answer**

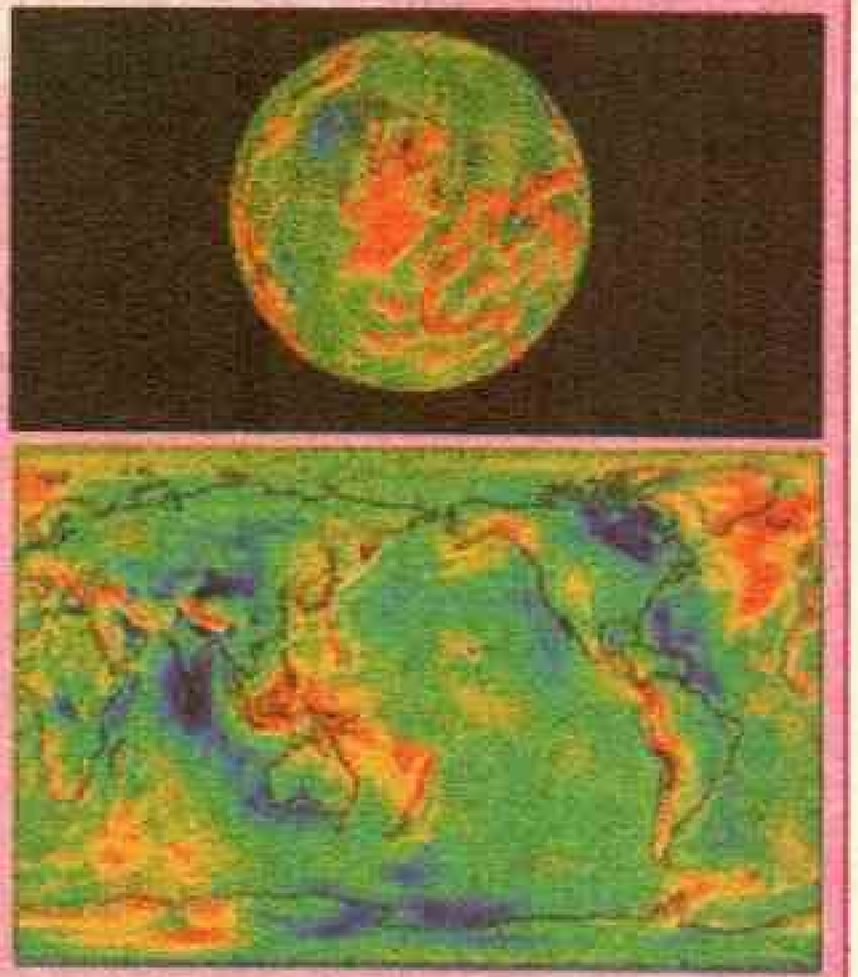
Notice that the mass of the Sun is almost a million times more than the mass of the Earth, and having gravitational acceleration of about 30 times that of earth.

Assignment 5.3 FREE FALL AT MOON

An astronaut of mass 65.0 kg (weighing 637 N on earth) is walking on the surface of the Moon, which has a mean radius of 1.74×10^{6} m and a mass of 7.35×10^{22} kg. What is the weight of the astronaut on moon? What is the free-fall acceleration at the surface of the moon?

INFORMATION CHART

This global model of the Earth's gravitational strength was constructed from a combination of surface gravity measurements and satellite tracking data. It shows how the acceleration of gravity varies from the value at an idealized "sea level" that takes into account the Earth's non-spherical shape. (The Earth is somewhat flattened at the poles—its radius is greatest at the equator.) Gravity is strongest in the red areas and weakest in the dark blue areas.



5.4 VARIATION of 'g' WITH ALTITUDE

The value of 'g' at a given place depends upon the distance from the centre of earth. Greater the distance from the centre of the earth, smaller will be the value of 'g'. Equation 5.3 shows that the value of 'g' varies inversely as the square of distance. Let 'g_h' be the value of acceleration due to garvity at a height 'h' from the surface of the earth we can modify Equation 5.4 as .

Figure 5.6

$$g_h = G\frac{m_E}{(r_E + h)^2} \quad \text{—— (1)}$$

equation 5.3 can also be written as

$$g = G\frac{m_E}{r_E^2}$$

or $$Gm_E = gr_E^2 \quad \text{—— (2)}$$

putting equation 2 in equation 1, we get $$g_h = \frac{gr_E^2}{(r_E + h)^2} \quad \text{—— 5.5}$$

Equation 5.6 shows that as we move away from the center of earth the value of 'g' decreases. The change in the value of g is significant only at very large distances.

Example 5.4 METEOROID IN EARTH'S FIELD

A meteoroid (a chunk of rock) is at 4.4×10^7 m from the earth, what is the value of free fall acceleration 'g' at this point due to earth.

SOLUTION

GIVEN:

Radius of earth $r_E = 6.4 \times 10^6$ m

Acceleration due to gravity $g = 9.8\ ms^{-2}$

height $h = 4.4 \times 10^7$ m $= 44 \times 10^6$ m

REQUIRED:

free-fall acceleration at height g_h = ?

The value of 'g_h' at height h, can be calculated by using equation 5.5

$$g_h = \frac{g r_E^2}{(r_E + h)^2}$$

putting values
$$g_h = \frac{9.8\ ms^{-2} \times (6.4 \times 10^6\ m)^2}{(6.4 \times 10^6\ m + 44 \times 10^6\ m)^2}$$

or
$$g_h = \frac{9.8\ ms^{-2} \times (6.4 \times 10^6\ m)^2}{(50.4 \times 10^6\ m)^2}$$

or
$$g_h = \frac{9.8\ ms^{-2} \times 4.1 \times 10^{13}\ m^2}{2.54 \times 10^{15}\ m^2}$$

therefore $g_h = 0.16\ ms^{-2}$ — Answer

EXTENSION EXERCISE 5.1

Confirm the value of 'g' for Jupiter given in Example 5.2. Using equation 5.5

Assignment 5.4 Value Of g At Specific Height

Calculate the value of g at 1000 km and 35900 km above the earth surface.

TABLE 5.1: CHANGE IN GRAVITATIONAL ACCELERATION WITH ALTITUDE

Altitude (km)	a (m/s²)	Altitude Example
0.0	9.8	Mean Earth radius
8.8	9.8	Mt. Everest
36.6	9.7	Highest manned balloon
400	8.7	Space shuttle orbit
35 700	0.2	Communications satellite

POINT TO PONDER

The magnitude of g on the moon's surface is about 1/6 of the value of g on Earth's surface. Can you infer from this relationship that the moon's mass is 1/6 of Earth's mass? Why or why not?

5.5 MOTION OF ARTIFICIAL SATELLITES

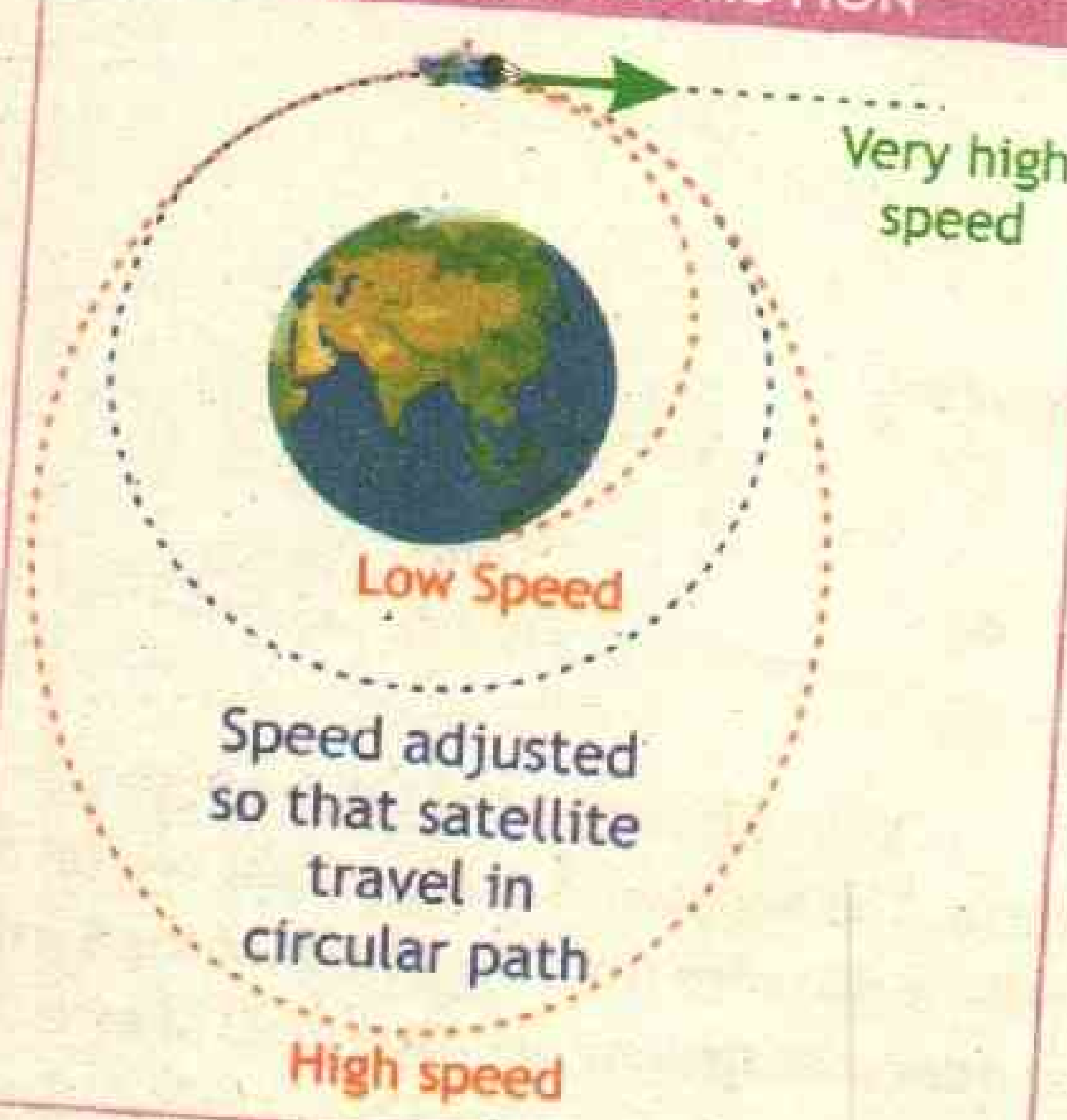
A **Satellite** is a naturally occurring or man-made object that orbits another object larger than itself by force of gravity.

A natural body orbiting another body so large that center of mass is well within the larger body is called natural satellites of that body. Six of the major planets possess natural satellites often termed as moons.

Any object purposely placed into orbit of earth or other planets, stars or sun are termed as artificial satellites. First artificial satellites was launched in 1957, since then thousands have been sent for communication industry (internet, mobile phones, TV communication etc.), weather, military purposes and scientific study.

A satellite is put into orbit by moving it to high altitude and then accelerating it to a sufficiently high tangential speed with the use of rockets, as shown in Fig. 5.7. If the speed is too high, the spacecraft either move in elliptical orbit or will not be confined by the Earth's gravity and will escape, never to return. If the speed is too low, it will fall back to Earth. Satellites are typically put into circular (or nearly circular) orbits, because such orbits require the least take off speed.

Figure 5.7 SATELLITE MOTION



You may be wondering "What keeps a satellite up?" The answer is: its high speed. If a satellite in orbit stopped moving, it would fall directly to Earth. But at sufficient speed a satellite would orbit in space around a larger body.

Speed in circular orbit calculation:

In circular orbit a satellite has a constant tangential speed called orbital velocity. Consider a satellite of mass m_s revolving in a circular orbit with velocity v from earth of mass m_E. Let r be the distance between the center of earth and the center of satellite as shown in figure 5.8. Then the gravitational force by Newton's law of universal gravitation is

$$F_g = \frac{Gm_E m_S}{r^2} \quad (1)$$

Then centripetal force to keep satellite of mass m_s revolving in a circular orbit of radius r with velocity 'v' is

$$F_C = \frac{m_S v^2}{r} \quad (2)$$

Then centripetal force is provided by gravitational force therefore

$$F_g = F_C \quad (3)$$

Putting values from equation 1 and equation 2 in equation 3, we get

$$\frac{m_S v^2}{r} = \frac{Gm_S m_E}{r^2}$$

or $$v^2 = \frac{Gm_E}{r}$$

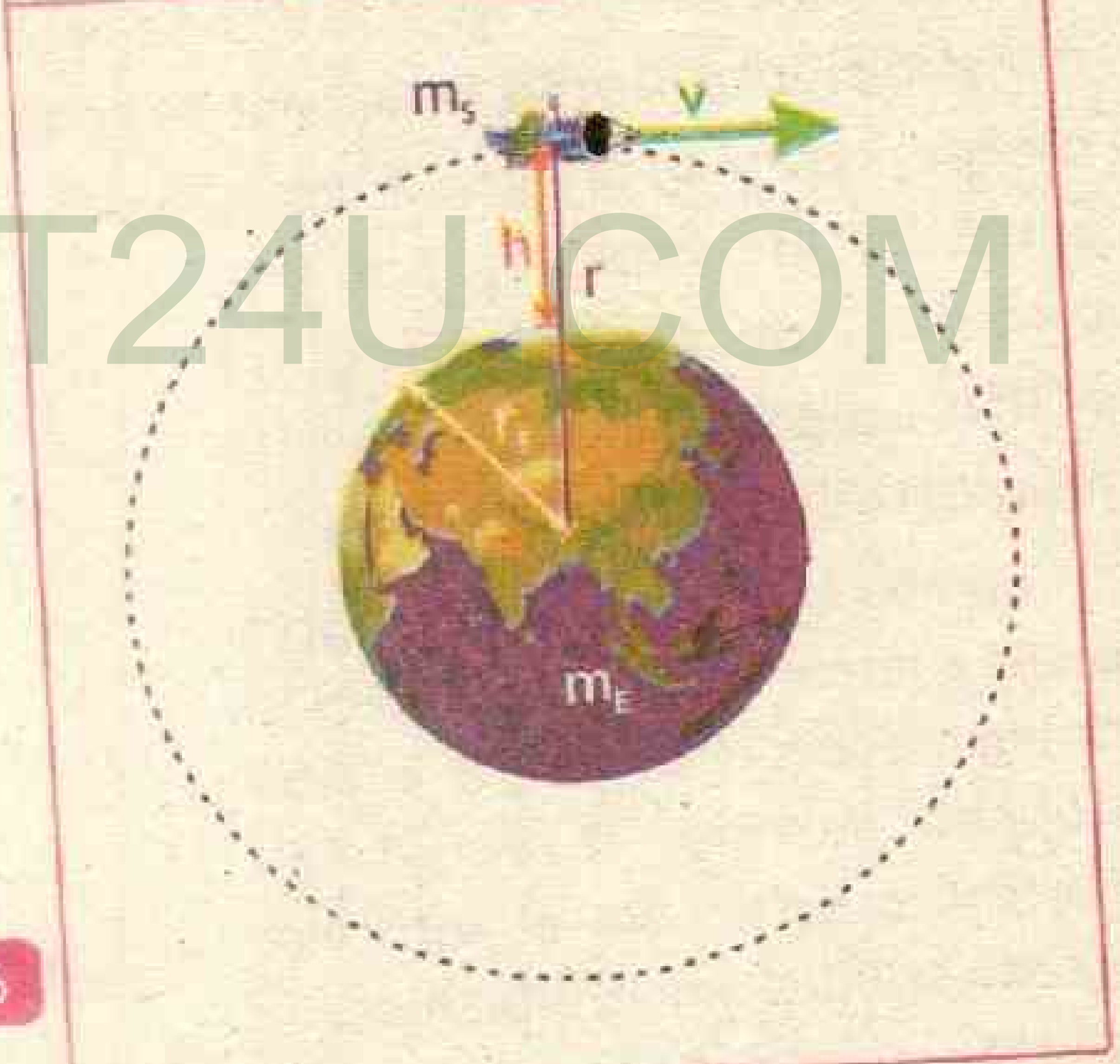
taking square root on both sides

$$\sqrt{v^2} = \sqrt{\frac{Gm_E}{r}}$$

therefore $$v = \sqrt{\frac{Gm_E}{r}}$$

or $$v = \sqrt{\frac{Gm_E}{r_E + h}} \quad (5.6)$$

Figure 5.8 ORBITAL SPEED



Where h is the height of satellite from surface of earth and r_E is the radius of earth. The equation 5.6 shows that orbital speed depends upon the mass of Earth and the distance from the center of the Earth to the center of mass of the satellite and does not depend upon the mass of satellite.

Which means that for particular distance from the center of earth, all the satellite should have the same orbital speed irrespective of the size of satellite.

Geostationary communications satellites are placed in a circular orbit that is 3.59 × 10 m = 35.9×10^6 m above the surface of the earth. Their orbital speed can be calculated by equation 5.6 as

$$v = \sqrt{\frac{Gm_E}{r_E + h}}$$

putting values $$v = \sqrt{6.673 \times 10^{-11}\,Nm^2kg^{-2}\,\frac{6 \times 10^{24}\,kg}{(35.9 + 6.4) \times 10^6\,m}}$$

therefore $$v = 3.07 \times 10^3\,ms^{-1}$$

or $$v = 3.07\,kms^{-1}$$

This equation can also be used to measure the velocity of any planet or celestial object moving in a circular path.

Example 5.5 SPEED OF EARTH AROUND SUN

The mass of the Sun is 1.99×10^{30} kg, and the radius of the Earth's orbit around the Sun is 1.5×10^{11} m. From this, calculate the orbital speed of the Earth.

SOLUTION

GIVEN:

Radius $r = 1.5 \times 10^{11}$ m

Mass of Sun $m_s = 1.99 \times 10^{30}$ kg

Gravitational Constant $G = 6.673 \times 10^{-11}\,Nm^2kg^{-2}$

REQUIRED:

Orbital Speed v = ?

the orbital speed is $$v = \sqrt{G\frac{m_s}{r}}$$

putting values $$v = \sqrt{6.673 \times 10^{-11}\,Nm^2kg^{-2}\,\frac{1.99 \times 10^{30}\,kg}{1.5 \times 10^{11}\,m}}$$

therefore $$v = 3.0 \times 10^4\,m/s = 30\,km/s$$ — Answer

Assignment 5.5 ORBITAL SPEED OF A SATELLITE

If a satellite orbits the earth at 2,000 km above sea level, how fast must the orbiting satellite travel to maintain a circular orbit?

KEY POINTS

Law of Gravitation: Every object in the universe attracts every other object with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between their centres.

Gravitational acceleration: The acceleration of bodies falling freely towards the earth is called gravitational acceleration 'g'. The value of 'g' decreases as altitude increases.

Artificial Satellite: The objects which are used for communication and space research revolve round the Earth under the force of gravity, which provides the necessary centripetal force.

Orbital Velocity: It is the velocity of a satellite which moves around the Earth at a specific height.

PROJECTS

GROUP - A

SUPARCO: What is SUPARCO? Research Pakistan Space Program 2040 and Develop a presentation on space prospects in Pakistan?

GROUP - B

Dream Space Visit: Research how do space scientists and engineers know what kinds of science instruments (cameras, spectrometers, etc.) to put on space craft that are destined for other planets, moons, asteroids, or comets? How do they decide what they will want to measure once they get to, say, Saturn's moon Titan or Jupiter's moon Europa? Select a place for your visit, then design a two day trip to that world, and describe the things you will carry with you. Write an essay and place it school library for reference.

GROUP - C

Pluto: In 2006 a new definition of planet was set and Pluto was demoted to dwarf planet, research the reason and present it in chart.

GROUP - D

Extra Solar Planet: Explore the discovery of planets around other stars. What methods did the astronomers use? What measurements did they take? Write a research article.

GROUP - E

Sky Observation: Consult your instructor or other sources to find out what planets are observable in the evening during the current month. Venus, Jupiter, or Mars are usually the best candidates.

a. Locate the planet visually and observe it with binoculars if possible. How does the planet differ in appearance from that of nearby stars?

b. Sketch the position of the planet relative to nearby stars for several nights. How does this position change?

EXERCISE

MULTIPLE CHOICE QUESTIONS

1. Two masses are separated by a distance r. If both masses are doubled, the force of interaction between the two masses changes by a factor
   A. 2 B. 4 C. 1/2 D. 1/4
2. The radius of earth r_E is
   A. 9.8 m B. 6.67×10^{-11} m C. 6×10^{24} m D. 6.4×10^{6} m
3. The S.I. unit for gravitational constant "G" is
   A. $N\,kg^2$ B. $N\,m^2\,kg^{-2}$ C. $N\,m^2\,kg^2$ D. $N\,m^{-2}\,kg^2$
4. What is the mass on planet Mercury of an object that weighs 784 N on the earth's surface?
   A. 80.0 kg B. 118 C. 784 kg D. More information needed
5. An object is orbiting a planet with orbital speed v, if the radius is same and mass is increased 4 times, by what factor orbital speed will change
   A. 2 B. 4 C. 1/2 D. 1/4
6. The value of 'g' at the surface of the moon is;
   A. $9.8\,m\,s^{-2}$ B. $1.63\,m\,s^{-2}$ C. $4.9\,m\,s^{-2}$ D. $8.9\,m\,s^{-2}$
7. The value of 'g' ________ with altitude
   A. increases B. decreases C. gets ZERO D. remains the same
8. When a body is moved from sea level to the top of a mountain, There is change in the body's
   A. mass B. weight C. none D. both mass and weight
9. The value of 'g' at equator is
   A. Same at poles B. Larger at poles C. Smaller at poles D. none

CONCEPTUAL QUESTIONS

Give a brief response to the following questions.

1. If there is an attractive force between all objects, why don't we feel ourselves gravitating toward nearby massive buildings?
2. Does the sun exert a larger force on the Earth than that exerted on the sun by the Earth? Explain.
3. What is the importance of gravitational constant 'G'? Why is it difficult to calculate?
4. If Earth somehow expanded to a larger radius, with no change in mass, how would your weight be affected? How would it be affected if Earth instead shrunk?
5. What would happen to your weight on earth if the mass of the earth doubled, but its radius stayed the same?
6. Why lighter and heavier objects fall at the same rate toward the earth?
7. The value of 'g' changes with location on earth, however we take same value of 'g' as 9.8 ms^{-2} for ordinary calculations. Why?
8. Moon is attracted by the earth, why it does not fall on earth?
9. Why for same height larger and smaller satellites must have same orbital speeds?

COMPREHENSIVE QUESTIONS

Give an extended response to the following questions.

1. State and explain the law of Universal Gravitation. Also show that the law obeys Newton's third law of motion.
2. Determine the mass of Earth by applying law of gravitation.
3. What is gravitational field and gravitational field strength? Show that the weight of an object changes with location.
4. How is the value of 'g' changing by going to higher altitude? Write the relevant formula.
5. Derive the formula for the orbital speed of an artificial satellite.

NUMERICAL QUESTIONS

1. Pluto's moon Charon is unusually large considering Pluto's size, giving them the character of a double planet. Their masses are 1.25×10^{22} kg and 1.9×10^{21} kg, and their average distance from one another is 1.96×10^{4} km. What is the gravitational force between them?
2. The mass of Mars is 6.4×10^{23} kg and having radius of 3.4×10^{6} m. Calculate the gravitational field strength (g) on Mars surface.
3. Titan is the largest moon of Saturn and the only moon in the solar system known to have a substantial atmosphere. Find the acceleration due to gravity on Titan's surface, given that its mass is 1.35×10^{18} and its radius is 2570 km.
4. At which altitude above Earth's surface would the gravitational acceleration be $4.9\ m/s^2$?
5. Assume that a satellite orbits Earth 225 km above its surface. Given that the mass of Earth is 6×10^{24} kg and the radius of Earth is 6.4×10^{6} m, what is the satellite's orbital speed?
6. The distance from center of earth to center of moon is 3.8×10^{8} m. Mass of earth is 6×10^{24} kg. What is the orbital speed of moon?
7. The Hubble space telescope orbits Earth ($m_E = 6 \times 10^{24}$ kg) with an orbital speed of 7.6×10^{3} m/s. Calculate its altitude above Earth's surface.

WEB LINKS

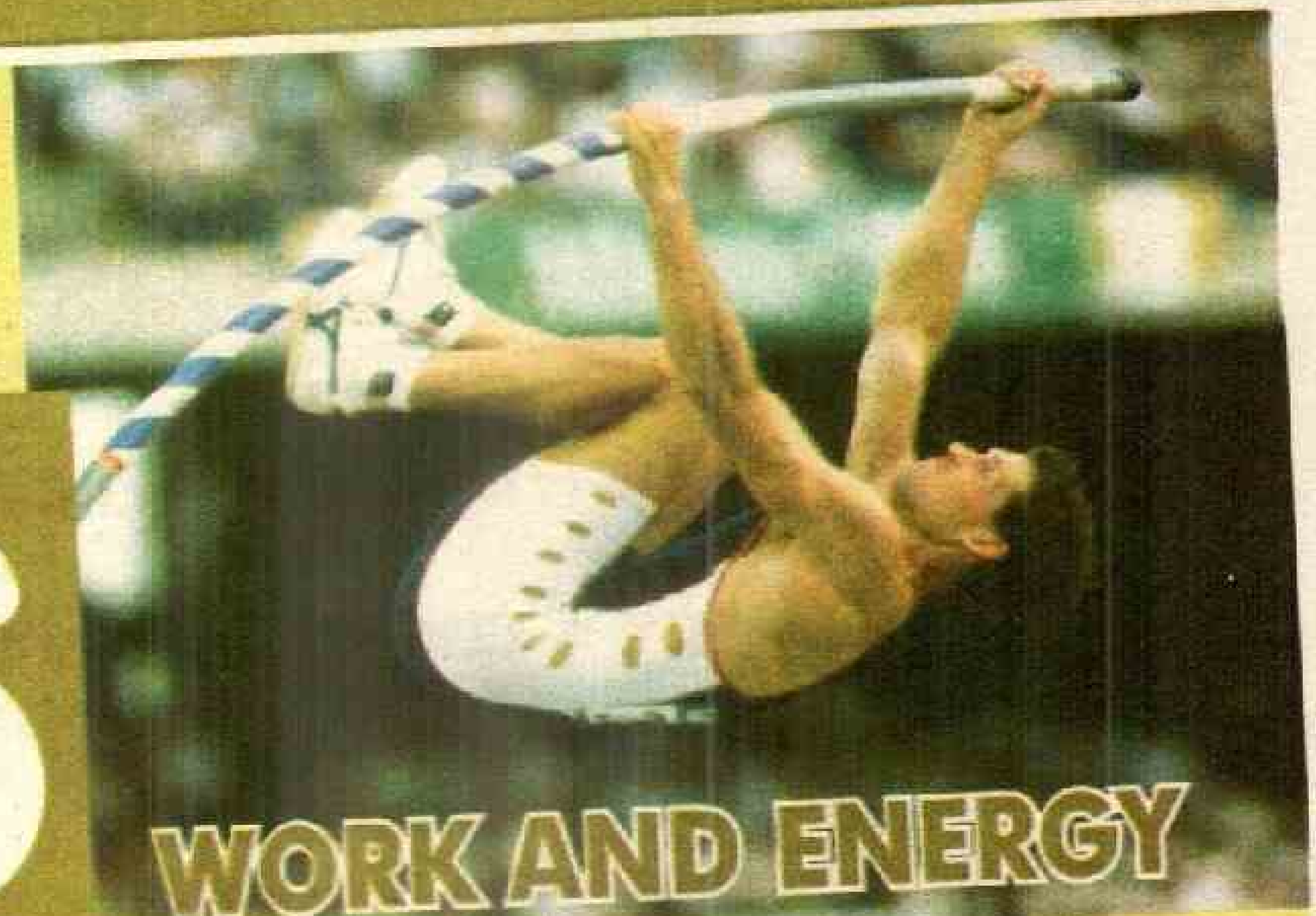
http://suparco.gov.pk/webroot/index.asp

https://www.nasa.gov/

http://www.ist.edu.pk/

https://www.space.com/

Why Pole vaulters use sticks that bends?



Unit 6

WORK AND ENERGY

CHECK LIST

After studying this unit you should be able to:

- ✓ define work and its SI unit.
- ✓ calculate work done using equation: *work = force x distance moved in the direction of force*
- ✓ define energy, kinetic energy and potential energy. State unit of energy.
- ✓ prove that Kinetic Energy $E_k = \frac{1}{2} mv^2$ and potential energy E_{GPE} = mgh and solve problems using these equations.
- ✓ list the different forms of energy with examples.
- ✓ describe the processes by which energy is converted from one form to another with reference to - fossil fuel energy - hydroelectric generation - solar energy - nuclear energy - geothermal energy - wind energy and biomass energy
- ✓ state mass energy equation $E = mc^2$ and solve problems using it.
- ✓ describe the process of electricity generation by drawing a block diagram of the process from fossil fuel input to electricity output.
- ✓ list the environmental issues associated with power generation.
- ✓ differentiate energy sources as non renewable and renewable energy sources with examples of each.
- ✓ explain by drawing energy flow diagrams through steady state systems such as Filament lamp, a power station, a vehicle traveling at a constant speed on a level road.
- ✓ define efficiency of a working system and calculate the efficiency of an energy conversion using the formula: *efficiency = energy converted into the required form / total energy input*
- ✓ explain why a system cannot have an efficiency of 100%.
- ✓ define power and calculate power from the formula *Power = work done / time taken*
- ✓ define the unit of power "watt" in SI and its conversion with horse power.
- ✓ Solve problems using mathematical relations learnt in this unit.

Newton laws can be used to predict motion using forces and accelerations. While dealing with Newton laws we freeze the action in particular instant of time, and then we draw a free body diagram and set-out equations e.t.c. Work energy allow us to predict motion by different technique - we just look at starting conditions and final conditions to get all the required information ignoring what happens in between.

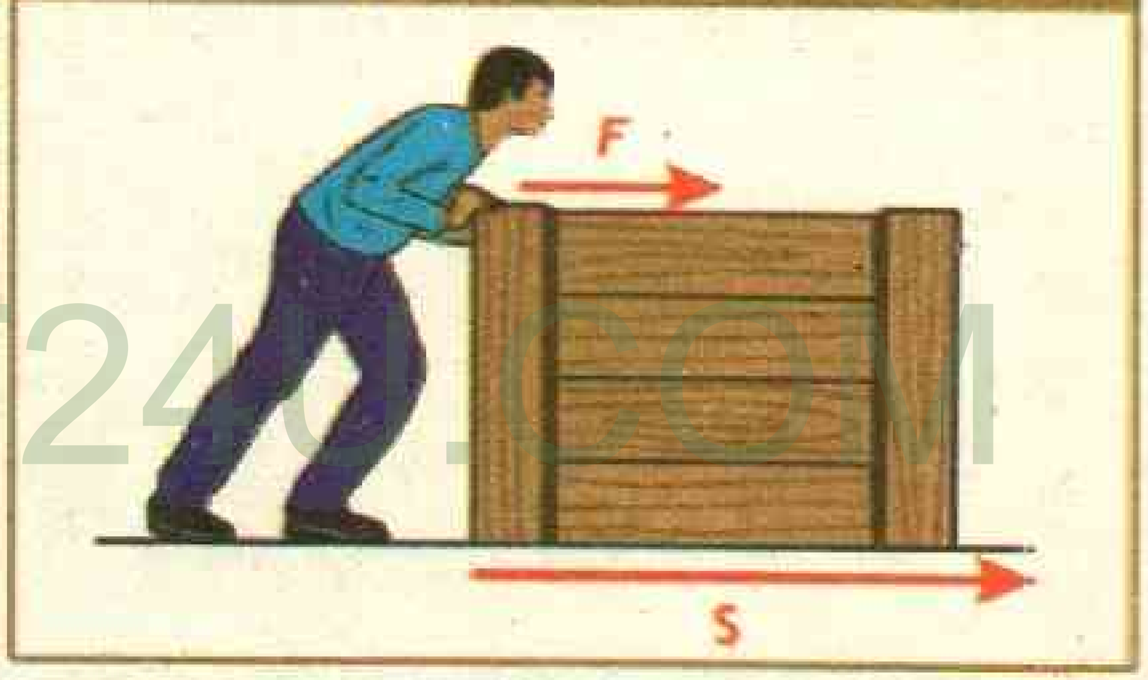
6.1 WORK

The scientific definition of work differs in some ways from its everyday meaning. Certain things we think of as hard work, such as writing an exam or carrying a heavy load on level ground, are not work as defined by a scientist. For work, in the scientific sense, to be done, a force must be exerted and there must be motion or displacement in the direction of the force.

Work is said to be done when a force displaces a body in its own direction. When an object moves distance 'S' in the direction of applied force F, then work done W is given mathematically as

$$W = F \times S \quad (6.1)$$

Figure 6.1 Work



Unit of Work:

The SI unit of work is joule (abbreviateds J, and named in honor of the 19th-century English physicist James Prescott Joule). The unit of work is the unit of force (newton) multiplied by the unit of distance (metre).

$$1\ joule = (1\ newton)(1\ meter)$$

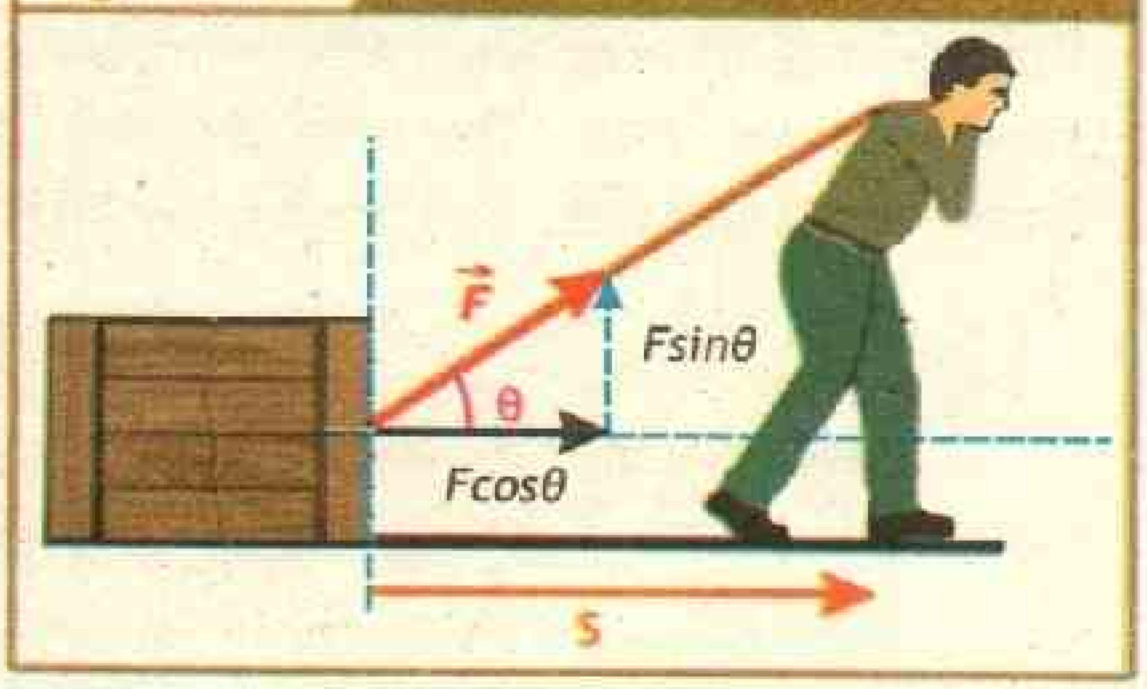
or $$1J = 1\ Nm$$

TID BIT — PLAY IS WORK?

Who is doing more work? A boy playing and running in school ground or a teacher sitting on chair working on physics problems.

Work done is scalar quantity, however force is vector quantity, sometime force is not perfectly applied in the direction of motion. For example consider the figure in which a box is moving in horizontal

Figure 6.2 Work



direction and force F is applied making certain angle θ with the horizontal. In such situations the force is resolved into its rectangular components.

From the figure it is clear that the effective component of force, in the direction of motion is $F\cos\theta$, Mathematically work done can be written as

$$W = F\cos\theta \times S \qquad (6.2)$$

Example 6.1 SUITCASE

A person pulls a suitcase through the airport at 45° angle . The tension in the rope is 20 N. How much work does the tension do if the suitcase is pulled 100 m?

SOLUTION

GIVEN:

Tension = Force F = 20 N

Distance = S = 100 m

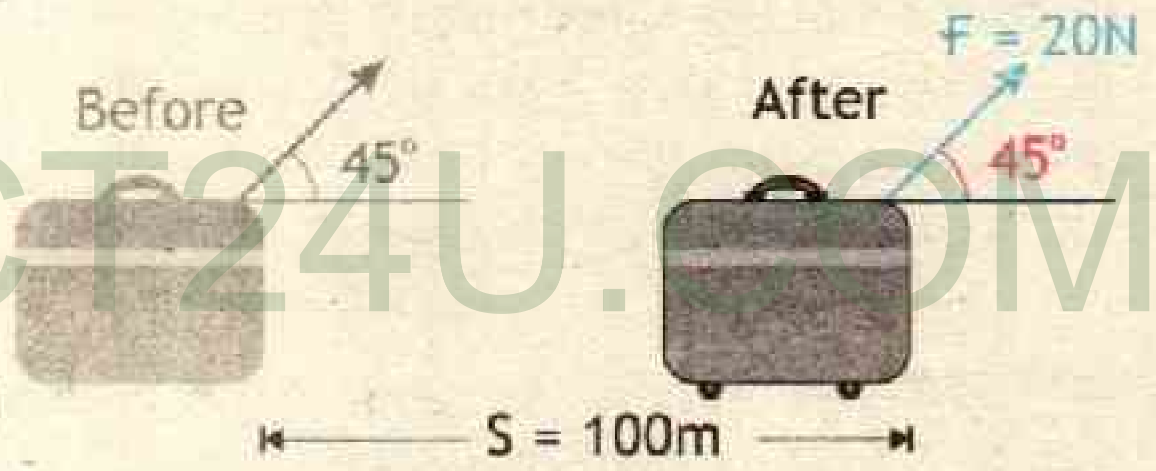
Angle = 45°

REQUIRED:

Work W = ?

By definition of workdone

$$W = F\cos\theta \times S$$



putting values

$$W = 20\,N\cos 45^{\circ} \times 100\,m$$

or $$W = 2000\,Nm \times 0.707$$

$$W = 1400\,J \qquad \text{Answer}$$

Because a person pulls the rope, we would say informally that the person does 1400 J of work on the suit case.

Assignment 6.1 TUG OF WAR

During a tug-of-war, team A pulls on team B by applying a force of 1100 N to the rope between them. The rope remains parallel to the ground. How much work does team A do if they pull team B toward's them a distance of 2.0 m?

6.2 ENERGY AND ITS FORMS

If we look at the world around us we can identify things that are capable of doing work, that is, exerting a force to move an object.

- A boy is kicking a ball. The boy exerts a force on the ball and the ball moves.

The work done on the ball is transfer energy from boy to the ball.

- A stretched bow can shot an arrow due to energy store in it. The energy is the stretched sting is transferred to arrow.

So energy is defined as '**Energy is the capacity of a body to do work**'.

Unit of energy:

The unit of energy is the same as that of work i.e. joule (abbreviated J = Nm).

As you have learned, Grade 6, Chapter Energy and its forms, all forms of energy (Heat, electrical, light and sound) can be classified as one of two types, either as stored or potential energy or as moving or kinetic energy. The few energy types are given in table 6.1.

6.3 KINETIC ENERGY

The energy possessed by a body due to its motion is called Kinetic energy.

When a cricket ball is thrown it moves, similarly a car starts moving when pushed. Now Think that a cricket ball and a car are moving with same speed. Which possess greater ability to do work? Of course it is the car with larger mass, it is difficult to stop. Similarly now two cricket balls are approaching you with different speeds, which can do more work? Again it is easy to answer as the ball with greater speed is difficult to stop. Thus object mass and its speed are contributing to its kinetic energy.

Mathematically Kinetic energy is one half the product of an object's mass 'm' and the square of its velocity 'v'.

$$E_K = \frac{1}{2}mv^2$$

POINT TO PONDER **DOES THE EARTH DO WORK ON THE MOON?**

The Moon revolves around the Earth in a nearly circular orbit, kept there by the gravitational force exerted by the Earth. This gravitational force provides it centripetal acceleration, inward along the radius of the Moon's orbit. The Moon's displacement at any moment is tangent to the circle, perpendicular to the force of gravity F_g. Hence the angle between the force and the instantaneous displacement of the Moon is 90°, and the work done by gravity is therefore zero. (W= F S cos 90° = 0). This is why the Moon, as well as artificial satellites, can stay in orbit without expenditure of fuel: no work needs to be done against the force of gravity.

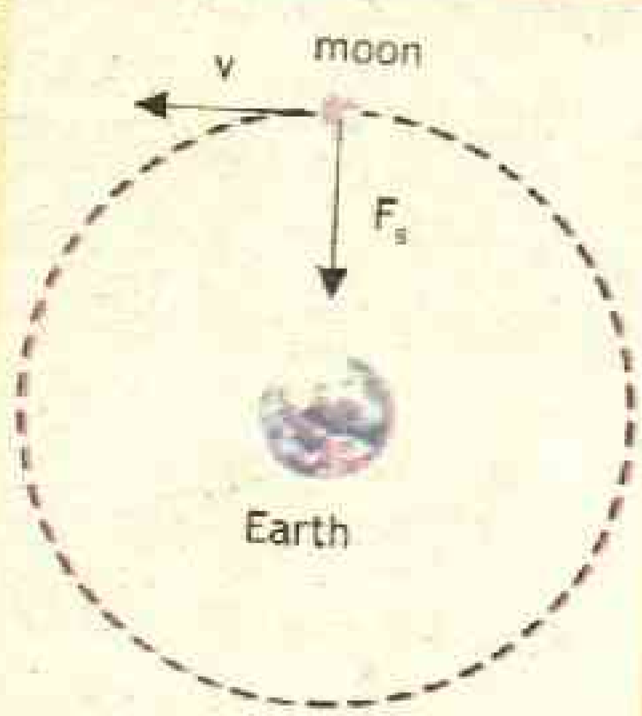


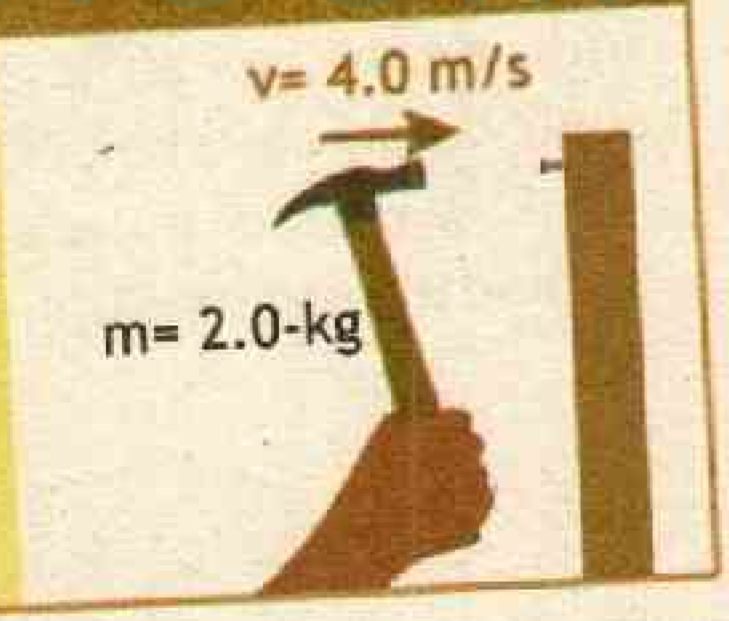
TABLE 6.1: TYPES OF ENERGY

Type	Description	Example
Chemical Energy	The energy contained within the bonds between atoms.	These bonds can take many different forms, including energy derived from carbohydrates in food to energy stored in gasoline.
Radiant Energy	Radiant energy travels as an electromagnetic (light) wave.	Radiant energy from the Sun supplies Earth with all of the energy required to sustain life.
Electrical Energy	The energy associated with charges.	Electrons moving from negatively to positively charged objects.
Heat Enrgy	Energy that travel from hot body to cold body.	Fire burning transfer the energy to keep room warm.
Sound Energy	Energy as wave, as a sound wave passes through, the atoms or molecules of the substance vibrate back and forth.	Sound vibrations cause a person's eardrums to vibrate.
Nuclear Energy	Energy in the Nucleus of an atom.	Nuclear power stations use nuclear energy to generate electric energy.

Like all energies kinetic energy is also a scalar quantity. For example, a 2.0-kg hammer head moving with a speed of 4.0 m/s has a kinetic energy of 16 J.

Figure 6.3

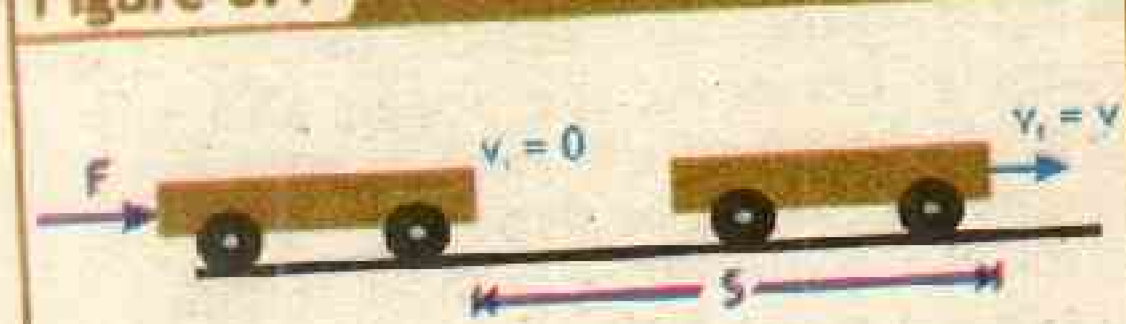
The moving hammer has kinetic energy and thus can do work on the nail, driving it into the wall.



Mathematical proof:

Consider a situation in which all of the work done on a cart transfers only kinetic energy to the cart. Consider a cart which is initially at rest. A horizontal force F is applied to it comes it to move through a displacement 's' and achieve a final volicty of $v_f = v$ as shown in figure 6.4. This work done W appears as the kinetic energy K_E. Such that

Figure 6.4 Work



$$W = E_K = F \times S \quad (1)$$

By Newton's Second Law of motion

$$F = ma \quad (2)$$

By third equation of motion

$$2as = v_f^2 - v_i^2$$

rearranging

$$S = \frac{v_f^2 - v_i^2}{2a} \quad (3)$$

putting equation 2 and 3 in equation 1

$$E_K = ma \times \frac{v_f^2 - v_i^2}{2a}$$

or $$E_K = m \times \frac{v_f^2 - v_i^2}{2}$$

As the object started from rest

therefore $v_i = 0$ and $v_f = v$

$$E_K = \frac{1}{2}mv^2 \quad (6.3)$$

INFORMATION

Magnetar: On December 27, 2004, astronomers observed the greatest flash of light ever recorded from outside the solar system. It came from the highly magnetic neutron star SGR 1806-20 (a magnetar). During 0.20 s, this star released as much energy as our sun does in 250,000 years.

This equation shows the relation between the kinetic energy of a moving object with its mass and velocity. Equally important, it demonstrate the work kinetic energy theorem which states that the work done on an object s equal to change in energy.

Example 6.2 **BULLET SPEED**

A 60.0-g bullet is fired from a gun with 3150 J of kinetic energy. Find its velocity.

SOLUTION

GIVEN:

mass m = 60 g = 0.06 kg

Kinetic energy E_k = 3150 J

REQUIRED:

velocity v = ?

The kinetic energy is given as

$$E_K = \frac{1}{2}mv^2$$

rearranging

$$v^2 = \frac{2E_K}{m}$$

EXTENSION EXERCISE 6.1

If a car of mass 800 kg is having same kinetic energy, what will be its speed?

taking square root on both sides

$$\sqrt{v^2} = \sqrt{\frac{2E_K}{m}}$$

or $$v = \sqrt{\frac{2E_K}{m}}$$

putting values

$$v = \sqrt{\frac{2 \times 3150\,J}{0.06\,kg} \times \frac{kg\,m^2\,s^2}{J}} \qquad as\ 1\,J = kgm/s^2\,m$$

therefore $v = 324\,m/s$ — **Answer**

The bullet is moving with speed 324 m/s.

Assignment 6.2 BULLET KINETIC ENERGY

A bullet of mass 30 g travels at a speed of 400 ms^{-1}. Calculate its kinetic energy.

6.4 POTENTIAL ENERGY

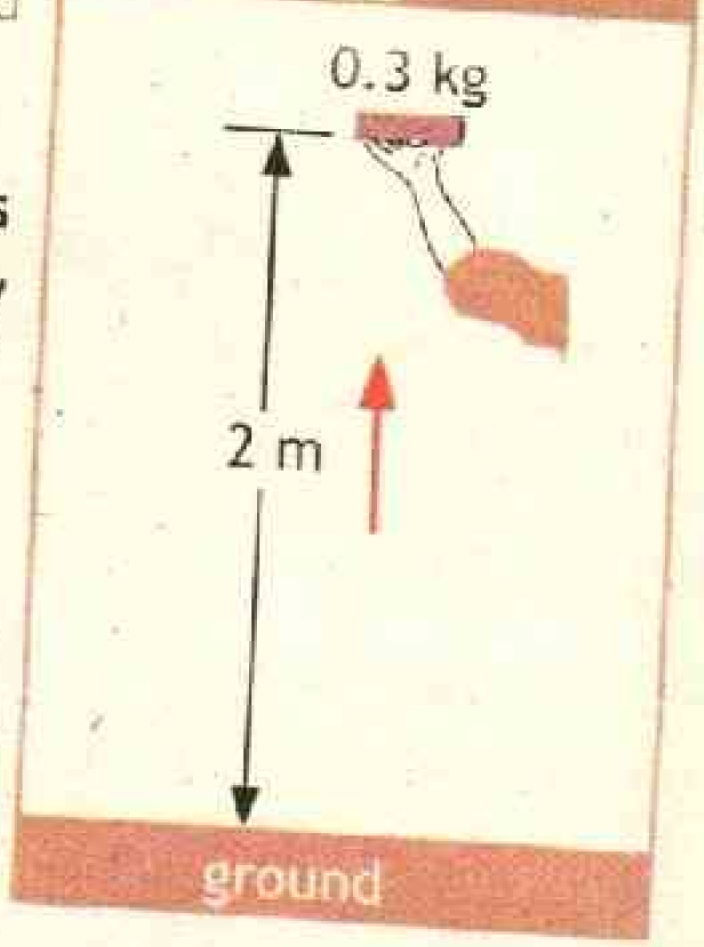
The energy possessed by a body by virtue of its position or configuration in a force field is called potential energy.

Consider the work you do on your physics textbook when you lift it from the floor and place it on the top shelf. You have done work on the textbook and yet it is not speeding off (not gained E_K). The work you did on your textbook is now stored in the book by virtue of its position. By doing work against the force of gravity, you have given your book a special form of potential energy called gravitational potential energy. You will come to know about this if you release book from the top shelf it will accelerate, gaining kinetic energy, thus gravitational potential energy can be released and have the ability to do useful work. Gravitational potential energy is only one of several forms of potential energy.

Figure 6.5 Potential Energy

For example, chemical potential energy is stored in the food you eat. Doing work on an elastic band by stretching it stores elastic potential energy in the elastic band (springs, slingshot in figure 6.5 are examples of elastic potential energy). A battery contains both chemical and electrical potential energy.

Figure 6.6



Mathematically Gravitational potential energy is the product of mass 'm', the acceleration due to gravity 'g', and the change in height 'h'.

$$E_{GP.E} = mgh$$

Like all energies potential energy is also a scalar quantity. For example if we lift a brick of mass 0.3 kg from the ground to 2 m high the work is done against the force of gravity, this work appears as 5.88 J of energy.

Mathematical proof:

consider an object of mass 'm' being lifted vertically by a force 'F' to 'h' as shown in figure 6.7. The work done by the force F is given by equation.

$$W = E_{GP.E} = F \times S \quad (1)$$

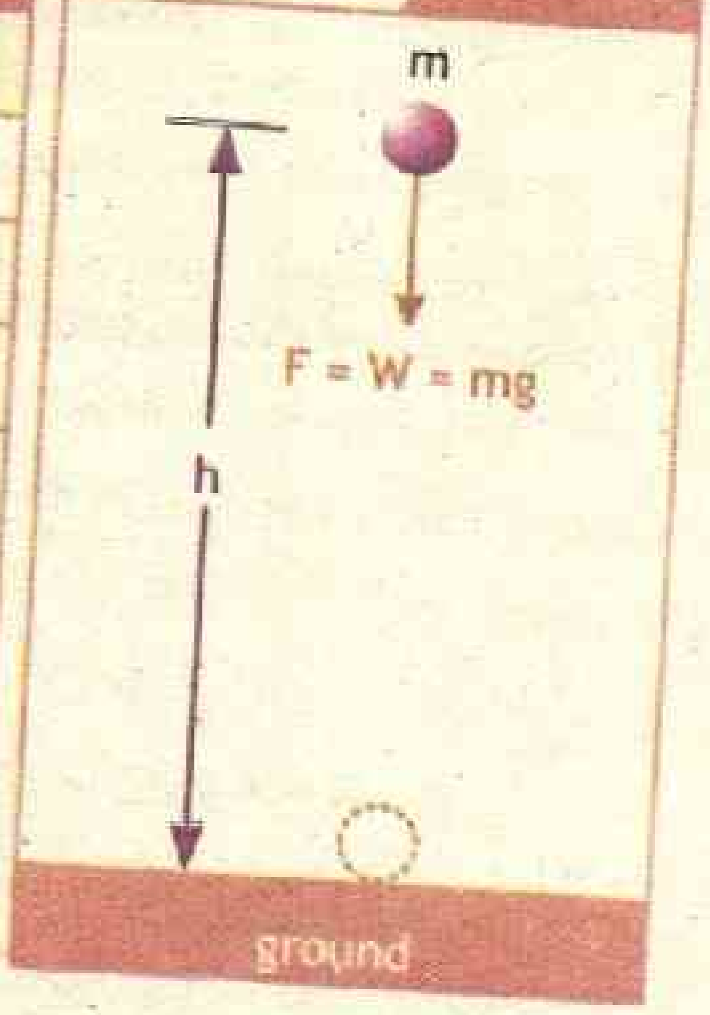
Since the force in this case is equal to its weight

$$F = W = mg \quad (2)$$

TABLE 6.2: Energy of Various Objects and Phenomena

Object/phenomenon	Energy in joules
Big Bang	10^{68}
Annual world energy use	4×10^{20}
1 kg uranium	4×10^{13}
1 ton TNT	4.2×10^{9}
1000-kg car at 90 km/h	3.1×10^{5}
Tennis ball at 100 km/h	22
Single electron in TV Screen	4×10^{-15}
Energy to break one DNA strand	10^{-19}

Figure 6.7



Here the distance moved is the height 'h' $S = h \quad (3)$

putting equation 2 and 3 in equation 1, we get

$$E_{GP.E} = mg \times h \quad (6.4)$$

Example 6.3 HUMAN JUMP

The maximum height a typical human can jump is about 60 cm. By how much does the gravitational potential energy increase for a 72-kg person in such a jump? Where does this energy come from?

SOLUTION

GIVEN:
mass m = 72 kg
height h = 60 cm = 0.06 m
acceleration due to gravity g = 9.8 m/s²

REQUIRED:
Gravitational Potential energy E_p = ?

The gravitational potential energy is given as

$$E_{GP.E} = mg \times h$$

putting values $E_{GP.E} = 72\text{kg} \times 9.8\text{m/s}^2 \times 0.6\text{m}$

$$E_{GP.E} = 423.36\text{J}$$

rounding off $E_{GP.E} = 420\text{J}$ — Answer

This gravitational potential energy comes from elastic potential energy stored in the jumper's tensed muscles.

Assignment 6.3 GAIN IN GRAVITATIONAL POTENTIAL ENERGY

An object of mass 10 kg is lifted vertically through a height of 5 m at a constant speed. What is the gravitational potential energy gained by the object?

6.5 ENERGY CONVERSION AND CONSERVATION

The law of conservation of energy states that '**energy can neither be created nor destroyed in any process. It can be converted from one form to another, but the total amount remains constant**'. The following examples explain the law of conservation of energy.

1. **A diver on a spring board:**

Stored chemical energy in the body of the diver allows him to bend the diving board. This causes the bent diving board to store elastic potential energy which is then converted into kinetic energy as an upward push.

2. **Generation of Electricity:**

Potential energy of water which is stored at a certain height is converted into kinetic energy by making it fall on turbine to produce electricity.

3. **Pole vault:**

Pole vaulters undergo several energy conversions. The initial run gives the vaulter kinetic energy. The vaulter plants the pole, transforming kinetic energy into potential energy of the deformed pole. Then the pole straightens and lifts the vaulter over the bar, transforming its elastic potential energy into gravitational potential energy. The athlete then falls toward's the pit, exchanging gravitational potential energy for kinetic energy. Finally, kinetic energy is dissipated in deforming the landing cushion.

POINT TO PONDER

What type of energy weightlifter used to lift weight?

The stored chemical energy in food enables a weightlifter to lift the barbell over her head.

6.5.1 MASS ENERGY EQUIVALENCE:

Einstein's mass energy equation is given by $E = mc^2$, *In other words:*

Energy = mass × the speed of light squared

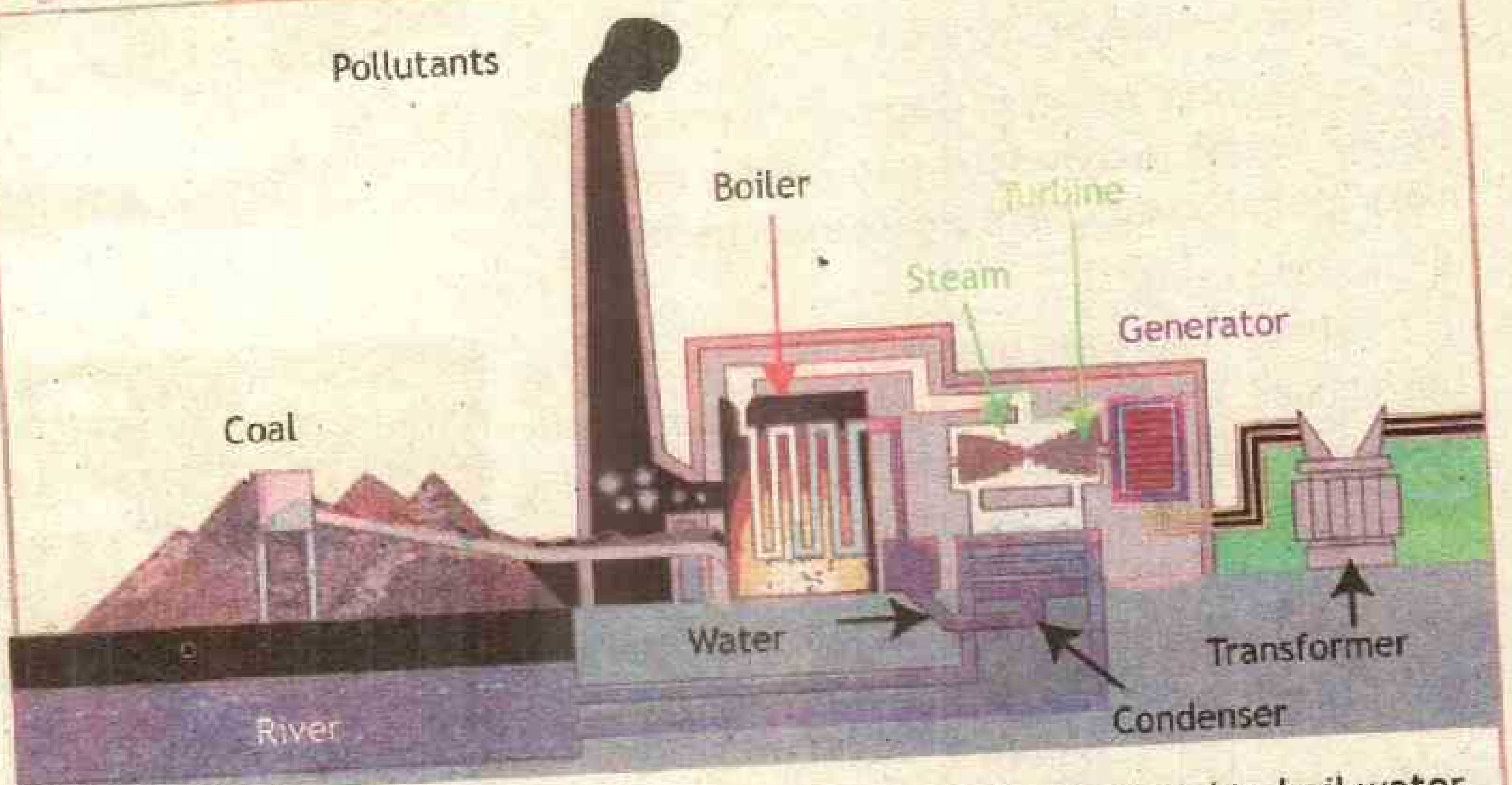
E = energy (measured in joules, J)

m = mass (measured in kilograms, kg)

c = the speed of light (measured in metres per second, ms^{-1}),

Speed of light is constant having value 3×10^8 ms^{-1}, however this value needs to be squared. This equation shows that mass and energy are the same physical entities and can be changed into each other.

Figure 6.8 PRODUCING ELECTRICAL ENERGY



In a power station, energy from a fuel (like burning coal) is used to boil water. The light-pressure steam is used to turn a turbine, which turns a generator to produce electricity

INFORMATION

Some insects jump using a catapult technique. The knee joint of a flea contains an elastic material called resilin (a rubber-like protein). The flea slowly bends its knee, stretching out the resilin and storing elastic energy, and then locks its knee in place . When the flea is ready to jump, the knee is unlocked and the resilin quickly contracts with a sudden conversion of the stored elastic energy into kinetic energy. Some of this kinetic energy is then converted into gravitational potential energy as the flea moves higher and higher.

Example 6.4 ENERGY WITHIN US

What is the energy released, when 50 kg person is converted completely into energy?

SOLUTION

GIVEN:

mass m = 50 kg

speed of light $c = 3 \times 10^8\ ms^{-1}$

REQUIRED:

Energy E = ?

By Einstein Famous equation

$$E = mc^2$$

putting values $E = 50\,kg \times (3 \times 10^8\ ms^{-1})^2$

therefore $E = 4.5 \times 10^{18}\ J$ — **Answer**

This is 450,000,000,000,000,0000 J, which is an incredibly large amount of energy. Equivalent to billion tons of TNT.

EXTENSION EXERCISE 6.2

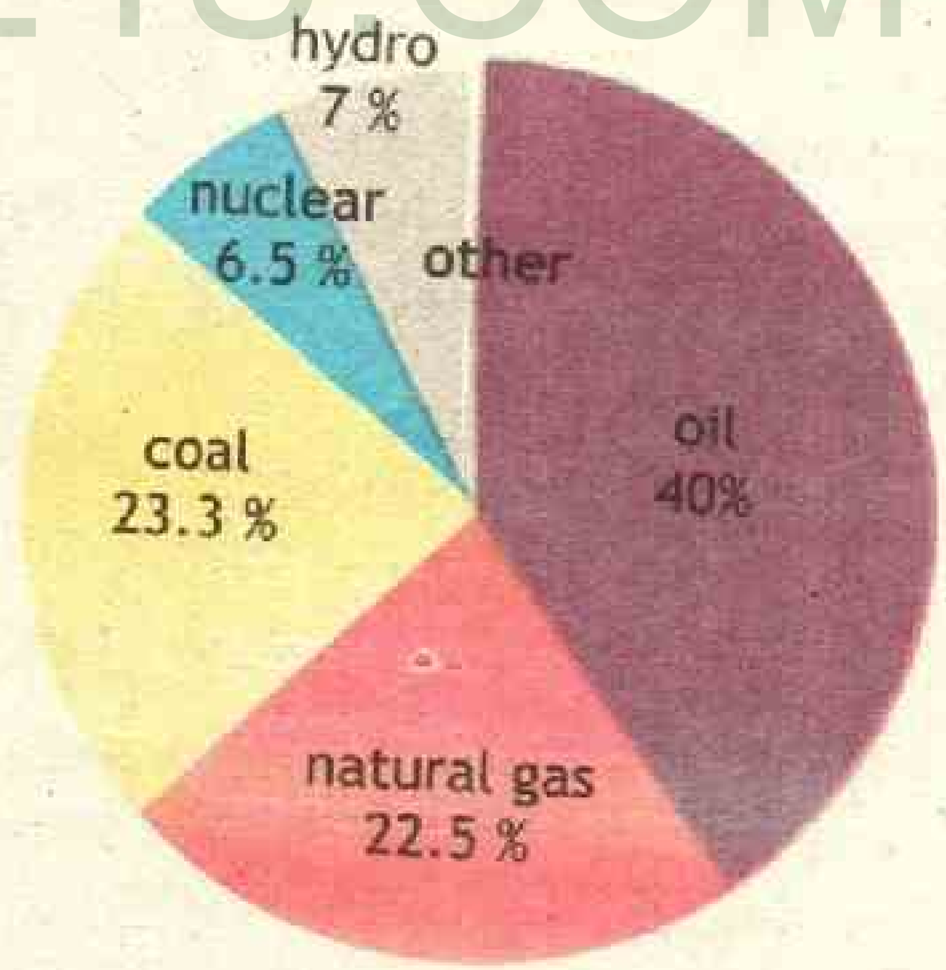
Find your mass and convert it into energy.

Assignment 6.4 ONLY 1g OF ENERGY

How much energy is generated when mass of 1g is completely converted into energy?

6.6 MAJOR SOURCES OF ENERGY

Energy transformation technologies convert energy from some source into a useful form of energy. The original source of the energy, called an energy resource, is a raw material obtained from nature that can be used to do work. A resource is considered renewable if it renews itself in the normal human life-span. All other resources are considered non-renewable.



Energy usage of the world

Scientific and technological advances have led society from a world that required only food energy to be transformed into muscle power, to one that makes use of every imaginable form of energy. In every energy-transformation process, some useful energy is lost. Clearly, society cannot continue to demand more and more energy without consideration for the future generations.

The challenge is to develop energy sources and processes that are sustainable. A sustainable resource is one that will not deplete over time and will not damage Earth's sensitive biosphere, while still being able to provide for the energy demands of society. Some of the important energy resources are:

A. Fossil Fuels:

Fossil fuels are the remains of millionyear- old plant life – now coal – or aquatic animal life – now gasoline and natural gas.

1. Coal:

Coal is the most abundant fossil fuel in the world, with an estimated reserve of one million metric tons. but burning coal results in significant atmospheric pollution.

2. Oil:

Crude oil is refined into many different energy products such as gasoline, jet fuel and heating oil. Despite the limited reserves of oil in the world it is a preferred source over coal because oil produces more energy than same amount of coal.

3. Natural gas:

Natural gas is often a by product of oil, it is mixture of gases the most common of which is methane. The advantage that natural gas has is that, it is easy to transport.

Fossil fuels are consumed in more than 80% of the world demand for energy. However the waste gases produced in the consumption is polluting the atmosphere.

Figure 6.9 FOSSIL FUELS

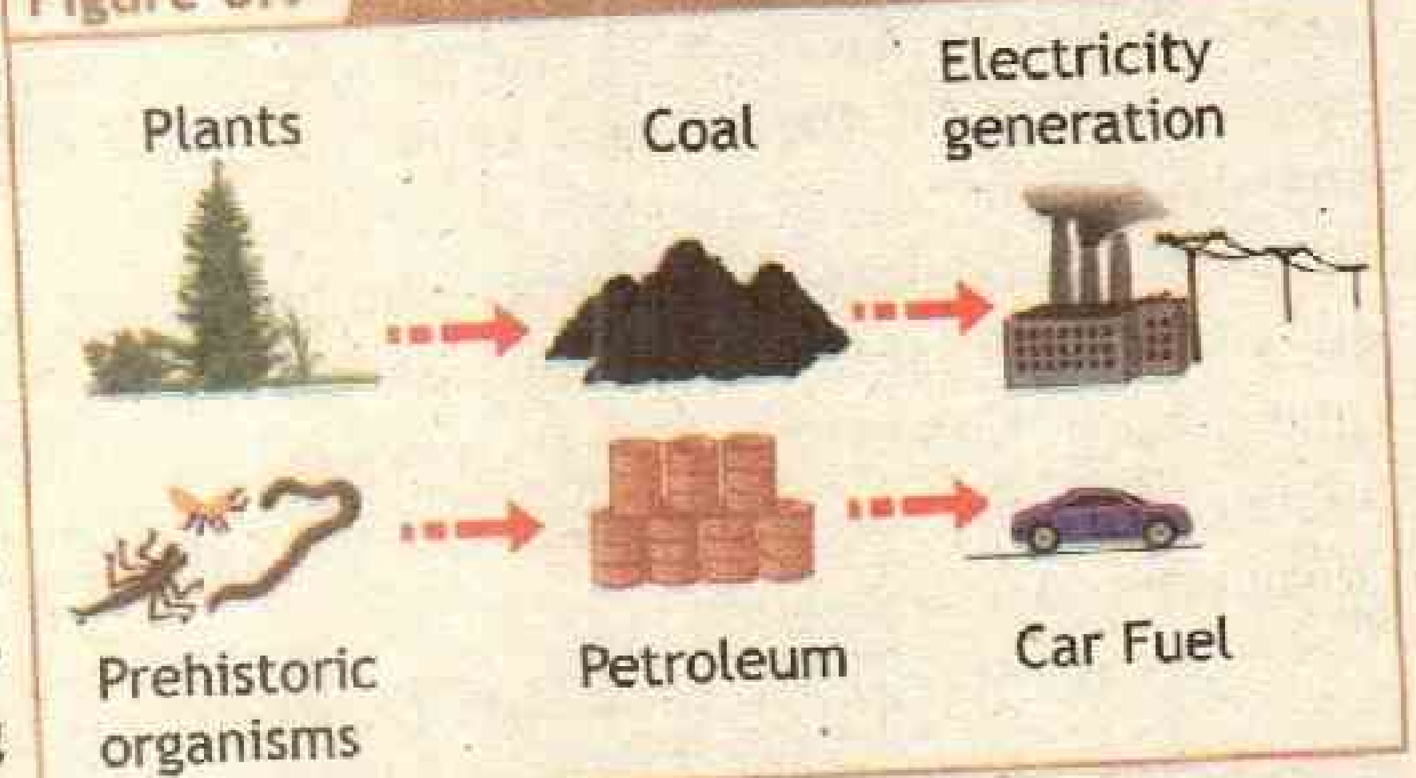


Figure 6.10 BIOMASS

B. Bio-mass:

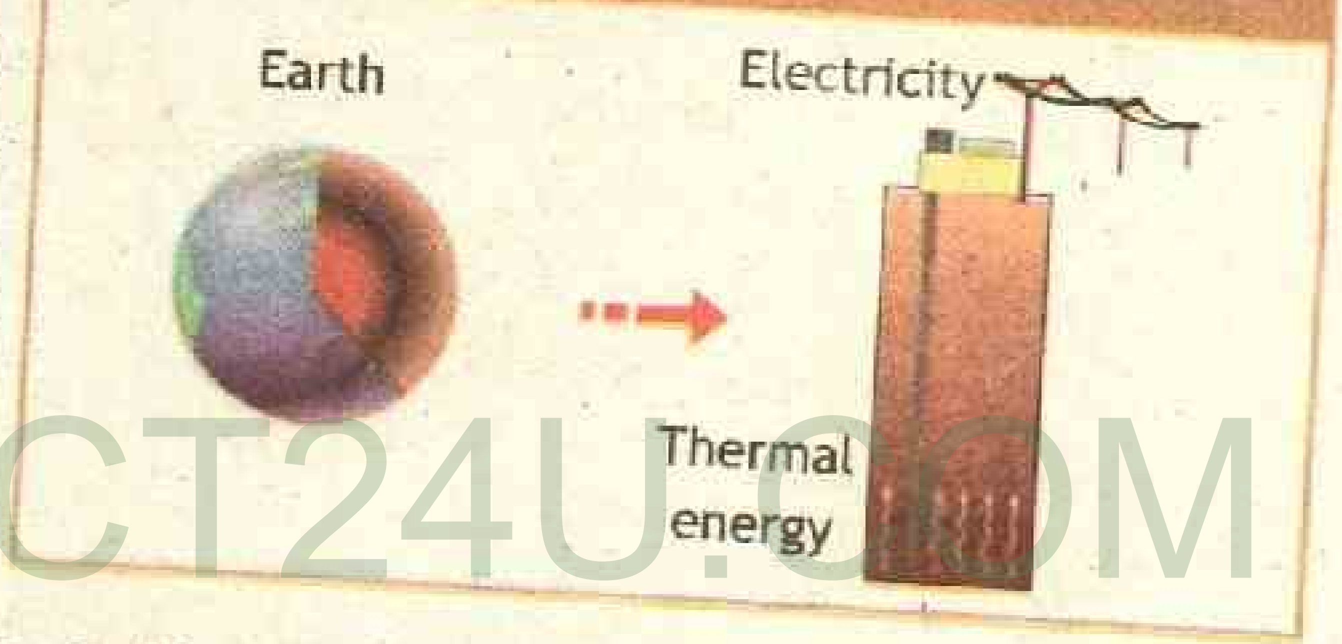
"Bio" means life, so bio-energy is energy from living things. The term "biomass" refers to the material from which we get bio-energy. Biomass is produced when the Sun's solar energy is converted into plant matter (carbohydrates) by the process of photosynthesis. Only green plants and photo synthetic algae, containing chlorophyll, are able to use solar energy.

The simplest process employed to make use of this energy is eating. Every time you eat a fruit, a vegetable, or a processed version of either, you are taking advantage of the energy stored as biomass.

C. Geothermal Energy:

Geothermal energy is the energy recovered from Earth's core. The thermal energy contained within Earth's core results from energy trapped almost five (5) billion years ago during the formation of the planet. In many countries geothermal energy is used to generate electricity.

Figure 6.11 GEOTHERMAL



D. Wind Energy:

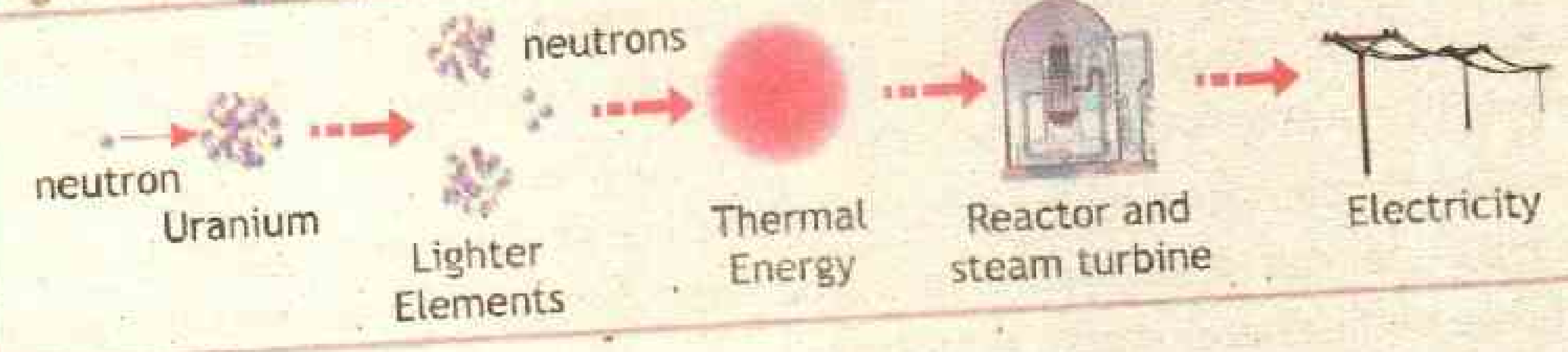
The kinetic energy of the wind is currently used in many parts of the world to generate electricity. It is eco friendly source of energy but require very large open space.

E. Nuclear Energy:

Nuclear fission is the process of splitting extremely large atoms (Like Uranium or Polonium) into two or more pieces, which releases an enormous amount of energy in the form of radiation or heat. The heat is used to boil water that eventually is used to produce electricity. In nuclear reactor small quantities of fuel produce large amounts of energy ($E = mc^2$). However there is the potential for catastrophic damage to human life and the environment that an accident – however unlikely – could cause.

Figure 6.12 WIND

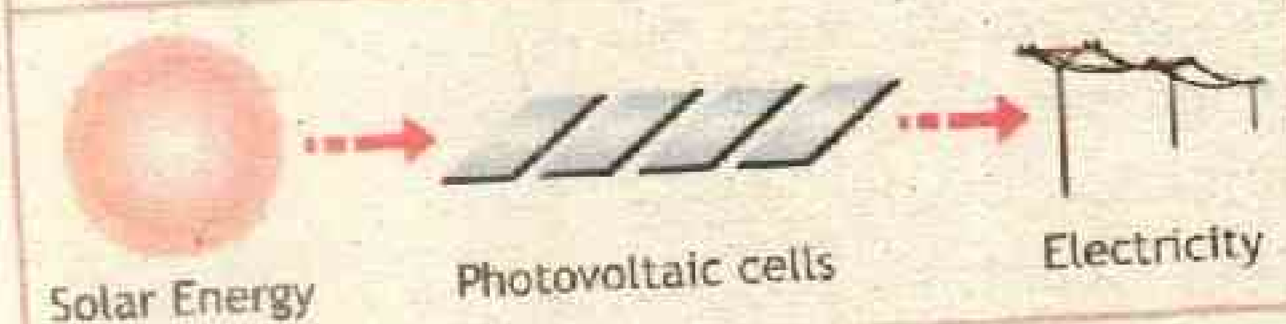
Figure 6.13 NUCLEAR



F. **Solar Energy:**

The energy from direct sun light can be used to produce electricity. Today, solar cells are used to power everything from calculators and watches to small cities. Sunlight, the fuel required by solar cells, is 100% free and is very eco friendly. However just like wind energy significant land area is required to produce large amounts of electricity.

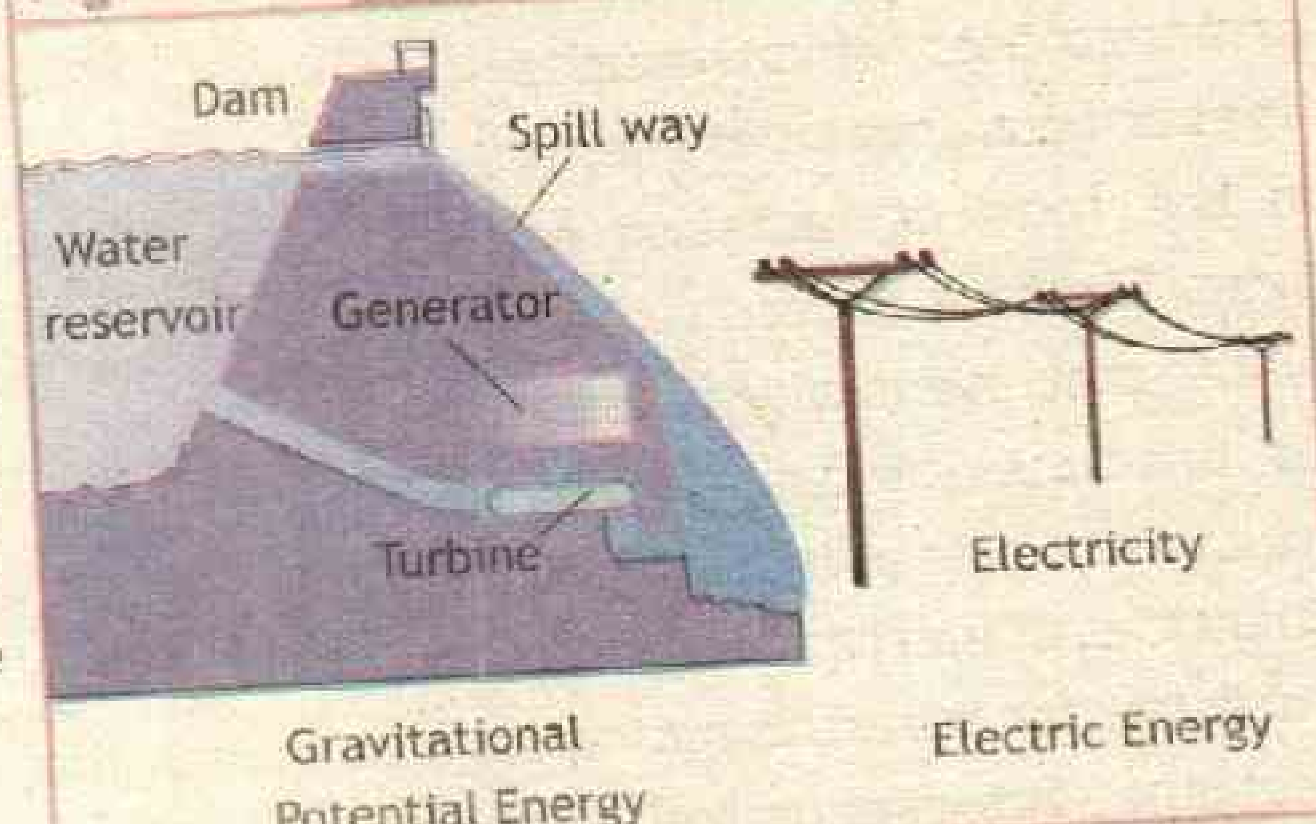
Figure 6.14 SOLAR



G. **Hydroelectric generation:**

Electric energy generation using the gravitational potential energy of water is known as hydroelectric generation. The force of gravity does work on the water, pulling it down and providing it with a tremendous amount of kinetic energy. This kinetic energy is transformed into electric energy by very large turbines. Such large reservoirs sometimes flood thousands of hectares of farmland drastically altering the ecosystem. For many years, engineers did not have the technology to economically use smaller reservoirs for generating electricity. With improvements in technology, smaller generation facilities are becoming much more popular.

Figure 6.15 HYDRO



6.7 EFFICIENCY

A light bulb is designed to convert electric energy into light energy. A car engine is designed to convert chemical potential energy stored in the fuel into kinetic energy for the car. While the light bulb and the car engine are transforming some of the potential energy into the desired form of energy, part of its energy is 'lost'.

As you know, energy can neither be created nor destroyed. The lost energy is converted into forms that do not serve the intended purpose. Often the lost energy is transformed into heat. The efficiency of a machine or device describes the extent to which it converts input energy or work into the intended type of output energy or work.

Efficiency is the ratio of useful energy or work output to the total energy or work input.

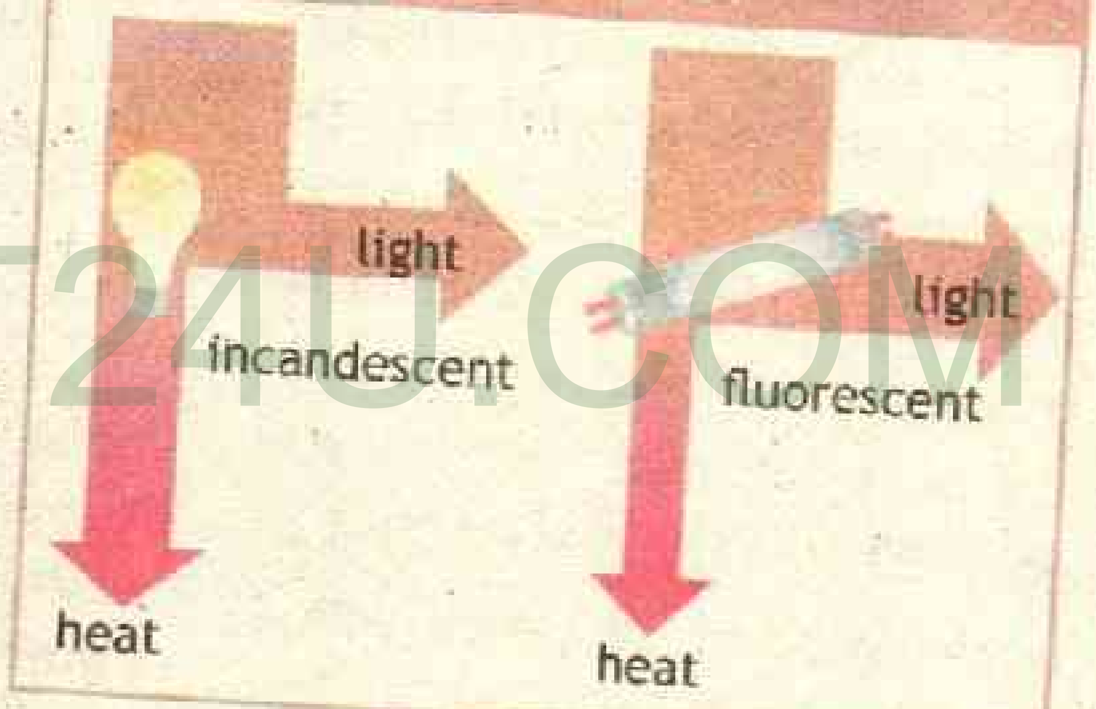
$$\text{efficiency} = \frac{\text{useful output work}}{\text{input work}}$$

$$\text{or efficiency} = \frac{W_o}{W_i} \quad (6.5)$$

$$\text{efficiency} = \frac{\text{useful energy output}}{\text{energy input}}$$

$$\text{or efficiency} = \frac{E_o}{E_i} \quad (6.6)$$

Figure 6.16 EFFICIENCY



Efficiency is the ratio of same quantities and therefore units cancel, therefore efficiency has no units. An incandescent light bulb is designed to provide light energy. Unfortunately, it also produces a lot of thermal energy while in use. In fact, only about 5% of the electrical energy delivered to the bulb transforms to light energy; the rest becomes waste thermal energy. We say that the incandescent light bulb is only 5% efficient.

A florescent lamp is about 20 % efficient of converting electrical energy into light as shown in the figure 6.16. Efficiency, expressed as a percentage, is the ratio of the useful energy provided by a device to the energy required to operate the device. The efficiency of an energy transformation as percentage is calculated as follows:

$$\text{efficiency} = \frac{E_o}{E_i} \times 100\% \quad (6.7)$$

It is not possible to have a machine with 100% efficiency, because friction lowers the efficiency of a machine. Work output is always less than work input, so an actual machine wasting input energy as heat(which is not required) cannot be 100% efficient. Typical Efficiencies of Energy Transformation Technologies are shown in the table 6.3.

TABLE 6.3 : Typical Efficiencies of Energy Transformation Technologies

Device	Efficiency (%)
electric generator	98
hydroelectric power plant	95
large electric motor	95
home gas furnace	85
wind generator	55
fossil fuel power plant	40
automobile engine	25
fluorescent light	20
incandescent light	5

6.8 POWER:

The definition of work makes no reference to the passage of time. For example, if you lift a barbell weighing 100 N through a vertical distance of 1.0 m at constant velocity, you do (100 N) (1.0 m) = 100 J of work whether it takes you 1 second or 1 hour to do it. But often we need to know how quickly work is done. We describe this in terms of power.

INFORMATION

Solar energy can be used to power road signs. Photo voltaic cells convert the energy of light into electric energy.

Power is the time rate at which work is done. Mathematically

$$P = \frac{W}{t} \qquad (6.8)$$

Like work, power is a scalar quantity. The SI unit of power is watt (W), in honour of James Watt, a Scottish physicist who invented the first practical steam engine. From equation (6.8), the unit of power is given by 1 watt = 1 joule / 1 second or in symbols 1 W = 1 Js^{-1}

INFORMATION

Shuttle puts out a few GW (giga-watts, or 10^9 W) of power!

In the British system, the unit of power is the foot-pound per second (ft.lb/s).

For practical purposes, a larger unit is often used, the **horse power** (hp). One horsepower (hp) is defined as 550 ft.lb/s which equals 746 W.

$$1 \text{ hp} = 746 \text{ W}$$

A unit of energy (or work) can now be defined in terms of the unit of power. One **kilowatt hour (kWh)** is the energy converted or consumed in 1h at the constant rate of 1kW = 1000 J/s. The numerical value of 1 kWh is, **1 kWh = (10^3 W)(3600 s) or 1 kWh = 3.6 ×10^6 J**

The electricity bills that we pay are measured in terms of this unit.

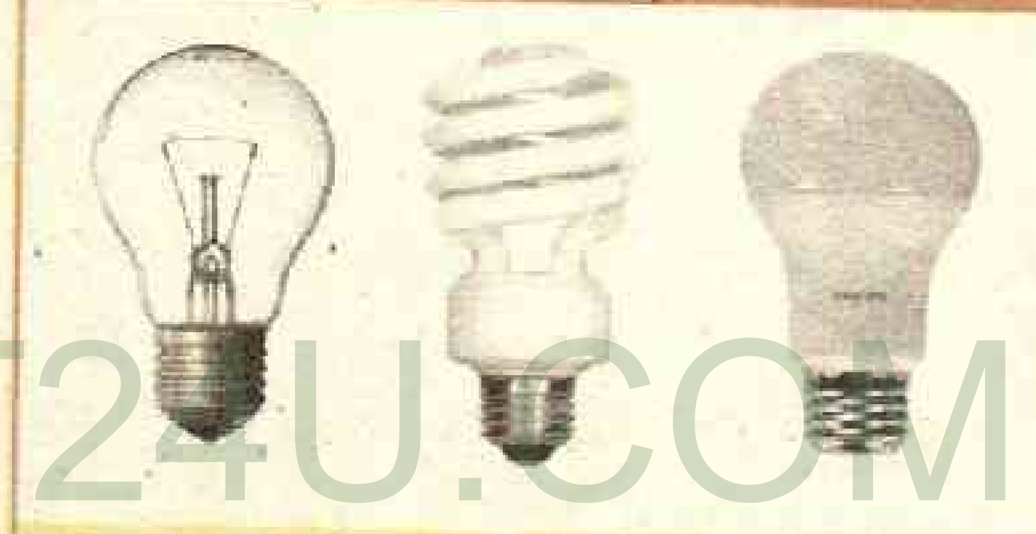
TABLE 6.4: Power Output or Consumption

Object/phenomenon	Power in Watts
Milky Way galaxy	10^{37}
Sun	4×10^{26}
Lightning bolt	2×10^{12}
Nuclear power plant (total)	3×10^{9}
Car (total)	8×10^{4}
Person at rest (all heat transfer)	100
Electric clock	3
Pocket calculator	10^{-3}

INFORMATION

Light bulbs are rated with a certain number of watts. Many light fixtures have limits on the power of light bulb that can be used. Stereo speakers are rated according to their power output in watts

POINT TO PONDER — ENERGY



The light Generated by 16 W LED is same as light emitted by 23 W CFL and 100 W bulb. What are the energy used per day (24hrs) for these three types in kWh.

TID-BIT — RUNNING 100 W

The energy does a 100-watt light bulb use is W = PΔt = (100W)(3600s) W= 3.6 × 10^5 J. How fast would a 70-kg person have to run to have that amount of kinetic energy?

Example 6.5 — CRANE POWER

A crane is capable of doing 1.50 × 10^5 J of work in 10.0 s. What is the power of the crane in watts and hp?

SOLUTION

GIVEN:

Work $W = 1.50 \times 10^5$ J

time t = 10 s

REQUIRED:

Power P = ?

By definition of power $P = \frac{W}{t}$

putting values $P = \frac{1.50 \times 10^5 J}{10 s}$

or $P = 1.50 \times 10^4 J/s$

therefore $P = 1.50 \times 10^4 W$ — Answer

the conversion factor for hp to W is 1 hp = 746 W

or $1 W = \frac{1}{746} hp$

or $1.50 \times 10^4 W = \frac{1.50 \times 10^4}{746} hp$

Hence $1.50 \times 10^4 W = 20 hp$

therefore $P = 20 hp$ — Answer

Assignment 6.5 ELECTRIC HEATER

An electric heater is heated at 250 W. Calculate the quantity of heat generated in 10 minutes.

KEY POINTS

Work: Work is force multiplied by distance moved in the direction of the force **W = FS cos θ**

Energy: Energy is the capacity of a body to do work.

Kinetic Energy: It is the energy of an object due to its motion and is given by $E_k = \frac{1}{2} m v^2$

Potential Energy: It is the energy of an object due to its position. Gravitational potential energy is given by $E_{P,grav} = mgh$

Law of conservation of energy: Energy can neither be created nor destroyed in any process. It can be converted from one form to another or transferred from one body to another, but the total amount remains constant.

Power: It is the rate of doing work or rate of conversion of energy. **P = W/t**

PROJECTS

GROUP - A

RESEARCH ARTICLE ON LIGHT TYPES EFFICIENCIES: Search library or internet and compare the efficiencies of lighting technology available in Pakistan (incandescent bulbs, fluorescent lamps, LED lights). Compare their advantages and disadvantages. Write a research article for school library.

GROUP - B

ENERGY GENERATION MODELS: Create your own homemade models of structures, such as wind turbines and geothermal plants, and put them to work with wind and water power donate the model for school laboratory.

GROUP - C

ARTICLE ON ENERGY **FOR SCHOOL MAGAZINE:** Pakistan is hit by worst energy crisis in the recent years. Analyze the economic , social and environmental impact of various energy sources. e.g. fossil fuel, wind, falling water, solar, biomass, nuclear, thermal energy. Research different types of power generation facilities developed in Pakistan to overcome this problem and articulate which energy resource must be used in Pakistan for energy production. Write your research article to be published in school magazine.

GROUP - D

SPORTS AND ENERGY CONSERVATION: Make a presentation of energy to explain improvements in sports performance using principles and concepts related to work and law of conservation of energy.

GROUP - E

YOUR POWER: Design experiments for measuring your power output when doing push-ups, riding on swings running up a flight of stairs, loading boxes onto a truck, throwing a cricket ball, or performing other energy transferring activities. What data do you need to measure or calculate? Form groups to present and discuss your plans. If your teacher approves your plans, perform the experiments.

EXERCISE

MULTIPLE CHOICE QUESTIONS

Choose the best possible answer:

1. Work done will be zero when the angle between force and displacement is
   A. 30° B. 45° C. 60° D. 90°
2. 30 N force is exerted and the trolley moves a distance of 5 m in the direction of the force, the work done is
   A. 6 J B. 25 J C. 150 J D. 0.17 N
3. If the speed of a car decreases by half, The kinetic energy change by factor
   A. 4 B. 2 C. 1/2 D. 1/4
4. An object of mass 10 kg is lifted vertically through a height of 5 m. The gravitational potential energy gained by the object is
   A. 0.5 J B. 2 J C. 50 J D. 490 J
5. If a petrol engine does 20 J of useful work for every 100 J of energy supplied to it, then its efficiency is
   A. 80 % B. 60 % C. 40 % D. 20 %
6. kWh is unit for
   A. Energy B. Power C. Efficiency D. None
7. 1 hp =
   A. 476 W B. 550 W C. 746 W D. 1 ft.lb/s
8. Hira weighing 500 N takes 90 s to reach the top of a hill 18 m high. Her average muscle power is
   A. 2500 W B. 100 W C. 32.8 W D. 3.24 W
9. A machine is able to lift 200 N of concrete slab vertically up to a height of 30 m above the ground in 50 s. The average power of the machine is
   A. 1.33 W B. 60 W C. 120 W D. 6000 W

CONCEPTUAL QUESTIONS

Give a brief response to the following questions.

1. Can a centripetal force ever do work on an object? Explain.
2. What happens to the kinetic energy of a bullet when it penetrates into a sand bag?
3. A meteor enters into earth's atmosphere and burns. What happens to its kinetic energy?
4. Two bullets are fired at the same time with the same kinetic energy. If one bullet has twice the mass of the other, which has the greater speed and by what factor? Which can do the most work?
5. Can an object have different amounts of gravitational potential energy if it remains at the same elevation?
6. Why do roads leading to the top of a mountain wind back and forth?
7. Which would have a greater effect on the kinetic energy of an object, doubling the mass or doubling the velocity?
8. If the speed of a particle triples, by what factor does its kinetic energy increase?
9. The motor of a crane uses power P to lift a steel beam. By what factor must the motor's power increase to lift the beam twice as high in half the time?

COMPREHENSIVE QUESTIONS

Give an extended response to the following questions.

1. Define work and explain how work is calculated if force is applied at an angle.
2. Define kinetic energy. Derive the expression used for kinetic energy.
3. What is potential energy? Prove that the gravitational potential energy of a body of mass m at a height h above the surface of earth is given by mgh.
4. State the law of conservation of energy and mass energy conversion relation.
5. Explain briefly major sources of energy. Such fossil fuel, wind, solar, biomass, nuclear and thermal energy.
6. Define and explain efficiency.
7. Define and explain power.

NUMERICAL QUESTIONS

1. Determine the work done in each of the following cases:
   a) Kicking a soccer ball forward with a force of 40 N over a distance of 15 cm
   b) Lifting a 50-kg barbell straight up 1.95 m
2. Calculate the velocity of a 1.2 kg falling star (meteorite) with 5.5×10^8 J of energy.
3. Calculate the gravitational potential energy of a 2000 kg piano
   a) resting on the floor b) with respect to the basement floor, 1.9 m below.
4. An elevator weighing 5000N is raised to a height of 15.0 m in 10.0 s, how much power is developed?
5. What power is required for a ski-hill chair lift that transports 500 people (average mass 65 kg) per hour to an increased elevation of 1200 m?
6. How long will it take a 2750-W motor to lift a 385-kg sofa set to a sixth-story window 16.0 m above?
7. How much work can a 2.0-hp motor do in 1.0 h?

WEB LINKS

www.mowp.gov.pk/

http://www.aedb.org/

What is common in ice cube and water?

Unit 7

PROPERTIES OF MATTER

CHECK LIST

After studying this unit you should be able to:

- ✓ state kinetic molecular model of matter (solid, liquid and gas forms).
- ✓ describe briefly the fourth state of matter i.e. "Plasma".
- ✓ define the term 'Density'.
- ✓ compare the densities of a few solids, liquids and gases.
- ✓ define the term pressure (as a force acting normally on unit area).
- ✓ explain how pressure varies with force and area in the context of everyday examples.
- ✓ explain that the atmosphere exerts a pressure.
- ✓ describe how the height of a liquid column may be used to measure the atmospheric pressure.
- ✓ describe that atmospheric pressure decreases with the increase in height above the Earth's surface.
- ✓ explain that changes in atmospheric pressure in a region may indicate a change in the weather.
- ✓ state Pascal's law. Apply and demonstrate the use with examples of Pascal's law
- ✓ state relation for pressure beneath a liquid surface to depth and to density i.e., ($p=\rho gh$) and solve problems using this equation.
- ✓ state Archimedes principle. Determine the density of an object using Archimedes principle.
- ✓ state the upthrust exerted by a liquid on a body.
- ✓ state principle of floatation.
- ✓ explain that a force may produce a change in size and shape of a body.
- ✓ define the terms Stress, Strain and Young's modulus.
- ✓ state Hooke's law and explain elastic limit.

Look around , everything, from our body to the air we breath is matter. The features of a substance and how it behave are called its properties. Therefore it is important to know about the properties of matter. Knowing about properties of matter helps us to understand what ice cube rain and steam have in common? What is the impact of amount of substance in a body? How matter behaves when forces are applied? Questions like these can be answered after reading this chapter.

We will see how solids respond to external forces, and how fluids liquids and gases develop pressure that is responsible for such phenomena as buoyancy and fluid flow.

7.1 KINETIC MOLECULAR MODEL OF MATTER

It is a well established by chemical and physical evidence that matter is composed of molecules. Matter has three states solids, liquids and gases. These three states of matter are explained on the basis of Kinetic Molecular Theory. In kinetic molecular model, it is assumed that:

Solids:

1. Solids are made up of molecules which are arranged closely in a fixed pattern.
2. Molecules in solids vibrate about their mean positions.
3. The attractive forces between the molecules are strong.

Liquids:

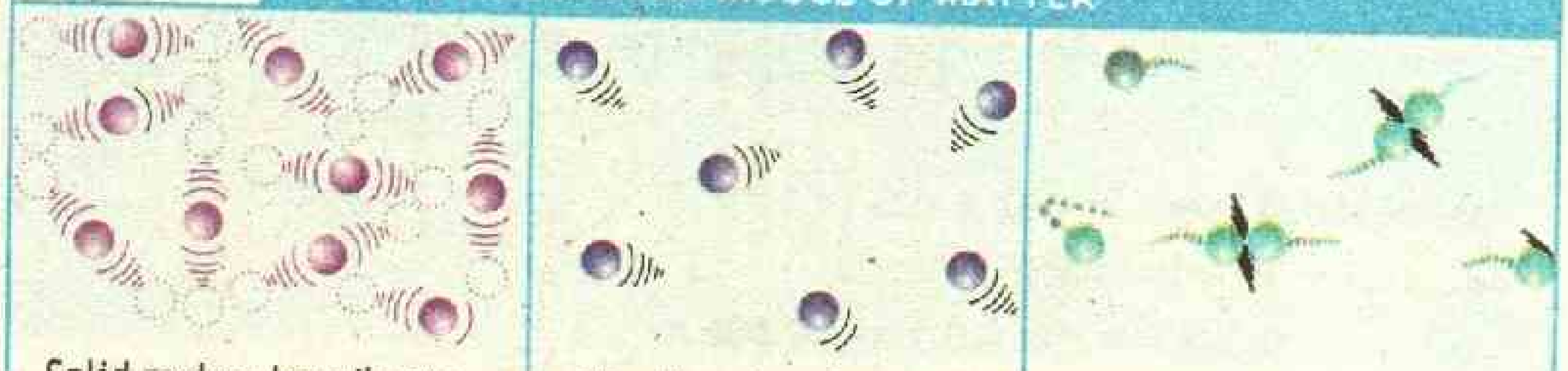
1. Liquids are also made up of molecules which are close together.
2. The pattern of molecules is not fixed and does not extend far. The molecules in a pattern keep changing their position.
3. Molecules are able to move about, which means that a liquid is able to change its shape and can adopt the shape of the container.
4. The attractive forces between the molecules of liquid is less than the solid..

Gases:

1. A gas is made up of molecules which are in constant random motion.
2. The distance between molecules is larger as compared to the size of the molecules.
3. The molecules are constantly colliding elastically with each other and with the walls of the container.
4. Forces between molecules are negligible, except during collisions.

Because liquids and gases do not maintain a fixed shape, they both have the ability to flow. They are thus also referred collectively as fluids.

Figure 7.1 KINETIC MOLECULAR MODEL OF MATTER



Solid molecules vibrate in fixed positions. | Liquid molecules flow over each other. | Gas molecules move rapidly in all directions and collide.

PLASMA:

There is another state of matter, the fourth state, called Plasma. It consists of free electrons and atoms from which the electrons have been removed. Plasma exists in the sun, where thermonuclear reactions take place at very high temperatures.

7.2 DENSITY

Density of a substance is defined as the mass of substance per unit volume. For example iron is denser than air, because iron has more mass in the same volume as compared to air. Conversely for same mass of iron and air, volume of iron will be less than air. Symbolically density is denoted by 'ρ' (called Rho). For an object of mass 'm' and volume 'V', density is given as

$$\rho = \frac{m}{V} \qquad (7.1)$$

TABLE 7.1 DENSITIES

Material	Density (kg/m^3)
iron	7900
gold	19300
ice	920
polythene	900
petrol	800
pure water	1000
mercury	13600
air	1.3
carbon dioxide	2.0

Hence the S.I. unit of density is kg m^{-3}. Some common density values, are given in table 7.1.

Example 7.1 DENSITY OF METAL

A rectangular metal piece has length 0.3 m, width 0.2 m and height 0.1 m. If its mass is 47.4 kg. Calculate its density.

SOLUTION

GIVEN:

Mass of metal piece m = 47.4 kg

Volume V = length × width × height

0.3 m × 0.2 m × 0.1 m = 0.006 m

REQUIRED:

density ρ = ?

By definition of density $\rho = \frac{m}{V}$

putting values $\rho = \frac{47.4\,kg}{0.006\,m^3}$

therefore $\rho = 7900\,kg\,m^{-3}$ —— Answer

From the table 7.1 we can see that it is density of iron, therefore the metal piece under study is that of iron.

Assignment 7.1 DENSITY OF DIAMOND

A diamond has a volume of 0.00002 m^3, its mass is measured as 0.072 kg. Calculate its density.

7.3 PRESSURE

Pressure is defined as force per unit area. Pressure is represented by letter 'P', if force 'F' is applied on area 'A', the pressure is

$$P = \frac{F}{A} \qquad (7.2)$$

The SI unit of pressure is the newton per square meter (N/m^2), which is given a special name, the pascal (Pa).

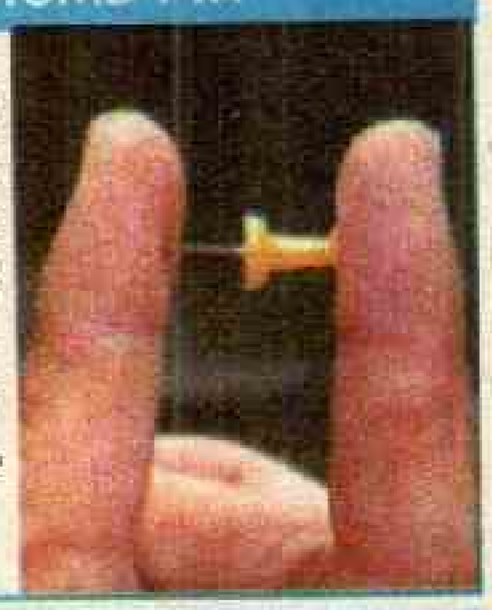
$$1Pa = \frac{1N}{1m^2}$$

QUIZ ? SMAE VOLUME OBJECTS

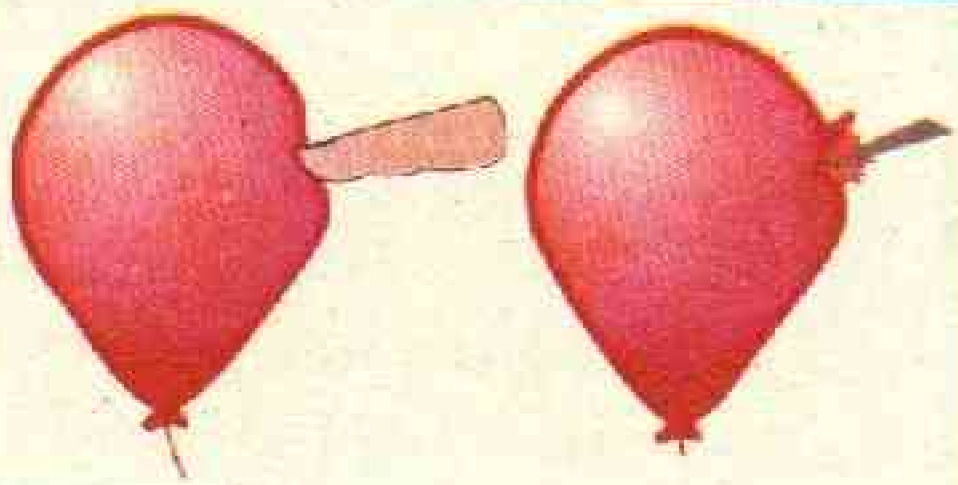
Which is a heavier, a cubic metre of steel or a cubic metre of wood? Why?

TID-BIT THUMB PIN

Assuming same force is applied at both ends of this thumb-pin, On which side pressure is greater?

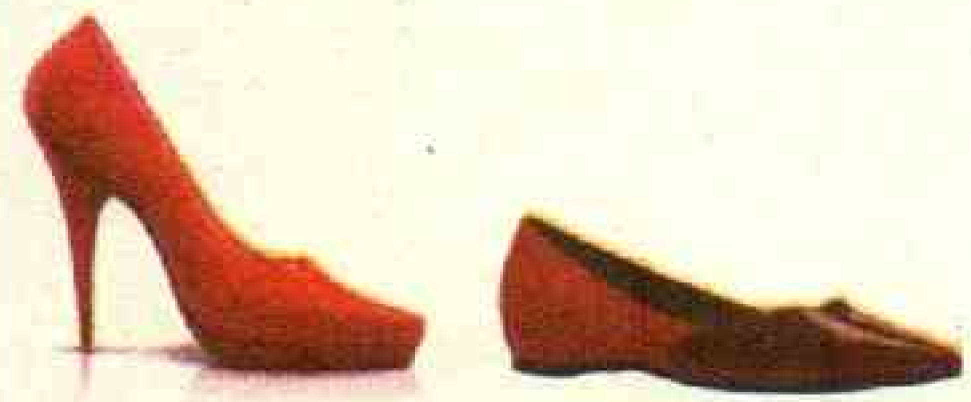


ACTIVITY PRESSURE AND PRICKING



Pressure is increased if the force applied to a given area is increased, or if a given force is applied to a smaller area. For example, if you press your finger against a balloon, not much happens—your finger causes a small indentation. On the other hand, if you push a needle against the balloon with the same force, you get an explosive pop. The difference is that the same force applied to the small area of a needle tip causes a large enough pressure to rupture the balloon.

POINT TO PONDER HEELES



Have you ever wonderd why getting steped on by heeled shoe hurts more than getting stepped by flat one?

Since the pressure depends upon the amount of force acting on the surface and size of the surface. Therefore for same force smaller surface exerts greater pressure. For the same reason the spiked shoes are painful to wear, as it concentrate your body weight (force) on the ball of foot.

Example 7.2 WEIGHT AS PRESSURE ON GROUND

A 40-kg girl's two feet cover an area of 500 cm^2 (a) Determine the pressure exerted by the two feet on the ground. (b) If the girl stands on one foot, what will be the pressure under that foot?.

SOLUTION

GIVEN:

Force F = Weight W = mg = 40 kg × 9.8 ms^{-2} = 392 N

Area A = 500 cm^2 = 500 × $(10^{-2})^2$ m^2 = 500 × 10^{-4} m^2 = 0.05 m^2

REQUIRED:

Pressure P = ?

(a) Assume the girl is at rest. Then she exerts a force equal to her weight mg on the ground where her feet contact it. Therefore by definition of pressure

$$P = \frac{F}{A}$$

putting values $P = \frac{392 N}{0.05 m^2}$

EXTENSION EXERCISE 7.1

What will be pressure if she is wearing heeled shoe with an area of tip 0.0001 m^2, and stand with all her weight on that tip?

or $P = 7840\,Nm^{-2}$

or $P = 7.8\times10^{3}\,Nm^{-2}$

or $P = 7.8\,kPa$ — Answer

(b) If the person stands on one foot, the force is still equal to the person's weight, but the area will be half as much, so the pressure will be twice as much

$P = 15.6\,kPa$ — Answer

Assignment 7.2 CONCRETE BLOCK

A block of concrete weighs 900 N and its base is a square of side 3 m. What pressure does the block exert on the ground?

7.4 ATMOSPHERIC PRESSURE

Pressure is particularly useful for dealing with fluids. It is an experimental observation that a fluid exerts pressure in every direction. This is well known to swimmers and divers who feel the water pressure on all parts of their bodies. A person need not be under water to experience the effects of pressure. Walking about on land, we are at the bottom of the earth's atmosphere, which is a fluid and pushes inward on our bodies just like the water in a swimming pool.

The pressure that atmosphere exerts is called atmospheric pressure. The pressure of the air at a given place varies slightly according to the weather. At sea level, the pressure of the atmosphere on average is $1.013\times10^{5}\,Nm^{2}$ (or 1.013×10^{5} Pa).This value lets us to define a commonly used unit of pressure, the atmosphere (abbreviated atm), such that 1 atm = 1.013×10^{5} Pa.

Another unit of pressure sometimes used (in meteorology and on weather maps) is the bar, which is defined as 1 bar = 1.000×10^{5} Pa

Thus standard atmospheric pressure is slightly more than 1 bar. The air around us exerts a force in all directions and is opposed by an equal pressure inside our body, thus we are generally unaware of it. However, when the air is pumped out of a sealed can, atmospheric pressure produces an inward force that is unopposed. The resulting collapse of the can illustrates the pressure that is all around us.

The climbers at high altitudes encounter lower atmospheric pressure due to the thinner air. The thinner air causes breathing difficulties due to the lower level of oxygen.

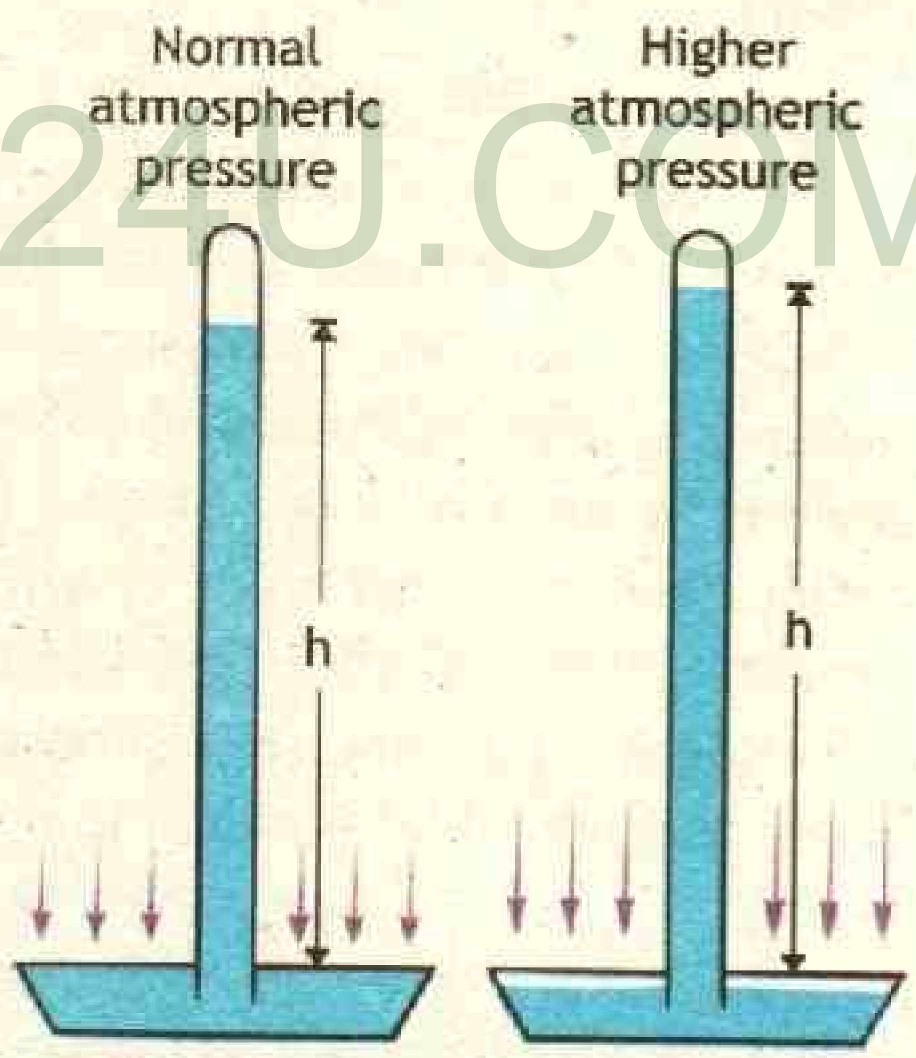
ACTIVITY USING ATMOSPHERIC PRESSURE TO CRUSH CAN

Figure shows a thin-walled metal can, attached to a vacuum pump. Before the air was pumped out, the pressure inside the can is equal to that outside (atmospheric) pressure. As the air is pumped out, a partial vacuum of very low pressure forms inside the can and immediately the external atmospheric pressure crushes the can. It will only happen if the material of the can is thin or flexible.

7.4.1 MEASUREMENT OF ATMOSPHERIC PRESSURE

An instrument that is commonly used to measure atmospheric pressure is the **mercury barometer**. Italian mathematician Evangelista Torricelli (1608-1647) invented it in 1643. Figure 7.2 shows a Torricellian barometer. A long tube that is open at one end and closed at the other is filled with mercury and then inverted into a dish of mercury. Once the tube is inverted, the mercury does not empty into the bowl. Instead, the atmosphere exerts a pressure on the mercury in the bowl. This atmospheric pressure pushes the mercury in the tube to some height 'h' above the bowl. In this way, the force exerted on the bowl of mercury by the atmosphere is equal to the weight of the column of mercury in the tube. Any change in the height 'h' of the column of mercury means that the atmosphere's pressure has changed. At sea level, the atmosphere will push down on a pool of mercury and make it rise up in a tube to a height of approximately 760mm.

Figure 7.2 BAROMETER



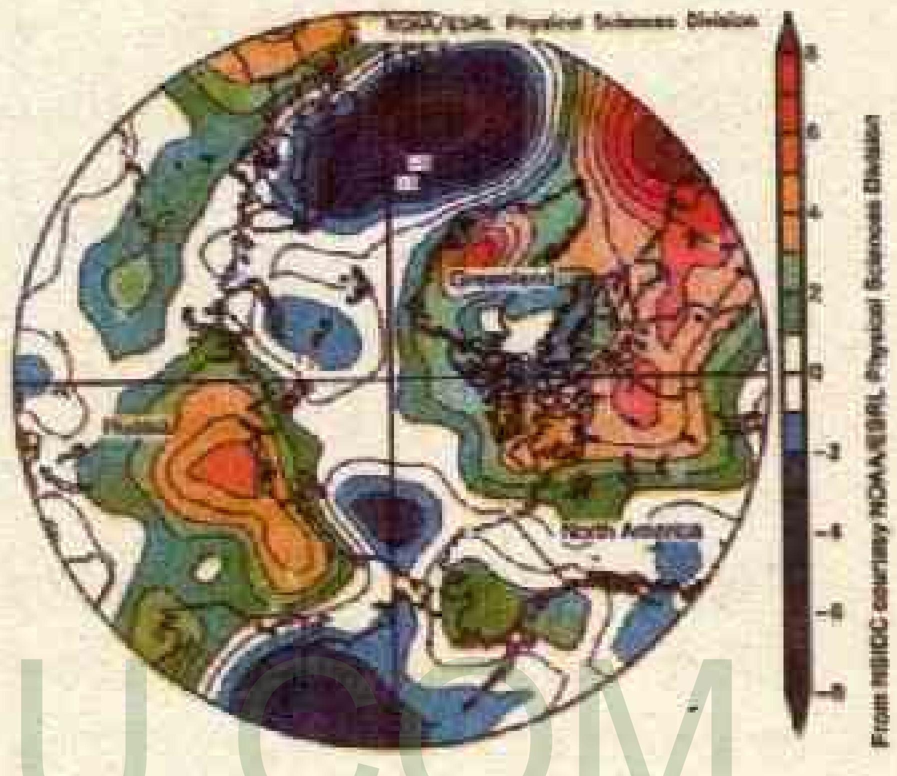
A mercury barometer. If there is no air in the tube, the air pressure on the mercury in the bowl forces the mercury to rise up the tube. The pressure at the bottom of the tube equals the air pressure. The higher the air pressure, the higher the column of mercury.

Is it possible to build a barometer with water rather than mercury?

Water is less dense (less heavy, in effect) than mercury so air pressure will lift a certain volume of water much higher up a tube than the same volume of mercury. In other words, if we use water, we would need a really tall tube and our barometer will be so enormous as to be impractical.

7.4.2 ATMOSPHERIC PRESSURE AND WEATHER

Sea level Pressure Anomaly (mb)
May 2011



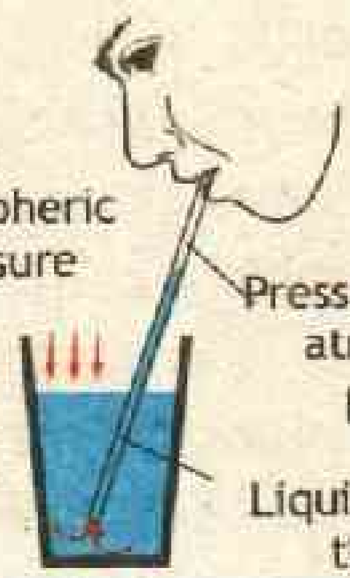
Barometers kept in the same place at the same height above sea level shows some variation in atmospheric pressure from day to day. These pressure variations are shown on weather maps. The lines in the map joining all those places with the same atmospheric pressure are called isobars. The unit for pressure used in weather maps is the millibar (mbar).

1000 mbar = 1 bar

1 bar = 100 kPa, nearly equal to normal atmospheric pressure. Usually the range of atmospheric pressure varies from the very high pressure of 1040 mbar to as low as 950 mbar. Winds move from high pressure regions to low pressure regions. In the northern hemisphere, the wind moves anticlockwise around areas of low pressure and clockwise around areas of high pressure. The strength of the wind is determined by the pressure gradient. From the weather map, when the isobars are packed closely together, it indicates a high pressure gradient. This means that strong winds may result.

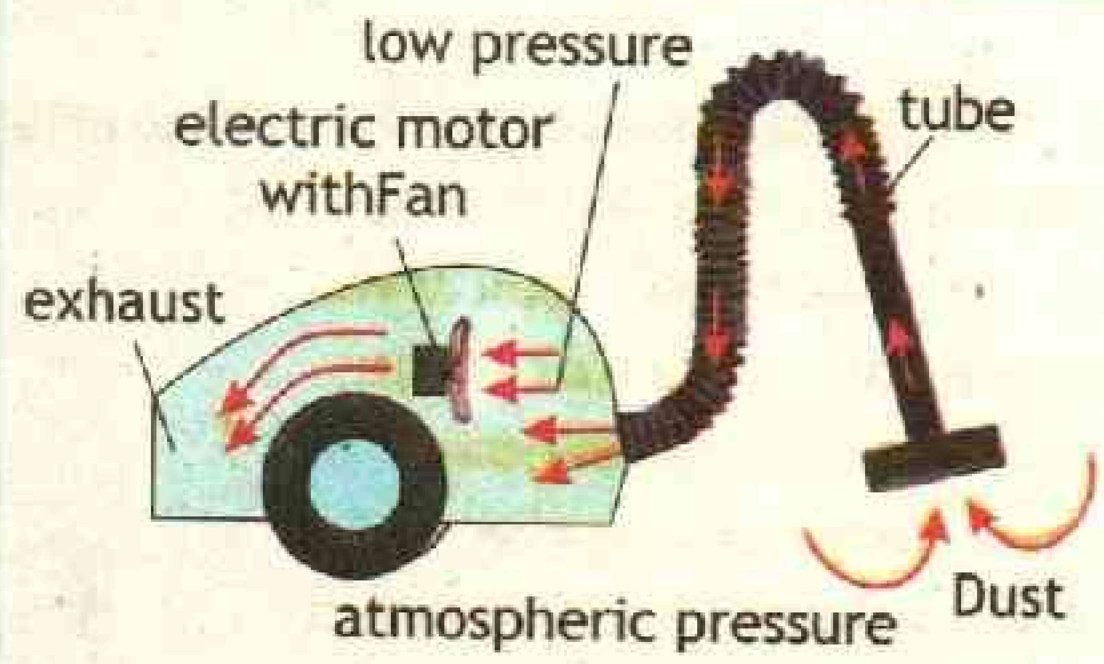
APPLICATION DRINKING THROUGH STRAW

The action of sucking increases the volume of lungs, thereby reducing the air pressure in the lungs and the mouth. The atmospheric pressure acting on the surface of the liquid will then be greater than the pressure in the mouth, thus forcing the liquid to rise up the straw into the mouth.



APPLICATION WORKING OF VACUUM CLEANER

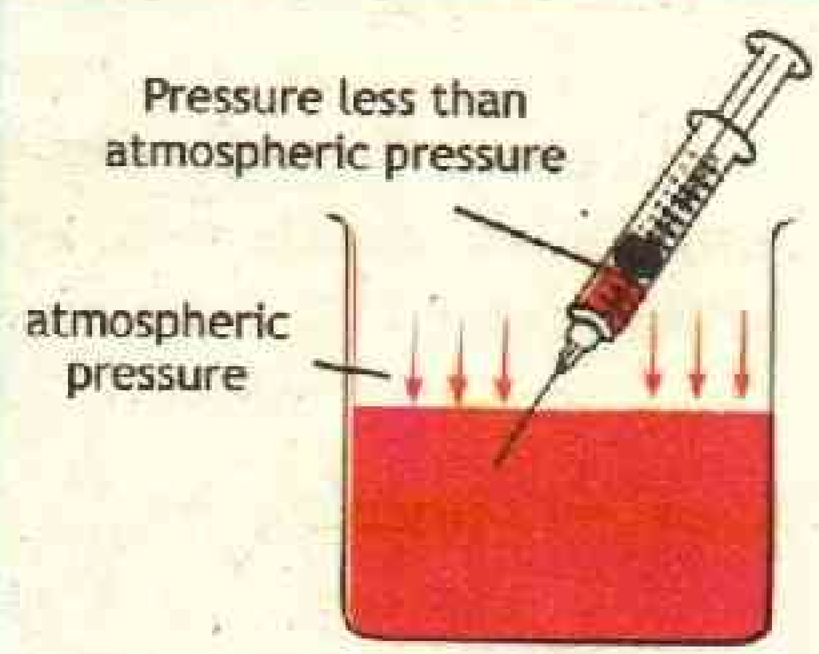
Vacuum cleaner consists of an electric motor with fan, filter bag (dirt bag) and a tube. When the electric motor is switched on the fan rotates in such a way it sucks the air inside container and sends it out through exhaust, creating a partial vacuum inside the container. By doing so, a low pressure region is created inside the container.



As we already know materials move from high pressure region to low pressure region, here, surrounding air moves from outside the container via the tube to inside the container. While surrounding air moves inside with more force, it gathers all the dirt and dust that comes across its way, thus pulling them inside the container. These dust and dirt particles are filtered and stored in the filter bag, which will be disposed later.

APPLICATION PULLING LIQUID UP THE SYRINGE

To draw liquid into the syringe, as shown in Figure, the piston of th⌐ sy·ˈnge is drawn back upwards. This decr⌐ ⸗ ressure within the cylinder. Atmospheric ⌐ sure acting on the surface of the liquid drives the liquid into ⌐linder through the nozzle of the syringe. .tomospheric pressure helps the fluid to lift up the cylinder.



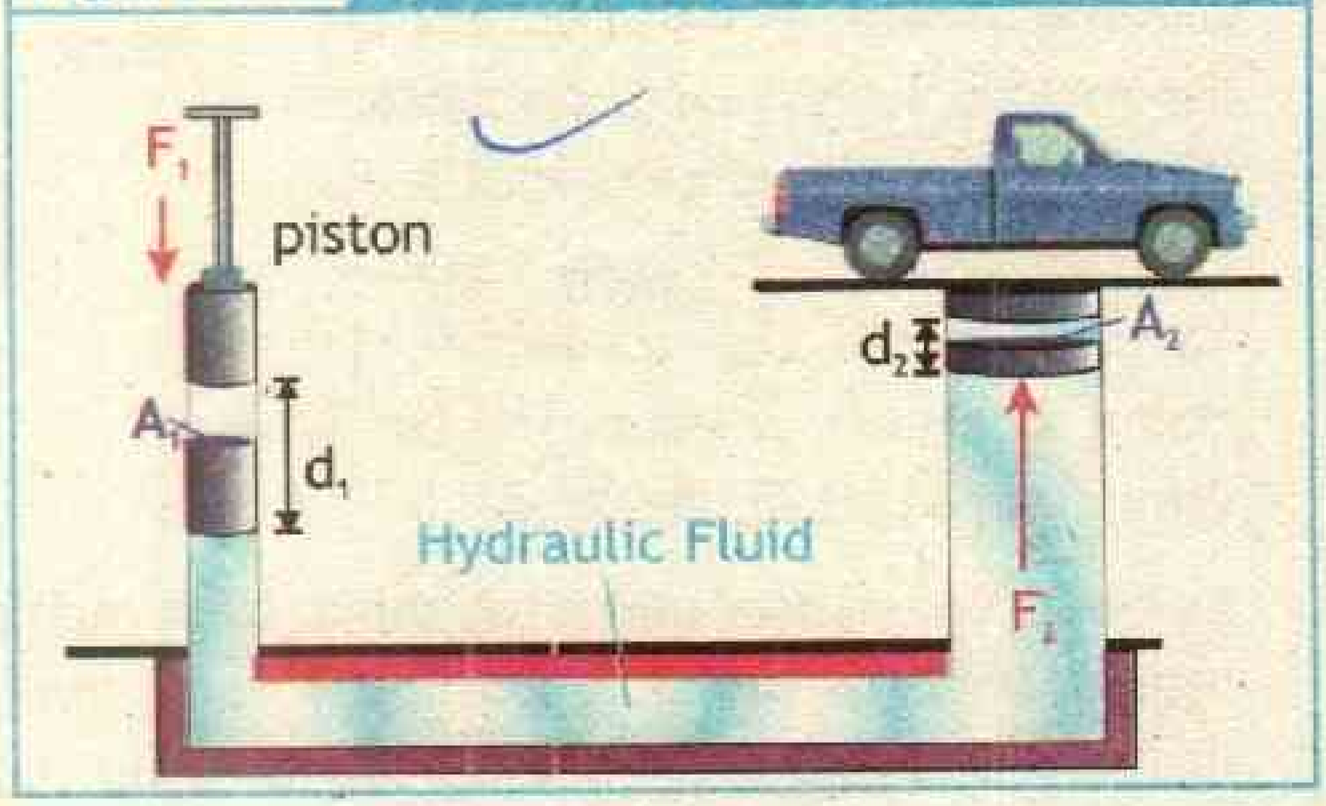
7.5 PASCAL'S PRINCIPLE

When you pump a bicycle **tyre**, you apply a force on the pump that in turn exerts a force on the air inside the **tyre**. The air responds by pushing not only against the pump but also against the walls of the **tyre**. As a result, the pressure increases by an equal amount throughout the **tyre**. In general, if the pressure in a fluid is increased at any point in a container (such as at the valve of the **tyre**), the pressure increases at all points inside the container by exactly the same amount. Blaise Pascal (1623-1662) noticed this fact in what is now called Pascal's principle (or Pascal's law):

An external pressure applied to an enclosed fluid is transmitted unchanged to every point within the fluid.

Classic example of Pascal's principle at work is the hydraulic lift, which is shown schematically in figure 7.3. Here we see two cylinders, one of cross-sectional area A_1 the other of cross-sectional area $A_2 > A_1$. The cylinders, each of which is fitted with a piston, are connected by a tube and filled with a suitable fluid usually oil called Hydraulic fluid. Initially the pistons are at the same level and exposed to the atmosphere.

Figure 7.3 HYDRAULIC LIFT



Now, suppose we push down on piston with the force F_1. The pressure P_1 exerted by this piston is

$$P_1 = \frac{F_1}{A_1} \quad \text{—— (1)}$$

Similarly, the pressure on the piston lifting vehicle is P_2, which can be written as

$$P_2 = \frac{F_2}{A_2} \quad \text{—— (2)}$$

By pascal's principle

$$P_2 = P_1 \quad \text{—— (3)}$$

putting values from equation 1 and equation 2 in equation 3, we get

$$\frac{F_2}{A_2} = \frac{F_1}{A_1}$$

or $$F_2 = \frac{A_2 \times F_1}{A_1}$$

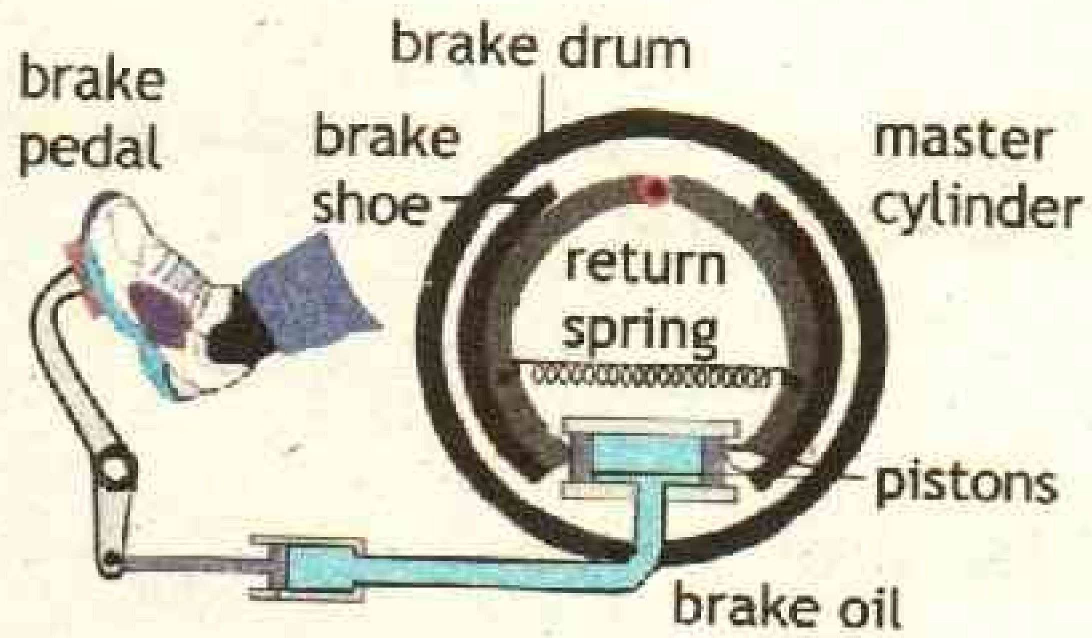
or $$F_2 = \frac{A_2}{A_1} F_1 \quad \text{—— (7.3)}$$

Depending on the ratio A_2/A_1 the force F_2 can be as large as required. To be specific, let's assume that A_2 is 100 times greater than A_1. Then, by pushing down on piston 1 with a force F_1 we push upward on piston 2 with a force of $F_2 = 100\ F_1$. Our force has been magnified 100 times! Hence a relatively small effort can be used to overcome a much larger load.

APPLICATION **HYDRAULIC BRAKES OPERATION**

Hydraulic car brakes are shown in Figure . When the brake pedal is pushed, the piston in the master cylinder exerts a force on the brake fluid and the resulting pressure is transmitted equally to eight other pistons.

These force the brake shoes or pads against the wheels and stop the car.



7.6 LIQUID PRESSURE

The liquid is incompressible therefore the pressure increases directly below the surface of the liquid. In figure 7.4 a disc is placed at the bottom of a tank in fluid. The force F acting on the disc is the weight W of the cylindrical column of liquid of mass m.

$$F = W = mg \quad (1)$$

For the fluid of density ρ, the mass m of the fluid above the disk, with volume V is

$$\rho = \frac{m}{V}$$

or

$$m = \rho V \quad (2)$$

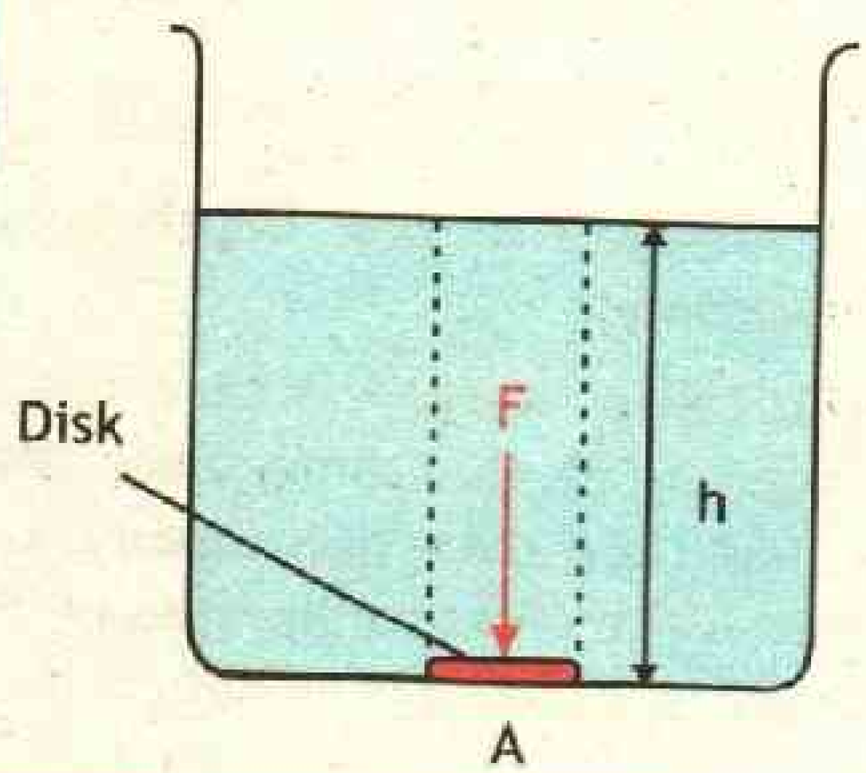
Since the fluid forms a cylindrical volume V shown by dotted lines in the figure which has height h and area of cross section A. Therefore

$$V = Ah \quad (3)$$

putting equation 3 in equation 2, we get

$$m = \rho Ah \quad (4)$$

Figure 7.4 **LIQUID PRESSURE**



putting equation 4 in equation 1, we get

$$F = \rho Ahg \quad (5)$$

Since pressure is defined as

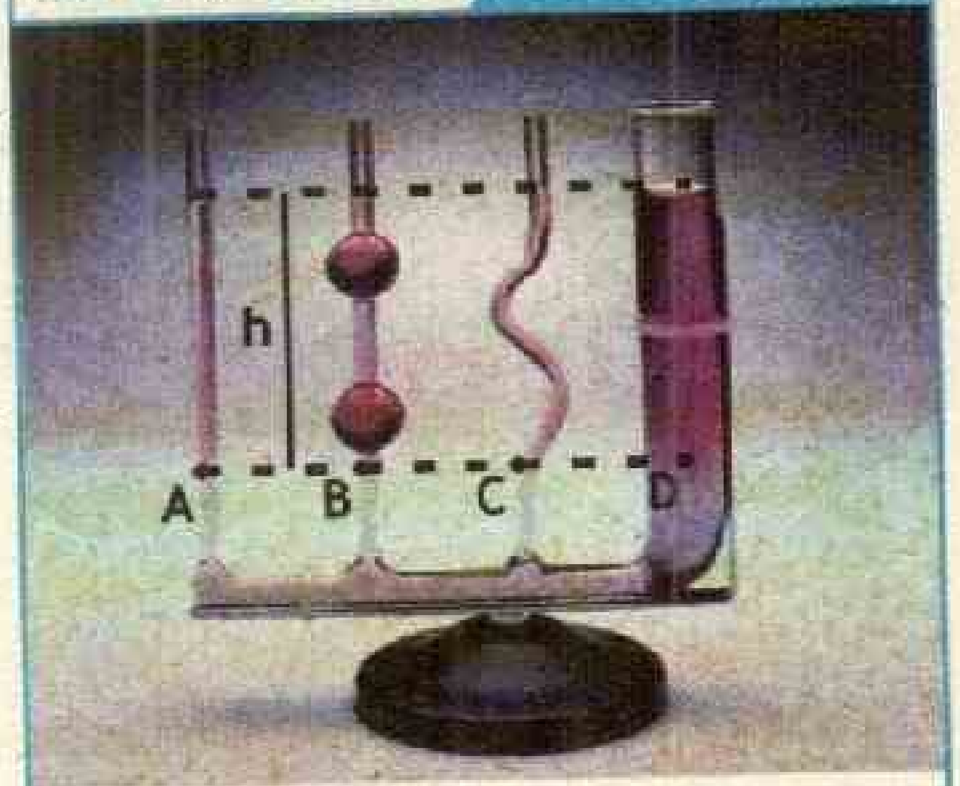
$$P = \frac{F}{A} \quad (6)$$

putting value of force from equation 5 in equation 6 we get

$$P = \frac{\rho Ahg}{A}$$

therefore $$P = \rho hg \quad (7.4)$$

INFORMATION



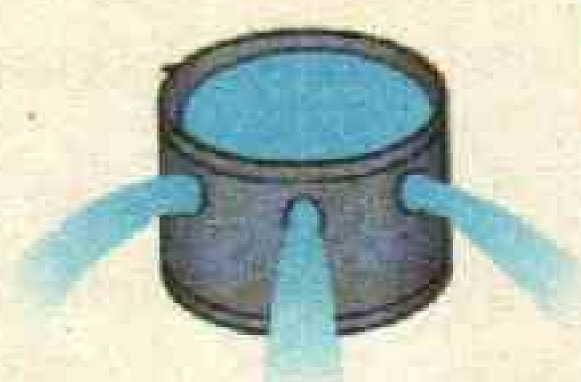
Since points A, B, C, and D are at the same distance h beneath the liquid surface, the pressure at each of them is the same.

PROPERTIES OF LIQUIDS AND PRESSURE

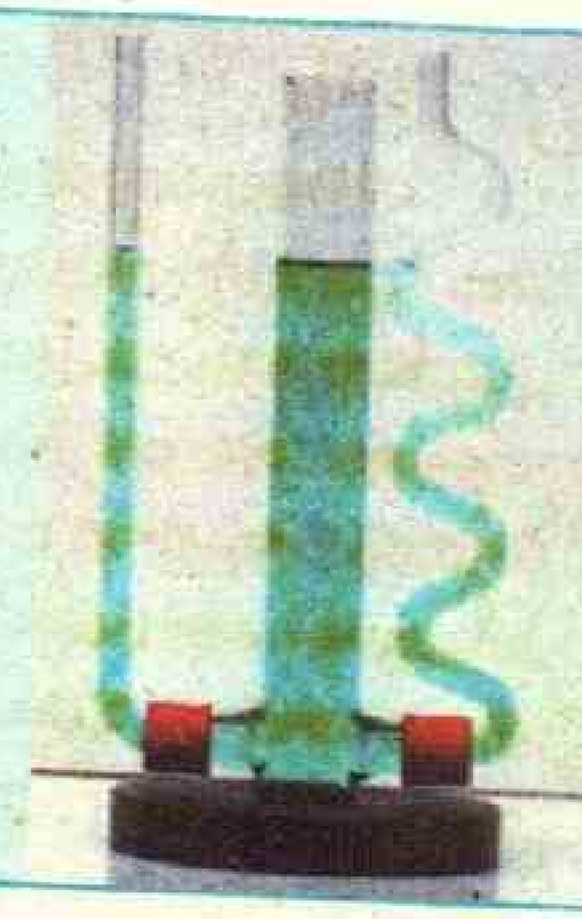
1) Pressure in a liquid increases with depth because the further down you go, the greater the weight of liquid above. As can be seen in Figure . A water spurts out fastest and furthest from the lowest hole.

2) Pressure at one depth acts equally in all directions.

The can of water in Figure has similar holes all round it at the same level. Water comes out equally fast and spurts equally far from each hole. Hence the pressure exerted by the water at this depth is the same in all directions.



3) A liquid finds its own level. In figure the liquid is at the same level in each tube and confirms that the pressure at the bottom of a liquid depends only on the vertical depth of the liquid and not on the tube width or shape.



Example 7.3 LIMITS ON SUBMARINE DEPTH

A submarine is constructed so that it can safely withstand a pressure of 1.6×10^7 Pa. How deep may this submarine descend in the ocean if the average density of seawater is $1025\ kg/m^3$?

SOLUTION

GIVEN:

Pressure $P = 1.6 \times 10^7\ Pa = 1.6 \times 10^7\ kgm^{-1}s^{-2}$

Density $= 1025\ kg/m^3$

Acceleration due to gravity $= 9.8\ ms^{-2}$

REQUIRED:

depth = height h = ?

(a) The maximum depth a submarine can go down can be measured by equation

$$P = \rho h g$$

or $$h = \frac{P}{\rho g}$$

putting values

$$h = \frac{1.6 \times 10^7\ kgm^{-1}s^{-2}}{1025\ kgm^{-3} \times 9.8\ ms^{-2}}$$

therefore $h = 1.6 \times 10^3 m = 1.6\ km$ —— Answer

Assignment 7.3 PRESSURE AT 100m DEPTH OF WATER

What is the pressure at a depth of 100 m below the surface of water?

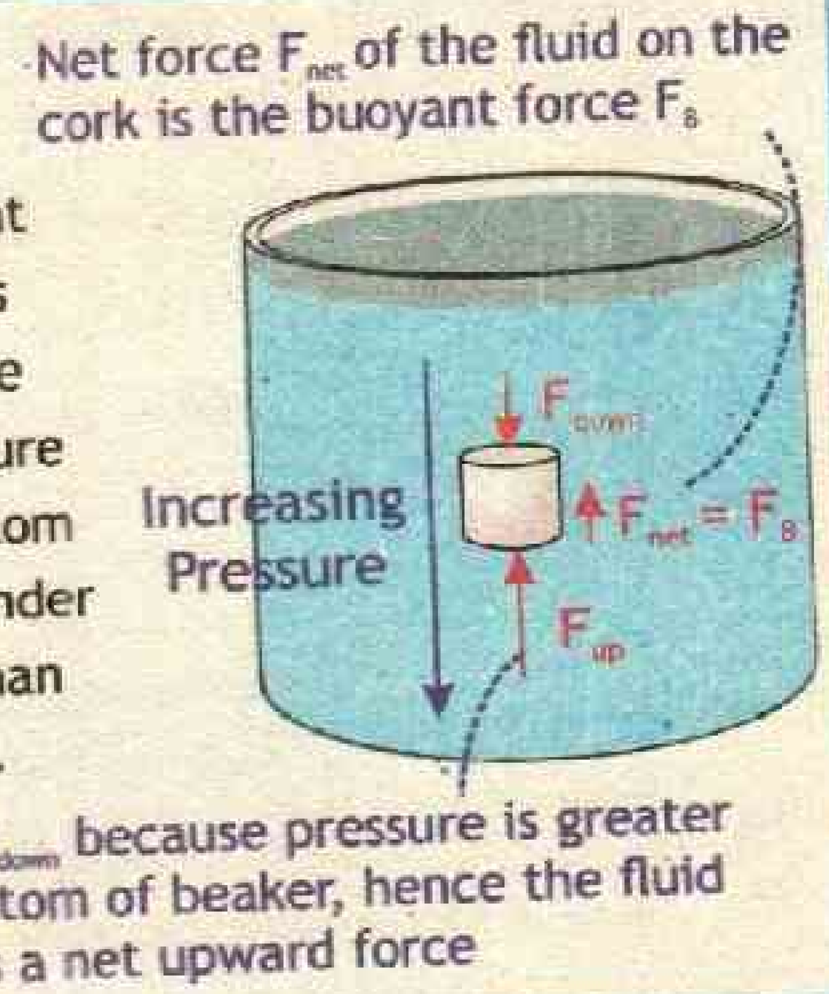
7.7 UPTHRUST AND BUOYANCY

When an object is immersed in a fluid, the pressure on the lower surface of the object is higher than the pressure on the upper surface. The difference in pressures leads to an upward net force acting on the object due to the fluid pressure called up-thurst or buoyant force and phenomena is called buoyancy.

If you try to push a piece of cork underwater, you feel the buoyant force pushing the cork back up.

Figure 7.5 UPTHRUST

The buoyant force arises because the fluid pressure at the bottom of the cylinder is larger than at the top.



7.8 ARCHIMEDES PRINCIPLE

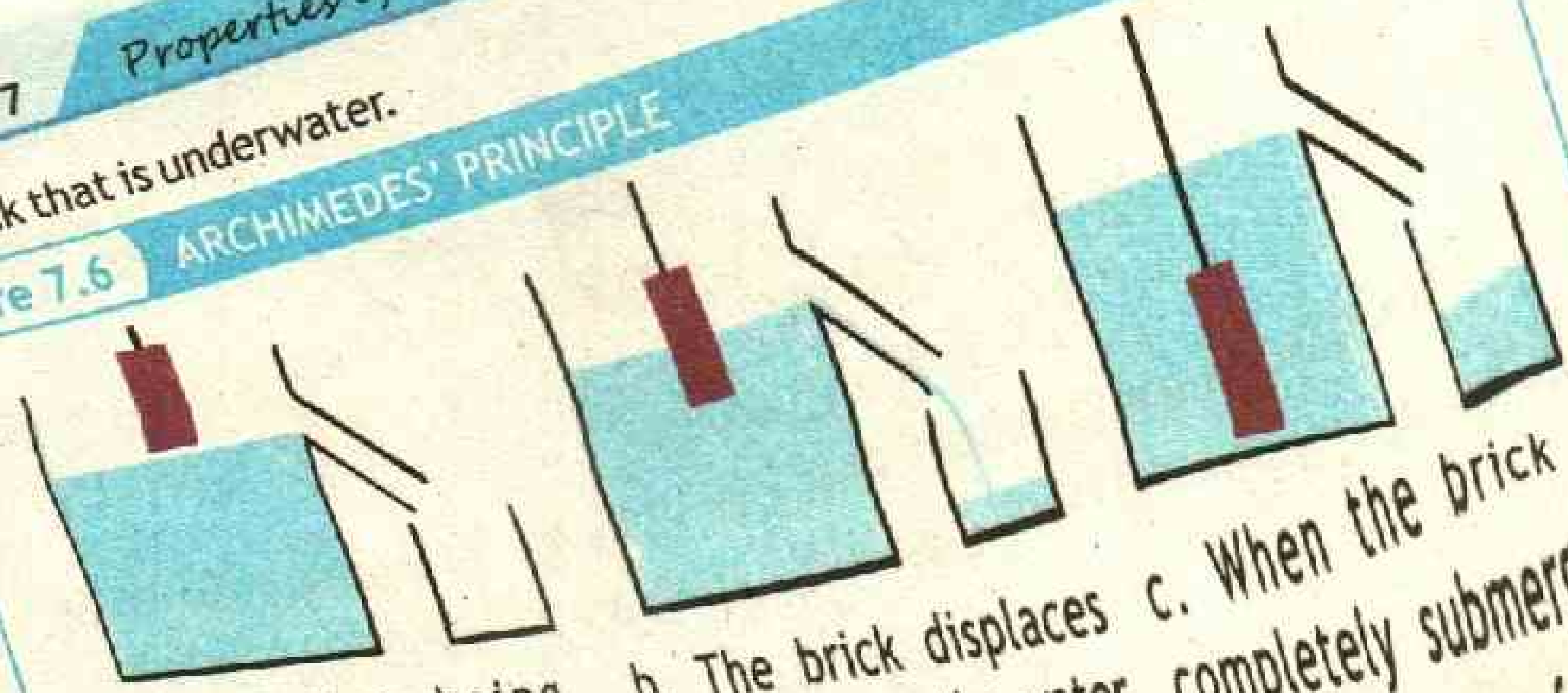
Why do some things float while others do not? Is floating determined by the weight of the object? A large ship floats, but a small pebble quickly sinks. Clearly, it is not a matter of the total weight of the object. The density of the object may be the key. Objects that are denser than the fluid they are immersed in, will sink—those less dense will float. The complete answer to the question of why things sink or float is found in Archimedes' principle, which is stated as

The buoyant force acting on an object fully or partially submerged in a fluid is equal to the weight of the fluid displaced by the object.

Everyone has experienced Archimedes' principle. For example, it is relatively easy to lift someone in a swimming pool.

Imagine that you submerge a brick in a container of water, as shown in Figure 7.6. A spout on the side of the container at the water's surface allows water to flow out of the container. As the brick sinks, the water level rises and water flows through the spout into a smaller container. The total volume of water that collects in the smaller container is the displaced volume of water from the large container. The displaced volume of water is equal to the volume of the portion of the brick that is underwater.

Figure 7.6 ARCHIMEDES' PRINCIPLE



a. A brick is being lowered into a container of water.

b. The brick displaces water, causing the water to flow into a smaller container.

c. When the brick is completely submerged, the volume of the displaced water is equal to the volume of the brick.

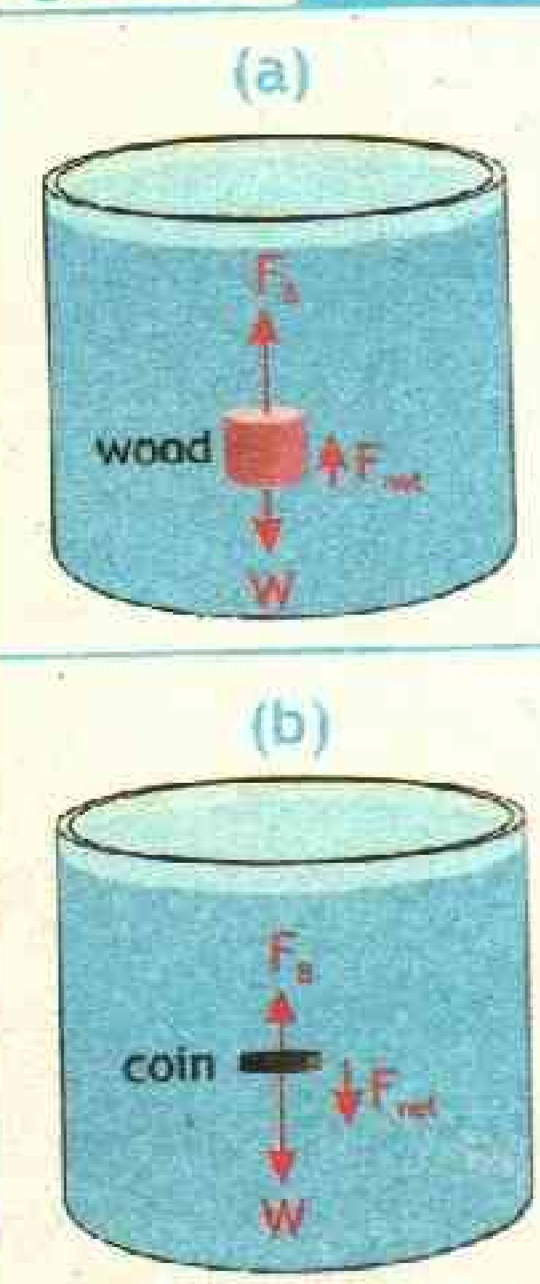
The magnitude of the buoyant force F_B acting on the brick at any given time can be calculated by using Archimedes' principle. Any object completely or partially submerged in a fluid experiences an upward buoyant force equal in magnitude to the weight of the fluid displaced by the object.

$$F_B = W\text{ (displaced fluid)} = m_f g$$

magnitude of buoyant force = weight of fluid displaced

According to Archimedes principle, every object experiences a buoyant force. The buoyant force will decrease the weight of the object which is termed as apparent lose of weight. Whether it floats or sinks depends on the object's density relative to the fluid. When we push a wood block underwater and you will feel the upward buoyant force as in figure 7.7(a). By Archimedes principle, the buoyant force equals the weight of water displaced; since water is denser than wood, the buoyant force is greater than the wood's *weight*, and that is why wood

Figure 7.7 FLOAT OR SINK



(a) F_B = weight of fluid displaced by wood. Water is denser than wood $\rho_{water} > \rho_{wood}$ so block's weight W is less than F_B, and the net force is upward.

(b) F_B = weight of fluid displaced by coin. Coin is denser than water $\rho_{water} < \rho_{coin}$ so coin's weight W is greater than F_B, and the net force is downward.

floats. Now when we submerge a coin figure 7.7(b). It's denser than water, so the coin's weight is greater than the weight of the displaced water. Hence the coin's weight is greater than the upward buoyant force, and it sinks.

Whether an object will float or sink depends on the net force acting on it. This net force can be calculated as follows:

$$F_{net} = F_B - W\,(object)$$

Now we can apply Archimedes' principle, using 'm_o' to represent the mass of the submerged object and 'm_f' as mass of fluid 'g' is acceleration due to gravity.

$$F_{net} = m_f g - m_o g$$

Remember that '$m = \rho V$', so the expression can be rewritten as follows:

$$F_{net} = \rho_f V_f\, g - \rho_o V_o g \quad \text{or} \quad F_{net} = (\rho_f V_f - \rho_o V_o)g$$

A simple relationship between the weight 'W' of a submerged object of mass m_o and density ρ_o and the buoyant force 'F_B' on the object by fluid displaced of mass m_B and density ρ_B can be found by considering their ratio as follows:.

$$\frac{W}{F_B} = \frac{m_O g}{m_B g}$$

$$\text{or} \quad \frac{W}{F_B} = \frac{m_O}{m_B} \qquad (1)$$

'or submerged object equal volume is displaced therefore

$$V_O = V_B = V$$

therefore $m_O = \rho_O V$ and $m_B = \rho_B V$

ting these values in equation 1, we get

$$\frac{W}{F_B} = \frac{\rho_O V}{\rho_B V}$$

$$\text{or} \quad \frac{W}{F_B} = \frac{\rho_O}{\rho_B} \qquad (7.5)$$

AB WORK

find the density of a body heavier than water by Archimedes Principle.

ample 7.4 IS CROWN MADE OF PURE GOLD?

rl purchases a "gold" crown at a flea market. After she gets home, she hangs the wn from a scale and finds its weight to be 7.84 N. She then weighs the crown while it is nersed in water, and the scale reads 6.86 N. Is the crown made of pure gold?

SOLUTION

GIVEN:

Weight in air $W_A = 7.84\ N$

Weight in water $W_B = 6.86\ N$

Density of water $\rho_B = 1.00 \times 10^3\ kg/m^3$

REQUIRED:

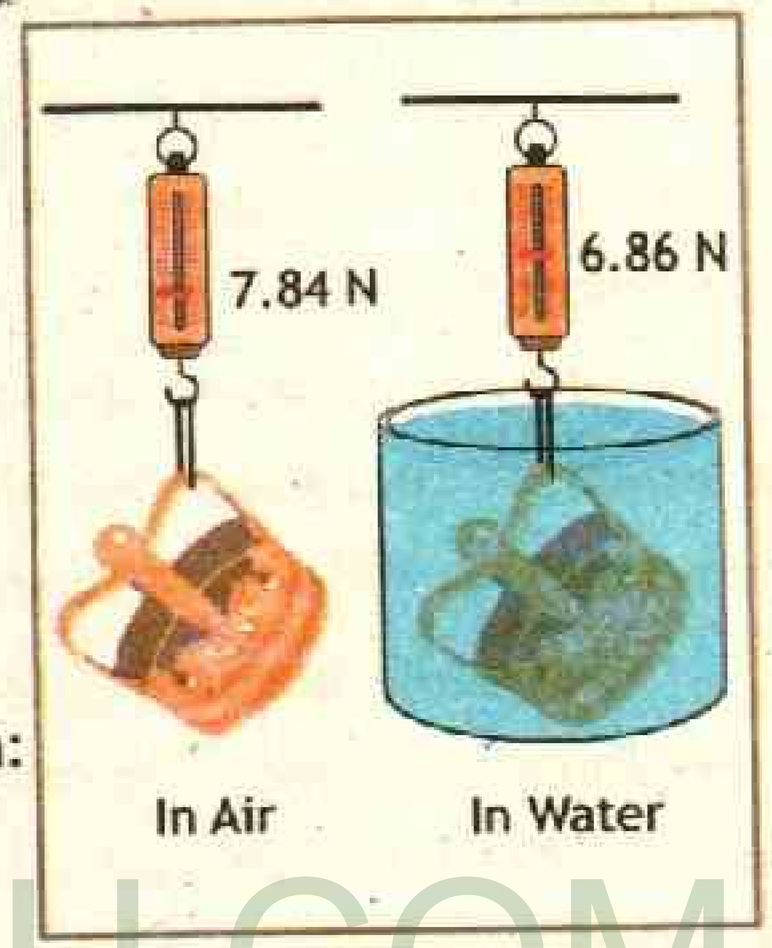
Density of crown ρ_o = ?

The apparent weight of the crown in water W_B is equal to the weight in air W_A minus the buoyant force F_B exerted by water i.e. $W_B = W_A - F_B$ which means that

$$F_B = W_A - W_B$$

$$F_B = 7.84N - 6.86N$$

$$F_B = 0.98N$$



The relationship between the weight 'W' and the buoyant force 'F_B' is

$$\frac{W}{F_B} = \frac{\rho_O}{\rho_B}$$

Rearrange the equation to isolate the unknown:

$$\rho_O = \frac{W}{F_B} \times \rho_B$$

putting values $\rho_O = \frac{7.84 N}{0.98 N} \times 1 \times 10^3\ kg/m^3$

therefore $\rho_O = 8 \times 10^3\ kg/m^3$ — **Answer**

From Table 7.1, the density of gold is $19.3 \times 10^3\ kg/m^3$. Because $8.0 \times 10^3\ kg/m^3$ is quite less than $19.3 \times 10^3\ kg/m^3$, the crown cannot be pure gold.

Assignment 7.4 DENSITY OF ROCK

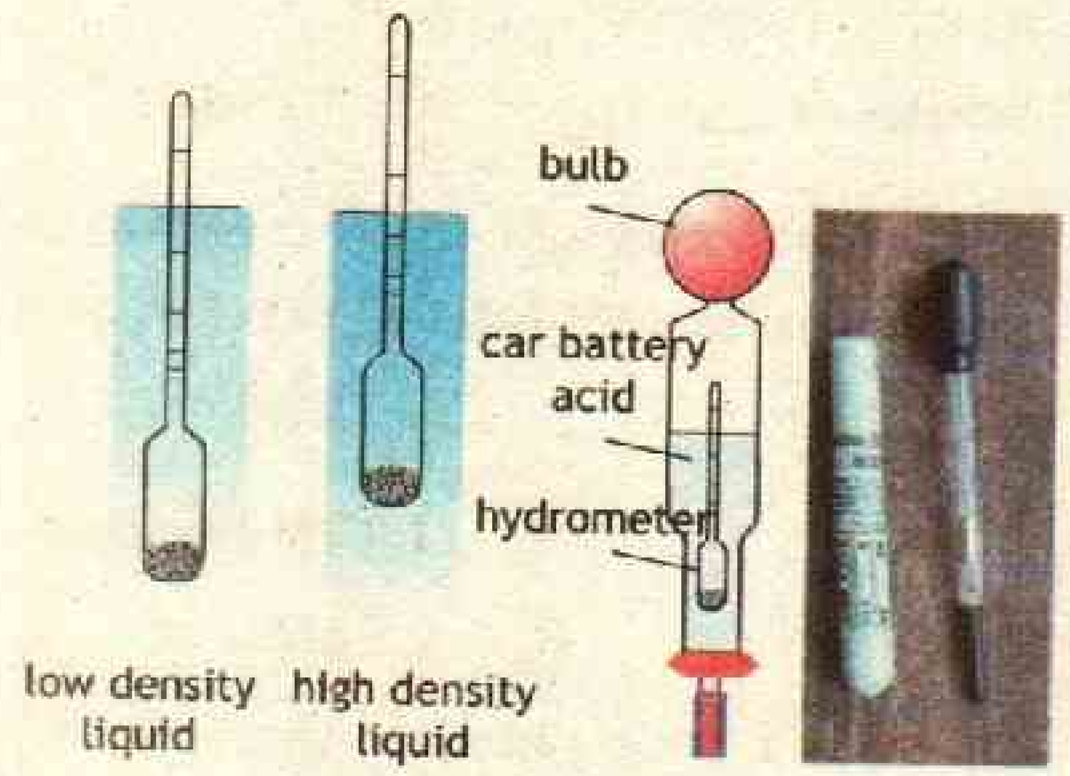
A geologist finds that a Moon rock whose weight is 90.9 N has an apparent weight of 60.6 N when submerged in water. What is the density of the rock?

ACTIVITY WATER AND OIL

Pour some water into a clear glass. Then pour in some cooking oil. Which liquid is less dense?

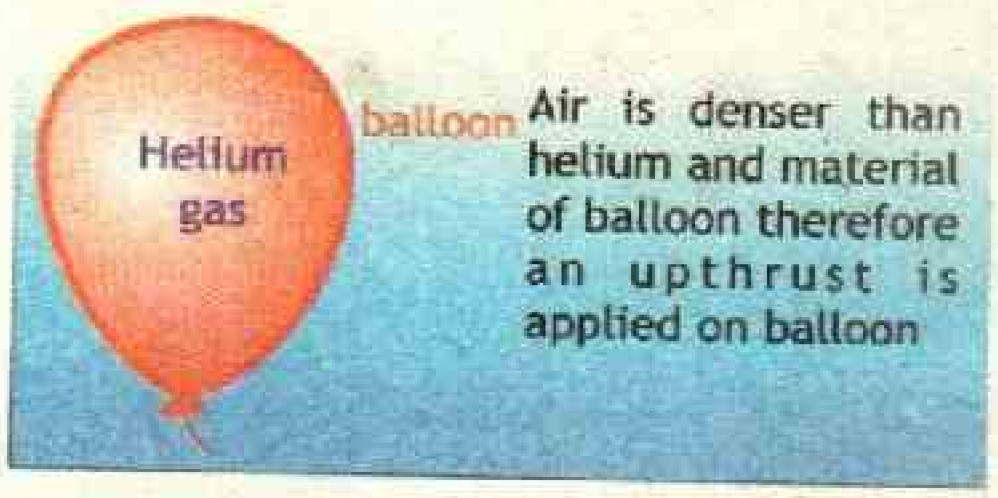
APPLICATION HYDROMETER

A hydrometer is an instrument that measures the —the ratio of the density of the liquid to the density of water. This is a glass tube with a scale on the side weighted at the bottom with lead shot. The hydrometer floats in the liquid and if the liquid is dense the hydrometer does not need to sink very low to displace its own weight of liquid. If the liquid has a lower density it will sink much deeper.



Hydrometers are calibrated for different uses, such as a lactometer for measuring the density (creaminess) of milk, a saccharometer for measuring the density of sugar in a liquid, or an alcoholometer for measuring higher levels of alcohol in spirits.

A balloon, filled with helium (a gas lighter than air) will be pushed upwards by the denser air when it is released. This is because upthrust is greater than the total downward weight of the helium and the material of the balloon.



POINT TO PONDER

Fluids of different densities float on top of each other.

A steel ball floats in mercury because the density of mercury is greater than that of steel.

7.9 ELASTICITY

In everyday conversation if someone speaks to you about an elastic body, you probably immediately think of a rubber band. A rubber band yields a great deal to a distorting force, and yet it returns to its original length after the distorting force is removed

The property of solid materials to return to their original shape and size after removal of deforming force is called elasticity.

When an archer shoots an arrow, he bends the bow which springs back to its original form after the arrow is released. When a tennis racket hits a tennis ball, the shape of the ball is distorted or deformed, but it regains its original shape when it bounces off the tennis racket.

Not all materials return to their original shapes when a deforming force acting on it is removed. Materials that do not return to their original shapes after being distorted are said to be inelastic. Examples of inelastic materials are plasticine, clay and dough.

Most materials are elastic up to a certain limit known as the elastic limit. Beyond the elastic limit a material will not return to its original dimensions break or permanently deforms when the deforming force is removed.

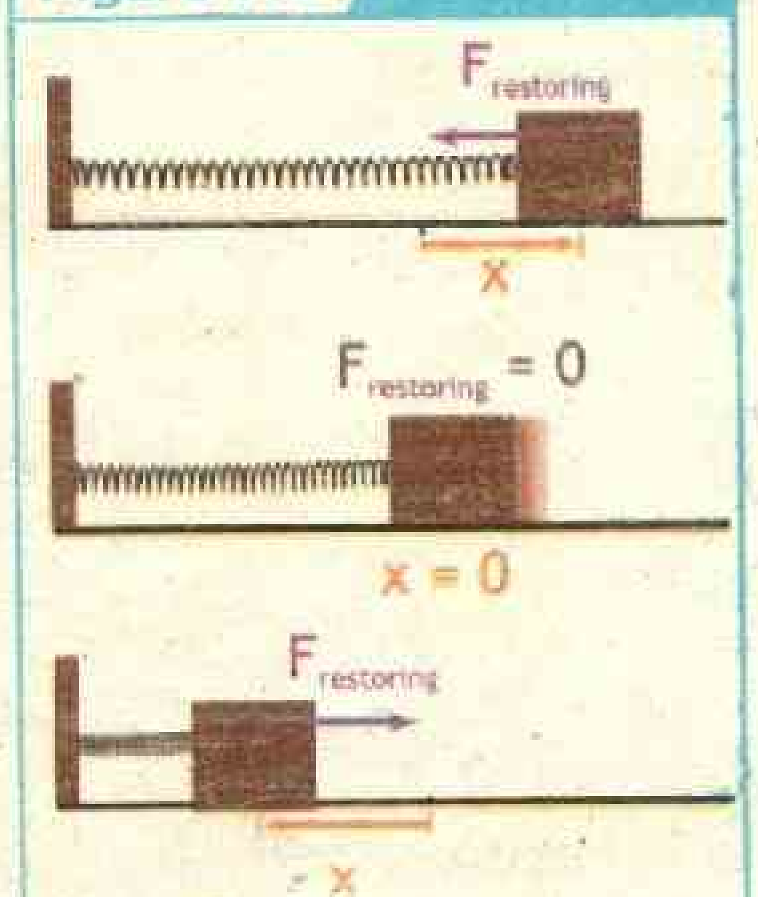
7.9.1 HOOKE'S LAW

When a spring is stretched or compressed, the extension or compression is directly proportional to the applied force (Figure 7.9). This relationship is known as Hooke's law which states that within elastic limits the extension (or

Figure 7.8

A tennis ball is flattened by the contact force exerted on it by the strings of the tennis racket. Likewise, the strings of the racquet are deformed by the contact force exerted by the ball. The two forces are interaction partners.

Figure 7.9



compression) x is directly proportional to the restoring force F_{res}, i.e.

$$F_{res} \propto -x$$

or $$F_{res} = -kx \quad \text{--- } 7.6$$

where k is known as the force constant having units $N\,m^{-1}$. The negative sign shows that force is directed against displacement. This relationship is also true for a wire under tension.

7.10 STRESS, STRAIN AND YOUNG'S MODULUS

A wire under tension will extend. Its extension depends on a number of factors such as the tension, its diameter and length and the material of the wire.

Suppose that a wire of length l and cross-sectional area 'A' is stretched by a force F and the extension produced is x as shown in figure 7.10

Stress:

The stress applied to the wire is defined as the force applied per unit area of cross-section to produce deformation. Mathematically

$$\text{stress} = \frac{\text{Force}}{\text{Area of crossection}}$$

or $$\text{stress} = \frac{F}{A} \quad \text{--- } 7.7$$

The unit for stress is Nm^{-2} or pascal.

Figure 7.10

Strain:

As a result of the wire being stretched, it is under strain. The strain is defined as the extension per unit length. Mathematically

$$\text{strain} = \frac{\text{extension}}{\text{Original Length}}$$

or $$\text{strain} = \frac{x}{l} \quad \text{--- } 7.8$$

Since strain is the ratio of two lengths, it does not have a unit.

Young's Modulus:

The strain produced in a stretched wire is proportional to the stress within

LAB WORK

To find the density of a liquid using 5 ml syringe (instead of dimity bottle).

the limit of proportionality. Within this limit, the ratio is a constant whose value depends on the material of the wire, and is known as the Young's modulus of the material. Mathematically

$$\text{Stress} \propto \text{Strain}$$

$$\text{or} \quad \text{Stress} = \text{Constant} \times \text{Strain}$$

Constant of proportionality is called Young's modulus is denoted by Y

$$\text{Stress} = \text{Young's Modulus} \times \text{Strain}$$

rearranging the above equation, we get

$$\textit{Young's Modulus} = \frac{\text{Stress}}{\text{Strain}}$$

Young's modulus is denoted by Y, putting values of stress and strain, we get

$$Y = \frac{F/A}{x/l}$$

rearranging $$Y = \frac{F \times l}{A \times x} \quad (7.9)$$

Modulus for Selected Materials	
Material	**Young Modulus, Y, (Pa)**
Aluminum	7.0×10^{10}
Brass	9.0×10^{10}
Copper	11×10^{10}
Crown glass	6.0×10^{10}
Iron	21×10^{10}
Lead	1.6×10^{10}
Nickel	21×10^{10}
Steel	20×10^{10}

Young Modulus for different materials are given in the table 7.2.

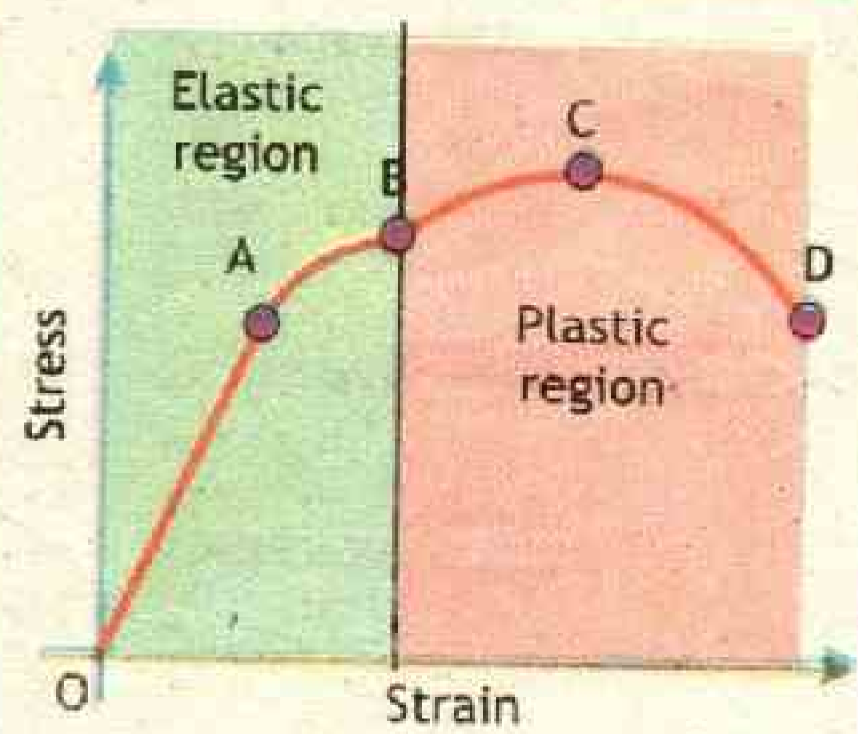
Stress strain curves:

Stress and strain curves are measured by stress tester.

The applied stress is increased and the change in length is noted. The values are then printed on graph. A typical graph for metal is shown in the figure 7.11.

Here, Point, A, is the limit of proportionality, the limit up to which Hooke'

Figure 7.11 Stress strain curve



LAB WORK

To study the relation between load and extension (helical spring) by drawing graph.

law is obeyed called **proportional limit**. Point, B, is the **elastic limit**, the limit up to which material shows elastic behavior, point C is the maximum stress wire can with stand without breaking and point D, is the **breaking point**, where material breaks.

Example 7.5 YOUNG'S MODULUS

A wire of length 5.0 m and area of $0.03\ m^2$ is stretched 0.15 m within elastic limit, by hanging weight of 270 N. Calculate stress, strain and Young's modulus of material of wire.

SOLUTION

GIVEN:

length $l = 5.0\ m$

area $A = 0.03\ m^2$

extension $x = 0.15\ m$

weight = force $F = 270\ N$

REQUIRED:

stress = ?

strain = ?

Young's modulus Y = ?

a) By definition of stress $\quad \text{stress} = \frac{F}{A}$

putting values $\quad \text{stress} = \frac{270\,N}{0.03\,m^2}$

$\text{stress} = 9 \times 10^3\ Nm^{-2}$ — Answer

b) By definition of strain $\quad \text{strain} = \frac{x}{l}$

putting values $\quad \text{strain} = \frac{0.15\,m}{5.0\,m}$

$\text{strain} = 0.03$ — Answer

c) Young's Modulus is $\quad Young's\ Modulus = \frac{\text{Stress}}{\text{Strain}}$

putting values $\quad Y = \frac{9.0 \times 10^3\ Nm^{-2}}{0.03}$

therefore $\quad Y = 3.0 \times 10^5\ Nm^{-2}$ — Answer

Assignment 7.5 WIRE STRETCHED

An elastic wire of length 2 m and cross sectional area $0.02\ m^2$ is stretched 0.10 m by a 300 N weight. Calculate the Young modulus of the material.

KEY POINTS

Density: Mass per unit volume

Pressure: Force applied per unit area

Barometer: Device used to measure atmospheric pressure

Pascal's Principle: if the pressure at one point of a confined fluid is increased by an amount, the pressure increases by the same amount at all other parts throughout the fluid.

Archimedes' principle: A body when completely or partially immersed in a fluid will experience an upthrust equal to the weight of the fluid displaced by the body. This upthrust will bring about an apparent loss of weight of the body.

Elasticity: The property of a body which enables the body to regain its original dimension when the deforming force acting on the body is removed.

Hooke's law: Within elastic limits the extension (or compression) is directly proportional to the force applied.

Stress: The force applied per unit area of cross-section to produce deformation.

Strain: the extension per unit length.

Young's Modulus: The ratio of stress to strain.

PROJECTS

GROUP - A

TYRE PRESSURE: Research air pressures in different tyre types (bicycles, motor bikes, cars and trucks). Why are the pressures different for different automobile tyres? Prepare a presentation to be presented in physics class.

GROUP - B

SUBMARINES: Prepare a chart on submarine technology, what is the science of their sinking and raising up.

GROUP - C

WEATHER IN PAKISTAN: What is the organization that monitors and predicts weather in Pakistan, write a research article for the school library.

GROUP - D

PRESSURIZED CABINS: Write an article for school magazine on why submarine and aircraft cabins are pressurized at certain level. What would happen if the cabins are not maintained at constant pressure.

GROUP - E

DENSITIES: Find a spring balance and use Archimedes Principle to determine the densities of few objects. Compare the calculated density results with the table and comment on their composition. Deliver presentation to the class for your findings.

EXERCISE

MULTIPLE CHOICE QUESTIONS

Choose the best possible answer:

1. A container having volume of 6 m^3 is full with a liquid, having density of 30 kg m^{-3}. The mass of the liquid is

A. 180 kg B. 24 kg C. 5 kg D. 0.2 kg

2. Liquids and gases and collectively categorized as

A. Liquids B. Pascals C. Fluids D. None

3. Which of the following cannot be used to measure pressure

A. Atm B. Pa C. bar D. kg m^{-3}

4. Pressure at depth in fluid

A. increases B. decreases C. none D. stays the same

5. The unit used for pressure in weather maps is

A. Atm B. Pa C. bar D. N m^{-2}

6. A rock weighs 25.7 N in air and 21.8 N in water. What is the buoyant force of the water

A. 4.1 N B. 3.9 N C. 1.18 N D. 0.84 N

7. Which of the following objects, submerged in water, experiences the largest magnitude of the buoyant force?

A. 1-kg helium balloon; B. 1 kg of wood;

C. 1 kg of iron; D all the same.

8. The unit of strain is

A. kg m^{-3} B. Pa C. N m^{-2} D. none

9. Young modulus is measured in units of

A. kg m^{-3} B. Pa C. N D. none

CONCEPTUAL QUESTIONS

Give a brief response to the following questions.

1. If you climbed a mountain carrying a mercury barometer, would the level of the mercury column in the glass tube of the barometer increase or decrease as you climb the mountain? Explain.
2. Walnuts can be broken in the hand by squeezing two together but not one. Why?
3. Why is the cutting edge of the knife made very thin?
4. Why water tanks are constructed at the highest level in our houses?
5. Why a small needle sinks in water and huge ships travel easily in water without sinking?
6. Explain how and why camels have adapted to allow them to walk more easily in desert conditions?
7. You would have probably experienced your ears 'popping' while driving in the mountains. Why ears 'pop'?
8. If you filled an airtight balloon at the top of a mountain, would the balloon expand or contract as you descend the mountain? Explain.
9. A rowboat is floating in a swimming pool when the anchor is dropped over the side. When the anchor is dropped, will the water level in the swimming pool increase, decrease, or remain the same? Explain.
10. Which material is more elastic, steel or rubber and why?

COMPREHENSIVE QUESTIONS

Give an extended response to the following questions.

1. Using kinetic molecular model of matter, explain three states of matter.
2. Define and explain density and pressure.
3. What is atmospheric pressure? How is it measured by using a mercury barometer? Also describe how weather changes with atmospheric pressure?
4. State Pascal's principle and explain with example?
5. How pressure varies with depth in liquids? Explain.
6. What is meant by buoyant force or upthrust in fluids?

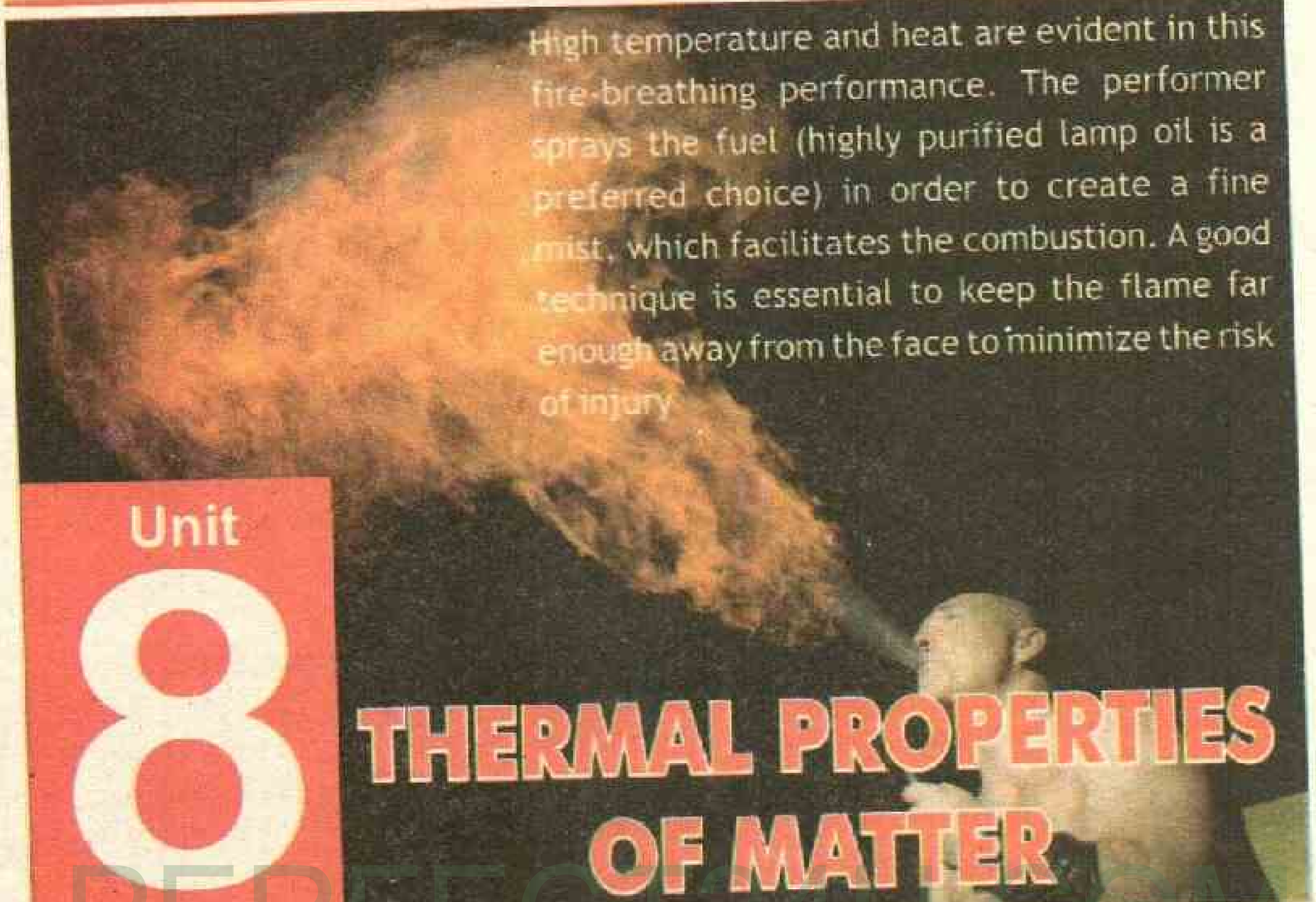
7. State and explain Archimedes principle.
8. What is elasticity? Explain.
9. State and explain Hooke's law.
10. Define and explain, Stress, Strain and Young's modulus

NUMERICAL QUESTIONS

1. A rectangular glass block of dimensions 30 cm by 5 cm by 10 cm weighs 37.5 N. Calculate the least and the greatest pressure it can exert when resting on a horizontal table?
2. What is the height of a water barometer at atmospheric pressure?
3. The small piston of a hydraulic lift has an area of $0.20\ m^2$. A car weighing 1.20×10^4 N sits on a rack mounted on the large piston. The large piston has an area of $0.90\ m^2$. How large a force must be applied to the small piston to support the car?
4. The deepest point in the ocean is 11 km below sea level, deeper than Mt. Everest is tall. What is the pressure in atmospheres at this depth?
5. A block is fully immersed in water. Before the immersion the block weighed 30 N and while immersed, its apparent weight was found to be 25 N. Calculate (a) the upthrust on the block (b) the weight of the water displaced, (c) the volume of water displace, (d) the volume of the block. and (e) the density of the block.
6. When a weight of 30 N is hung from a wire of original length 2.0 m, its new length becomes 2.20 m. Calculate the force constant for the wire, if the elastic limit is not exceeded?
7. An 80-cm-long, 1.0-mm-diameter steel guitar string must be tightened to a tension of 2000 N by turning the tuning screws. By how much is the string stretched?

WEB LINK

http://www.strangematterexhibit.com/whatis.html



High temperature and heat are evident in this fire-breathing performance. The performer sprays the fuel (highly purified lamp oil is a preferred choice) in order to create a fine mist, which facilitates the combustion. A good technique is essential to keep the flame far enough away from the face to minimize the risk of injury

Unit 8

THERMAL PROPERTIES OF MATTER

CHECK LIST

After studying this unit you should be able to:

- ✓ define temperature (as quantity which determine the direction of flow of thermal energy).
- ✓ define heat (as the energy transferred resulting from the temperature difference between two objects).
- ✓ list basic thermometric properties for a material to construct a thermometer.
- ✓ convert the temperature from one scale to another (Fahrenheit, Celsius and Kelvin scales).
- ✓ describe rise in temperature of a body in term of an increase in its internal energy.
- ✓ define the terms heat capacity and specific heat capacity.
- ✓ describe heat of fusion and heat of vaporization (as energy transfer without a change of temperature or change of state).
- ✓ describe experiments to determine heat of fusion and heat of vaporization of ice and water respectively by sketching temperature-time graph on heating ice.
- ✓ explain the process of evaporation and the difference between boiling and evaporation.
- ✓ explain that evaporation causes cooling.
- ✓ list the factors which influence surface evaporation.
- ✓ describe qualitatively the thermal expansion of solids (linear and volumetric expansion).
- ✓ explain the thermal expansion of liquids (real and apparent expansion).
- ✓ solve numerical problems based on the mathematical relations learnt in this unit.

The study of heat transformations into other forms of energy, called thermodynamics, began with the eighteenth-century engineers who built the first steam engines. These steam engines were used to power trains, factories, and water pumps for coal mines, and thus they contributed greatly to the Industrial Revolution. Although the study of thermodynamics began in the eighteenth century, it was not until around 1900 that the concepts of thermodynamics were linked to the motions of atoms and molecules in solids, liquids, and gases.

Today, the concepts of thermodynamics are widely used in various applications that involve heat and temperature. Engineers use the laws of thermodynamics to continually develop higher performance refrigerators, automobile engines, aircraft engines, and numerous other machines.

8.1 TEMPERATURE

Temperature is a concept we all understand from experience. Even as small children we learn to perceive hotness and coldness of objects. We hear weather forecasters tell us that the temperature will be 32 °C today. We hear doctors tell us that our body temperature is 98.6 °F. We know from General Science for class 8, chapter 9: SOURCES AND EFFECTS OF HEAT ENERGY, that temperature is defined as **'the measure of the degree of hotness or coldness of a body with respect to some standard'.**

Temperature is measured in °C, °F, and K. Here we would extend our understanding of temperature on the basis of kinetic molecular description. According to this theory atoms and molecules are in continuous random motion. According to this theory, the temperature can also be defined as: **'The average kinetic energy of molecules of a body'.**

INFORMATION

Death Valley, California: *The hottest place on Earth, in summer temperature reach to 56°C.*

The Antarctic: *During the continuous darkness of mid-winter, the temperature here can be as low as -87 °C.*

Internal Energy and Temperature:

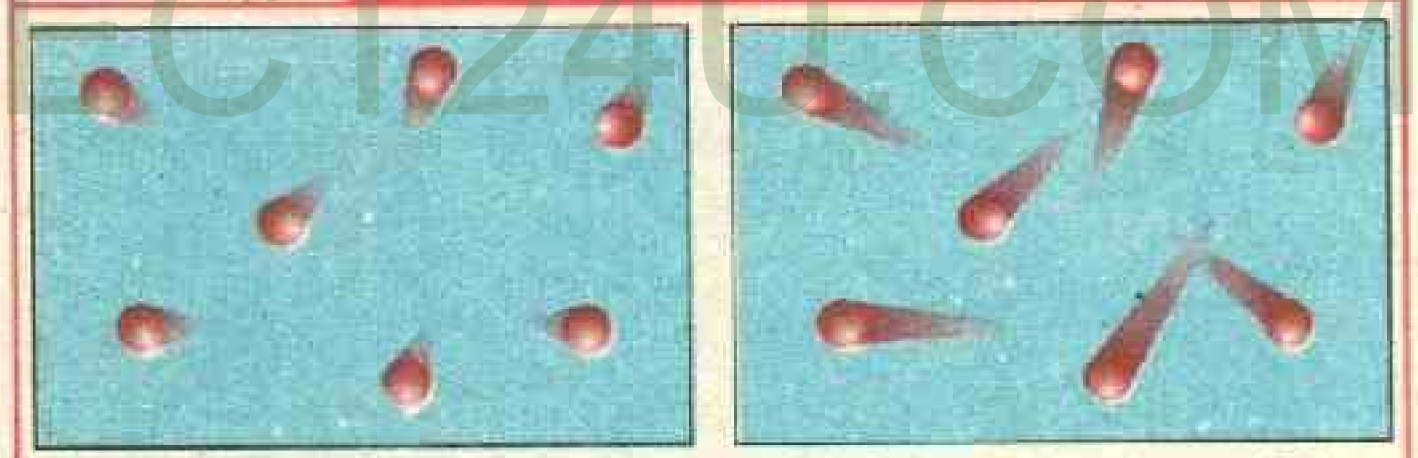
Internal energy is the sum of the kinetic and potential energies associated with the motion of the atoms of the substance. For example, in a gas made up of single atoms (monoatomic gas), such as helium, the atoms move around, randomly colliding with each other and the walls of the container. So each atom has some translational kinetic energy. However, if the gas is made up of molecules with two or more atoms, the molecules can also stretch, contract and spin, so these molecules also have other types of kinetic energy called vibrational and rotational kinetic energy.

Like a gas, molecules in a liquid are free to move, but within the confines of the surface of the liquid. There is some attraction between molecules, which means there is some energy stored as molecules approach each other.

In a solid, atoms jiggle rather than move around. They have kinetic energy, but they also have a lot of potential energy stored in the strong attractive force that holds the atoms together.

Temperature is a measure of the average kinetic energy of particles. The other contributions to the internal energy do not affect the temperature. The kinetic energy may be in the form of translational, vibrational and rotational kinetic energy. As atoms or molecules of the material are in constant motion, at high temperatures the kinetic energy of molecules is more and at lower temperatures it is less.

Figure 8.1 TEMPERATURE



(a) The low average kinetic energy of the particles

(b) the temperature of the gas, increases when energy is added to the gas

As atoms or molecules of the material are in constant motion, at high temperatures the kinetic energy of molecules increases. The monoatomic gas is shown in the figure 8.1 which only have translational kinetic energy, at high temperature the increase in translational kinetic energy is observed.

8.2 HEAT

Take some water in a kettle and place it on a flame. The water gradually becomes warmer and eventually starts boiling. How does it happen? In fact, the temperature of the flame is much higher than that of the kettle and the water. Something must have transferred from the hot flame to the cold water. In general temperature of any object can be raised (heated) by placing it in thermal contact with another hotter object.

For example, Water in a kettle can be heated by placing it on flame. The earth is heated by the hot sun as thermal contact.

It is evident from these examples that in the process of raising the temperature of a body something must have flown from the hotter body to the colder body. This something which flows from the hotter body to the colder body till the temperatures of the two bodies become equal is called heat. Thus we can define heat as,

Heat is thermal energy transferred from a hotter body to a colder body. When two objects with different temperatures are placed in thermal contact, the temperature of the warmer object decreases while the temperature of the cooler object increases. With time they reach a common equilibrium temperature (**thermal equilibrium**) somewhere in between their initial temperatures. During this process, we say that energy is transferred from the warmer object to the cooler one.

Figure 8.2 HEAT

Heat flows from the warmer substance to the cooler.

The relationship of heat to thermal energy is analogous to the relationship of work to mechanical energy we studied in Chapter 6. The symbol Q is used to represent the amount of energy transferred by heat between a system and its environment. *As heat (like work) is a measure of the transfer of energy, its SI unit is joule J.*

Distinguishing Temperature, Heat, and Internal Energy:

Using the kinetic theory, we can make a clear distinction between temperature, heat, and internal energy. Temperature (in kelvins) is a measure of the average kinetic energy of individual molecules. Internal energy refers to the total energy of all the molecules within the object. Thus two equal-mass hot ingots of iron may have the same temperature, but two of them have twice as much internal energy as one does. Heat, finally, refers to a transfer of energy from one object to another because of a difference in temperature.

8.3 MEASUREMENT OF TEMPERATURE

Temperature could be measured in a simple way by using our hand to sense the hotness or coldness of an object. However, the range of temperatures that our hand can bear is very small, and our hand is not precise enough to measure temperature correctly.

Temperature measurement in today's industrial environment encompasses a wide variety of needs and applications. To meet this wide array of needs inventors has developed a large number of sensors and devices to handle this demand. The branch of physics which deals with the measurements of temperature is called **thermometry**. For scientific work, we need some reliable device or instrument to measure temperature accurately. Such an instrument is called **thermometer**.

ACTIVITY **TEMPERATURE SENSE CAN BE DECEPTIVE**

Try an experiment at home, fill one container with water that is hot (but not too hot to touch); fill a second container with lukewarm water; and fill a third container with cold water. Put one hand in the hot water and one in the cold water for about 10 to 20 s. Then plunge both hands into the container of lukewarm water. Although both hands are now immersed in water that is at a single temperature, the hand that had been in the hot water feels cool while the hand that had been in the cold water feels warm. This demonstration shows that we cannot trust our subjective senses to measure temperature.

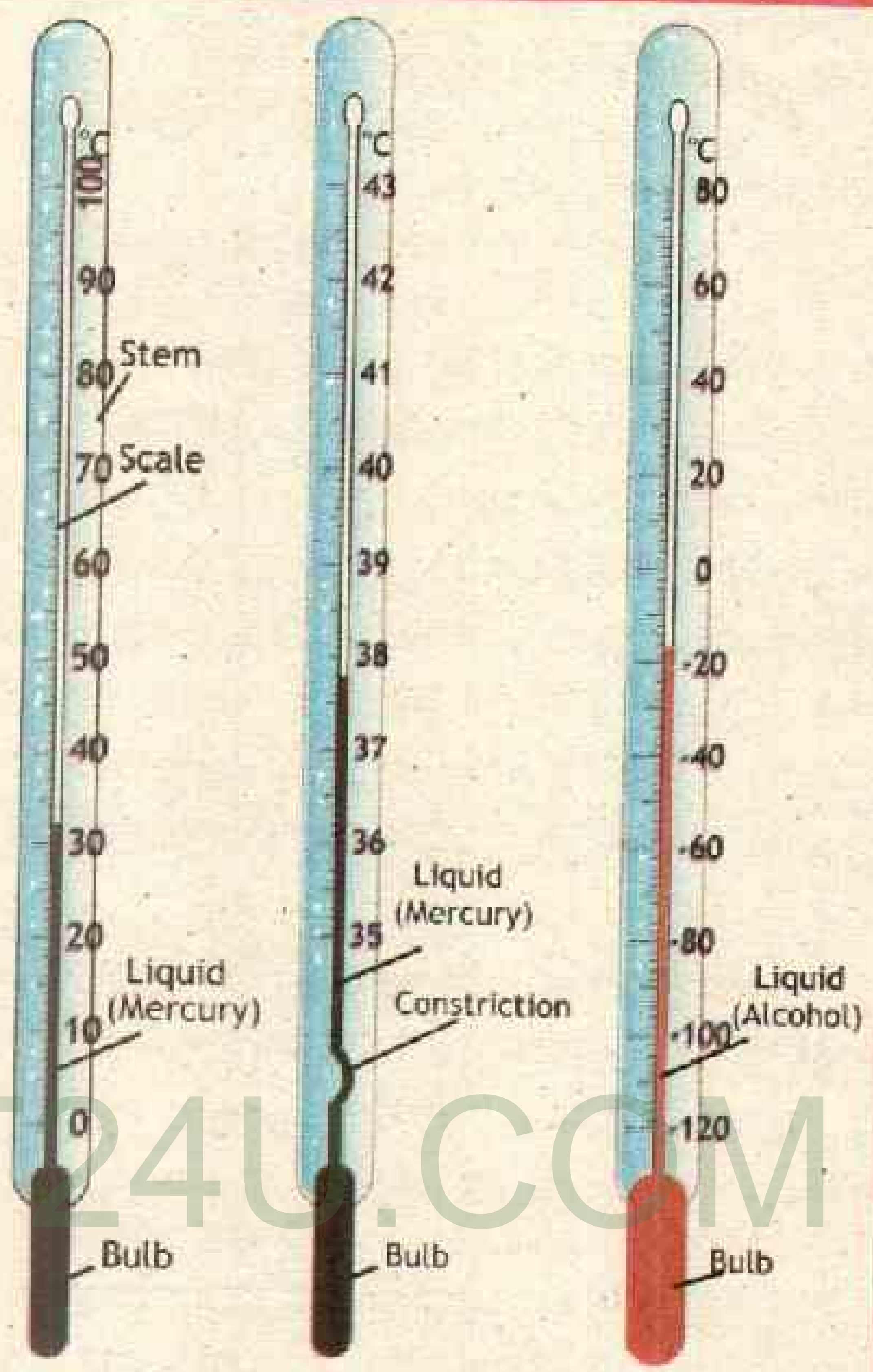
8.3.1 THERMOMETRIC PROPERTY

In order to construct a thermometer, we make use of a certain physical property of matter that increases or decreases uniformly with rise and fall in temperature. This particular property of a substance that increases and decreases uniformly with temperature and can be used for the measurement of temperature is called **thermometric property**. Some examples of thermometric properties include the volume of a liquid, length of a solid, gas pressure, electrical resistance and electromotive force.

The commonly used thermometric property is the thermal expansion of materials. This property make use of the fact that matter (solid, liquid or gas) expands on heating and contracts on cooling. Thus the degree of expansion or contraction of matter can be calibrated on suitable scale to record temperature. The most common of these devices is the liquid in glass thermometer.

The Liquid in Glass thermometer utilizes the variation in volume of a liquid in temperature. They use the fact that most fluids expand on heating. The fluid is contained in a sealed glass bulb, and its expansion is measured using a scale etched in the stem of the thermometer If we consider that the thermometer does not expand then as physical property it utilizes the variation of length of liquid with temperature. In this type the liquid in a glass bulb expands up a capillary tube when the bulb is heated. The liquid must be easily seen and must expand (or contract) rapidly and by a large amount over a wide range of temperature. It must not stick to the inside of the tube or the reading will be too high when the temperature is falling. Liquids commonly used include Mercury and Alcohol. Different Thermometers are shown in the figure 8.3.

Figure 8.3 THERMOMETERS



A. Mercury Thermometer B. Mercury (clinical) Thermometer C. Alcohol Thermometer

8.3.2 TEMPERATURE SCALES

The scale which is made for the measurement of temperature is called temperature scale or thermometric scale. The scale comprises of two reference points, called fixed points. These points are given arbitrarily assigned numerical values. They must be reproducible. The interval between these points is divided arbitrarily into equal divisions.

There are three scales of temperature which are commonly used.

A. Centigrade or Celsius scale:

This scale was introduced by a Swedish astronomer Anders

> **INFORMATION**
>
> Centigrade scale and Fahrenheit scale are the modified form of kelvin scale. Centigrade scale is used in laboratory for scientific purposes and fahrenheit scale is used for clinical purposes to measure the temperature of patient.

Celsius. In this scale of temperature, the ice point marked as 0 °C and the steam fixed point is marked as 100 °C at standard pressure. The interval between these two fixed points is divided into 100 equal parts (divisions). Each division on the scale is called one degree centigrade or Celsius and denoted by °C.

B. Fahrenheit Scale:

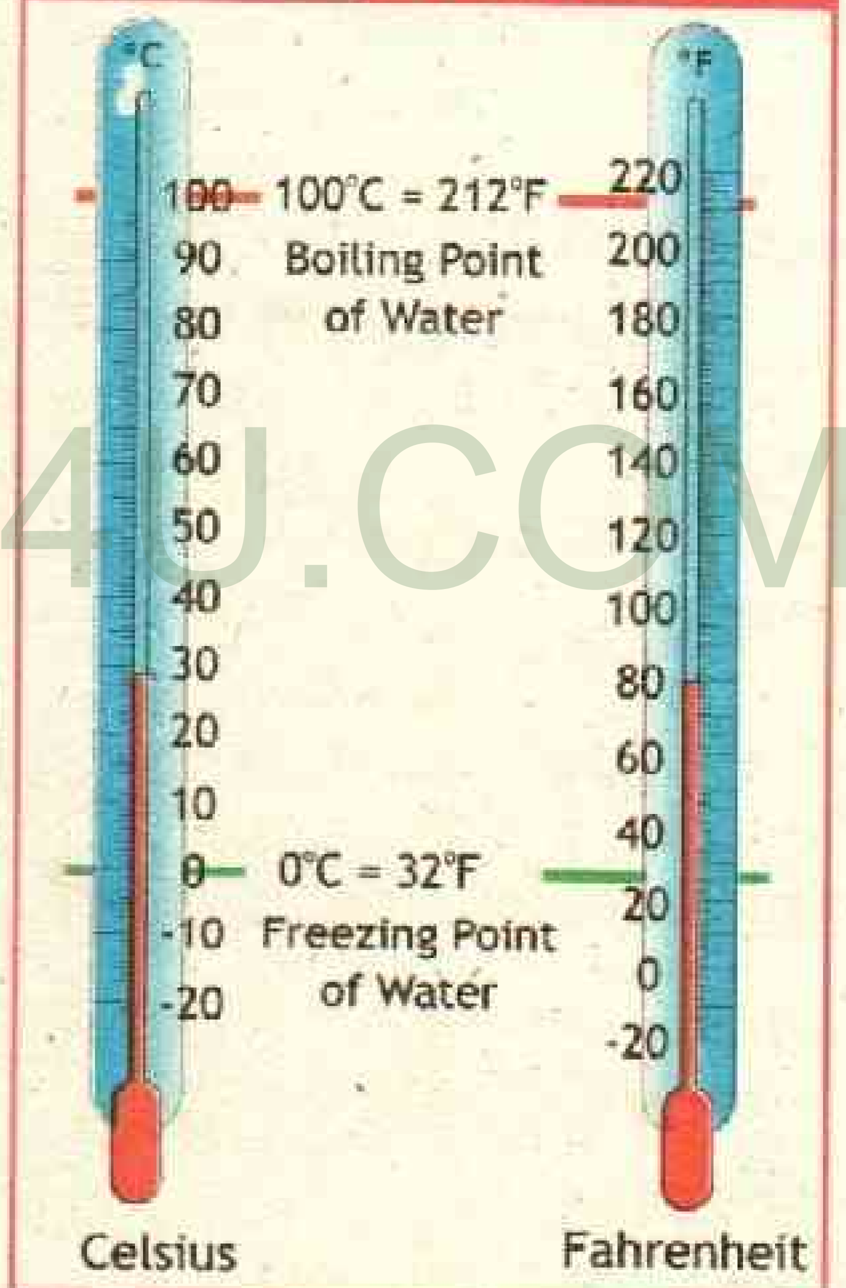
This scale was introduced by German physicist Daniel Gabriel Fahrenheit. In this scale of temperature, the ice point marked as 32 °F and the steam point is marked as 212 °F. The interval between these points is divided into 180 equal parts. Each part on the scale called one degree Fahrenheit and is denoted by °F.

C. Kelvin or Absolute Scale:

This scale was devised by William Thomson, (Lord Kelvin). He named this scale as absolute scale. In this scale of temperature, the ice points is marked as 273 K and the boiling point of water marked as 373 K. Thus the interval between them is divided into 100 equal parts. Each part on the scale is called one Kelvin and denoted by K.

The lowest temperature at which the molecular movements of matter ceases is called Kelvin Zero or absolute zero. Its magnitude on the Celsius scale is -273° C. **Kelvin scale is adopted in the international system (SI) of units.**

Figure 8.4 COMPARISON



8.3.3 RELATIONSHIP BETWEEN DIFFERENT SCALES of Temperature

A temperature measured on one scale, sometimes, needs conversion to another scale. Let °C, °F and K, as measured on the three scales, denote the same temperature. The length of the mercury column in the capillary of the thermometer is of fixed value. Degrees of temperature are measured from the ice - point which are respectively 0 °C, 32 °F and 273 K. A general relation for the conversion of temperature from one scale to the other is

$$\frac{\text{Temperature on one scale- ice point}}{\text{number of divisions between fixed points}} = \frac{\text{Temperature on other scale- ice point}}{\text{number of divisions between fixed points}}$$

or

$$\frac{T_{Scale\,1} - T_{Ice}}{N} = \frac{T_{Scale\,2} - T_{Ice}}{N} \qquad (8.1)$$

A. Conversion Between centigrade and Fahrenheit scale

Using the general relation we have

$$\frac{T_{°C}-0}{100}=\frac{T_{°F}-32}{180}$$

or $$\frac{T_{°C}}{100}=\frac{T_{°F}-32}{180}$$

or $$T_{°C}=100\times\left[\frac{T_{°F}-32}{180}\right]$$

or $$T_{°C}=\frac{100}{180}(T_{°F}-32)$$

therefore $$T_{°C}=\frac{5}{9}\times(T_{°F}-32) \quad (8.2)$$

or $$T_{°F}=\frac{9}{5}T_{°C}+32 \quad (8.3)$$

Conversion Between Centigrade and Kelvin scale

Using the general relation we have

$$\frac{T_{°C}-0}{100}=\frac{T_K-273}{100}$$

therefore $$T_{°C}=T_K-273 \quad (8.4)$$

or $$T_K=T_{°C}+273 \quad (8.5)$$

CAN YOU TELL?

How would we convert °F into K?

Example 8.1 HUMAN BODY TEMPERATURE

The temperature of a normal human body is 37°C. Find this temperature on the Fahrenheit and Kelvin Scale.

SOLUTION

GIVEN:

Celsius Temperature T_C = 37°C

REQUIRED:

Fahrenheit Temperature T_F = ?

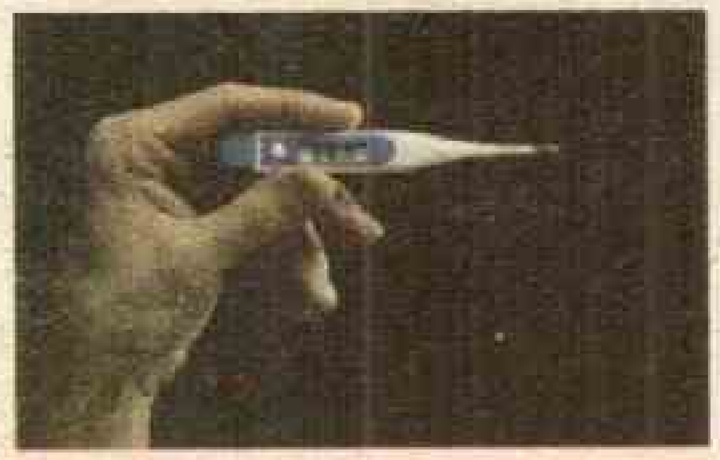
Kelvin Temperature T_K = ?

To convert °C into °F, we use $T_{°F}=\frac{9}{5}T_{°C}+32$

$$T_{°F}=\frac{9}{5}\times 37°C+32°C$$

or $$T_{°F}=66.6°C+32°C$$

therefore $$T_{°F}=98.6°C$$



thus $37^\circ C = 98.6^\circ F$

To convert °C into K, we use $T_K = T_{^\circ C} + 273$

putting values $T_K = 37^\circ C + 273^\circ C$

therefore $T_K = 310^\circ C$

thus $37^\circ C = 310\ K$ — Answer

Assignment 8.1 KELVIN SCALE

Temperature of an object is 250 K. Find its temperature in centigrade.

8.4 THERMAL EXPANSION

Thermal expansion means "increase in size of a substance on heating ". Most substances expand when heated and contract when cooled. However, the amount of expansion or contraction varies, depending on the material, the change in temperature and the original size of the substance. Thermal expansion is different for different states e.g. solid, liquid or gas of the same substance. It is experienced that gases expand more than liquids and liquids expand more than solids.

8.4.1 THERMAL EXPANSION OF SOLIDS

A solid substance can undergo three types of expansion : expansion in length (linear thermal expansion), expansion in area (superficial thermal expansion) and expansion in volume (volume or cubical thermal expansion). As the temperature of a solid is raised, the molecules vibrate through larger distance. The increase in amplitude of vibration of molecules causes an increase in the average distance between them. Hence Solids expand on heating. Conversely solids contract as the temperature is lowered.

A. Linear Thermal Expansion of solids:

The increase in length of a substance due to rise in temperature is called linear thermal expansion.

Consider a metal rod having an original length 'l_o', at temperature 'T_o'. After heating metal rod to temperature 'T', the rod expand to its new length 'l_T' as shown in the figure 8.5. This means for the change in temperature ΔT (where $\Delta T = T - T_o$) there is corresponding change in length Δl (where $\Delta l = l_o - l_T$). Experiments indicate that the change in length Δl of almost all solids is, to a good approximation, directly proportional to the change in temperature ΔT as long as is not too large. This means by changing temperature the length also change, more the change in temperature more is the change in length and vice versa.

$$\Delta l \propto \Delta T \quad (1)$$

The change in length Δl is also proportional to the original length l_o of the object, That is, for the same temperature increase, a 4-m-long iron rod will increase in length twice as much as a 2-m-long iron rod. We can write this proportionality as an equation:

$$\Delta l \propto l_o \quad (2)$$

Figure 8.5 LINEAR EXPANSION

combining equation 1 and equation 2 we get

$$\Delta l \propto l_o \Delta T$$

changing proportionality into equality

$$\Delta l = \alpha \, l_o \Delta T \quad (8.6)$$

where 'α' the proportionality constant, is called the coefficient of linear thermal expansion for the particular material and has units of $°C^{-1}$ and in SI as K^{-1}.

since $\Delta l = l_o - l_T$ we can write the above equation as

$$l_T - l_o = \alpha \, l_o \Delta T$$

taking l_o common

$$l_T = l_o + \alpha \, l_o \Delta T$$

therefore $$l_T = l_o(1 + \alpha \, \Delta T) \quad (8.7)$$

If the temperature change $\Delta T = T - T_o$ is negative, then $\Delta l = l_o - l_T$ is also negative; the length shortens as the temperature decreases.

From equation 8.6, we can define coefficient of linear thermal expansion α of a substance as the increase in length per unit length of the solid per kelvin 'K' rise in temperature.

$$\alpha = \frac{\Delta l}{l_o \Delta T} \quad (8.8)$$

In simple words, α is numerically the increase in 1 m long wire for 1 degree rise of temperature. The value of α depends upon the nature of material, the values of coefficients of linear thermal expansion (α) for different materials are given in the table 8.2.

Example 8.2 **BRIDGE ENGINEERING**

The steel ($\alpha = 12 \times 10^{-6}\ K^{-1}$) bed of a suspension bridge is 200 m long at 20°C. If the extremes of temperature to which it might be exposed are -5°C to 50°C how much will it contract and expand?

SOLUTION

GIVEN:

Original length $l_o = 200$ m

Coefficient of linear thermal expansion $\alpha = 12 \times 10^{-6}\ K^{-1}$

Reference Temperature $T_o = 20°C$

Temperature $T_1 = -5°C$

Temperature $T_2 = 50°C$

REQUIRED:

(a) Change in length $\Delta l_1 = ?$

(b) Change in length $\Delta l_2 = ?$

(a) When temperature decreases to -5 °C the change in temperature $\Delta T_1 = T_1 - T_o = -5°C - 20°C = -25°C$, since the change in temperature is same in Celsius (°C) and Kelvin scale (K). Therefore - 25°C = - 25 K. The linear thermal expansion is given by

$$\Delta l_1 = \alpha\, l_o\, \Delta T_1$$

putting values $\Delta l_1 = 12 \times 10^{-6}\ K^{-1} \times 200\,m \times (-25\,K)$

or $\Delta l_1 = -6 \times 10^{-2}\ m$

therefore $\Delta l_1 = -6\,cm$ — Answer

(b) When temperature increases to 50 °C change in temperature $\Delta T_2 = T_2 - T_o = 50°C - 20°C = 30°C$, since the change in temperature is same in Celsius (°C) and Kelvin scale (K). Therefore 30°C = 30 K. The linear thermal expansion is given by

$$\Delta l_2 = \alpha\, l_o\, \Delta T_2$$

putting values $\Delta l_2 = 12 \times 10^{-6}\ K^{-1} \times 200\,m \times 30\,K$

$\Delta l_2 = 7.2 \times 10^{-2}\ m$

therefore $\Delta l_2 = 7.2\,cm$ — Answer

The total range the expansion joints must accommodate is 7.2 cm + 6 cm = 13.2 cm

Assignment 8.2 **COEFFICIENT OF LINEAR THERMAL EXPANSION**

The length of a bar of certain metal is 60 cm. When the bar is heated from 8 °C to 100 °C, its length becomes 60.127 cm. Calculate the coefficient of linear thermal expansion of the metal.

B. Volume (cubical) thermal expansion of solids

The increase in volume of a substance due to rise in temperature is called volume thermal expansion.

Consider a metal block having an original volume 'V_o', at temperature 'T_o'. After heating metal block to temperature 'T', the block expand to its new volume 'V_T' as shown in the figure 8.6. This means for the change in temperature ΔT (where $\Delta T = T - T_o$) there is corresponding change in volume ΔV (where $\Delta V = V_o - V_T$).

The increase in volume of a metal block, on heating, is directly proportional to original volume of the metal block and rise in temperature. Mathematically,

$$\Delta V \propto \Delta T \quad \text{and} \quad \Delta V \propto V_o$$

combining these proportionalities, we get

$$\Delta V \propto V_o \Delta T$$

changing proportionality into equality

$$\Delta V = \gamma V_o \Delta T \qquad \text{— 8.9}$$

where 'γ' the proportionality constant, is called the coefficient of volume thermal expansion for the particular material and has units of $°C^{-1}$ and in SI as K^{-1}.

since $\Delta V = V_o - V_T$ we can write the above equation as

$$V_T - V_o = \gamma V_o \Delta T$$

taking V_o common $\quad V_T = V_o + \gamma V_o \Delta T$

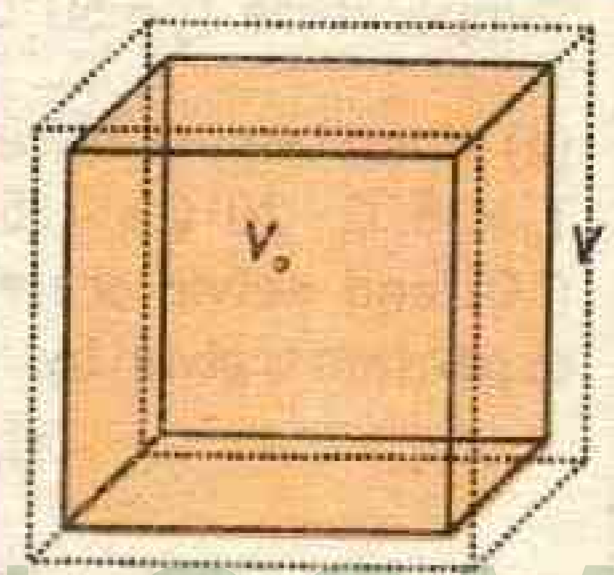
therefore $V_T = V_o(1 + \gamma \Delta T)$ — 8.10

From equation 8.9, we can define coefficient of volume thermal expansion (γ) of a substance as the change in volume per unit volume per kelvin change in temperature.

$$\gamma = \frac{\Delta V}{V_o \Delta T} \qquad \text{— 8.11}$$

This is a general rule for solids that they expand to the same extent in all three directions. It can be proved that the coefficient of volume thermal expansion of solids γ is about three times

Figure 8.6



Volume thermal expansion for cubical object

RECALL

General Science for class 8, chapter 9: SOURCES AND EFFECTS OF HEAT ENERGY, Thermal expansion of solids, liquids and gases. We also learned important applications of thermal expansion, we used bimetallic strip for fire alarms and automatized switching of electric iron. Also the effects of thermal expansion in daily life were discussed.

the coefficient of linear thermal expansion α of solids

$$\gamma = 3\alpha \qquad (8.12)$$

The values of coefficients of volume thermal expansion γ for different substances are given in the table 8.2, which is approximately three times the coefficient of linear thermal expansion α.

TABLE 8.2: THERMAL EXPANSION COEFFICIENTS AT 20°C

Material	Coefficient of linear expansion α (°C^{-1} or K^{-1})	Coefficient of volume expansion γ (°C^{-1} or K^{-1})
Solids		
Aluminum	25×10^{-6}	75×10^{-6}
Brass	19×10^{-6}	57×10^{-6}
Copper	17×10^{-6}	51×10^{-6}
Iron or Steel	12×10^{-6}	35×10^{-6}
Lead	29×10^{-6}	87×10^{-6}
Concrete, Brick	12×10^{-6}	36×10^{-6}
Fluids		
Ethyl alcohol	-	1100×10^{-6}
Petrol	-	950×10^{-6}
Mercury	-	180×10^{-6}
Water	-	210×10^{-6}
Air and most other gases at atmospheric pressure	-	3400×10^{-6}

To see how this relationship comes about, suppose that the solid has the shape of a cube of side L. The increment in the length of each side is L, and treating this as a small (infinitesimal) quantity, the increment in the volume L^3 is

$$\Delta V = \Delta(L)^3 = 3L^2 \Delta L$$

or $$\Delta V = 3L^2 \times \alpha L \Delta T$$

or $$\Delta V = 3\alpha L^3 \Delta T$$

therefore $$\Delta V = 3\alpha V \Delta T$$

Comparing this result for ΔV with Equation 8.9, we see that γ = 3α.

TID-BIT DO HOLES EXPAND OR CONTRACT?

If you heat a thin, circular ring in the oven, does the ring's hole get larger or smaller?

If you guessed that the metal expands into the hole, making the hole smaller, it is not so. Imagine the ring is solid, like a coin.

Draw a circle on it with a pen as shown. When the metal expands, the material inside the circle will expand along with the rest of the metal; so the dashed circle expands. Cutting the metal where the circle is shows that the hole in Figure a increases in diameter.

INFORMATION

Place a dented Ping-Pong ball in boiling water, and you'll remove the dent. Why?

Example 8.3 GLASS LASER EXPANSION

The active element of a certain laser is made of a glass rod 30.0 cm long and having volume $5.30 \times 10^{-5}\ m^3$. Assume the average coefficient of linear expansion of the glass is equal to $9.00 \times 10^{-6}\ K^{-1}$. If the temperature of the rod increases by 65.0°C, what is the increase in (a) its length and (b) its volume?

SOLUTION

GIVEN:

Original length $l_o = 30\ cm = 0.3\ m$

Original Volume $V_o = 5.30 \times 10^{-5}\ m^3$

Coefficient of linear thermal expansion

$\alpha = 9 \times 10^{-6}\ K^{-1}$

change in temperature $\Delta T = 65.0°C = 65\ K$

REQUIRED:

(a) Change in length $\Delta l = ?$

(b) Change in Volume $\Delta V = ?$

(a) The linear thermal expansion is given by $\Delta l = \alpha\, l_o\, \Delta T$

putting values $\Delta l = 9.00 \times 10^{-6}\ K^{-1} \times 0.300\ m \times 65 K$

therefore $\Delta l = 1.76 \times 10^{-4}\ m$ — **Answer**

(b) The Volume thermal expansion is given by $\Delta V = \gamma\, V_o\, \Delta T$

Since $\gamma = 3\alpha$, therefore $\Delta V = 3\alpha\, V_o\, \Delta T$

putting values $\Delta V = 3 \times 9.00 \times 10^{-6}\ K^{-1} \times 5.30 \times 10^{-5}\ m^3 \times 65 K$

therefore $\Delta V = 93.0 \times 10^{-9}\ m^3$ — **Answer**

Assignment 8.3 CHANGE IN VOLUME OF LEAD

A $200\ cm^3$ piece of lead ($\gamma = 87 \times 10^{-6} K^{-1}$) is at 10 °C. If it is heated to a temperature of 40 °C, find the change in volume of the lead.

8.4.2 THERMAL EXPANSION OF LIQUIDS

Like solids, liquids also expand on heating and contract on cooling. A liquid has no definite length and surface area; therefore, we cannot consider the linear expansion or superficial expansion of a liquid.

But liquids always take up the shape of the containing vessels. Therefore in case of liquids we are concerned only with volume changes when they are heated. The increase in the volume of a liquid due to the thermal effect of heating is called thermal expansion of liquids. Since heat effects both the liquid and the container the real expansion of a liquid cannot be detected directly. In case of liquids, we have two kinds of thermal expansion: the apparent expansion and the real expansion.

A. Real expansion of liquid:

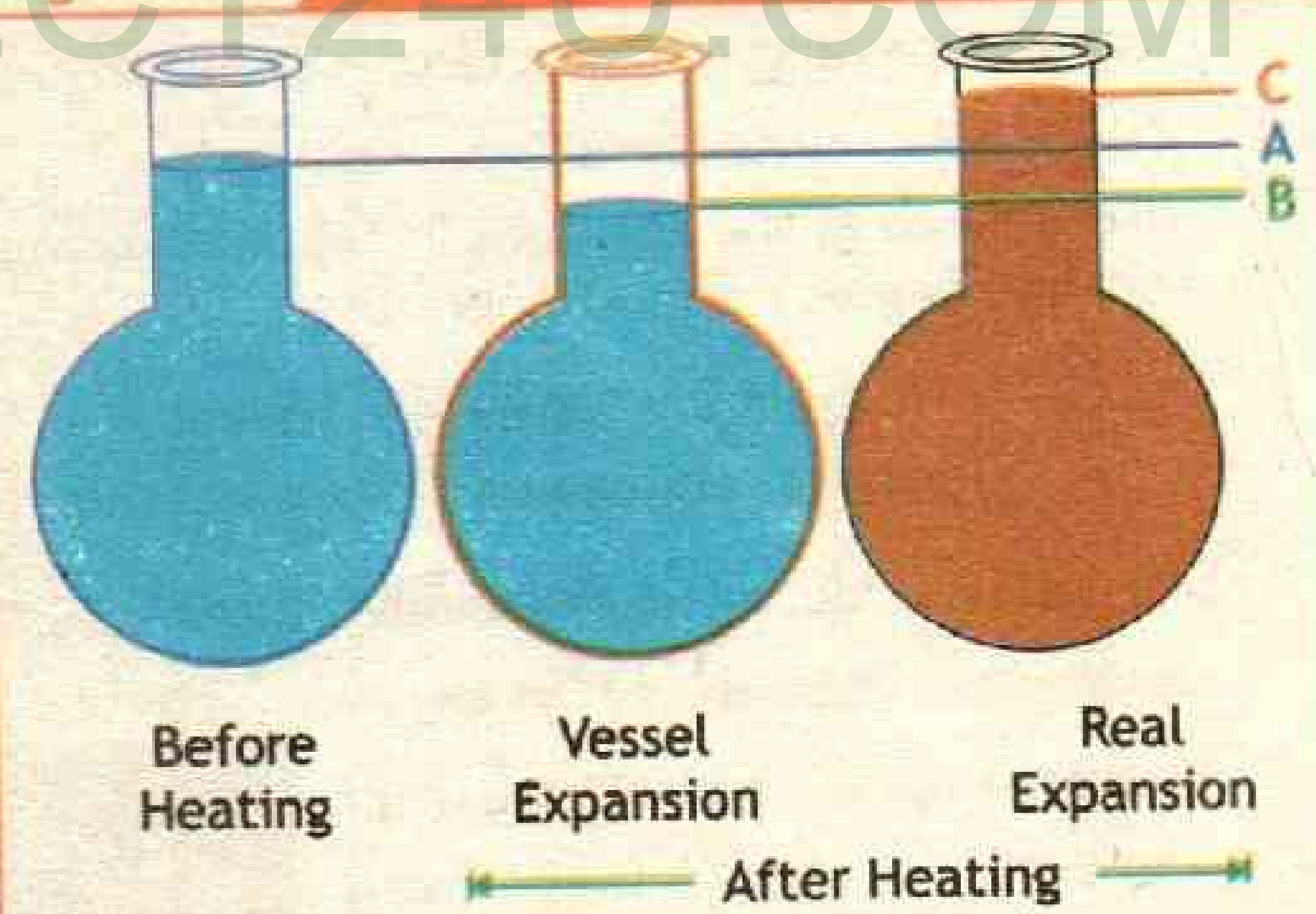
A real increase in the volume of a liquid, that takes place due to increase of temperature is called real expansion V_R of liquid. This expansion is independent of the expansion of the container.

B. Apparent expansion of liquid:

An appa[re]nt increase in the volume of a liquid, that takes place due to increase of ter[m]perature is called apparent expansion V_A of liquid.

When a liquid is taken in a [co]ntainer and heated, both the liquid and the container expand at same time. The difference of these expansions are called apparent expansion. If V_R is the expansion in the volume of the liquid (called real expansion) and V_C is the expansion in the volume of the container on heating then the apparent expansion V_A is given by as;

Figure 8.7 REAL AND APPARENT EXPANSION



$$V_A = V_R - V_C \quad (8.13)$$

Let a vessel has water up to level A. If heat is applied, the vessel will first expand which will produce an illusion that the water has fallen. This is due to the expansion of the vessel and is given by the measurement of the difference of the two levels i.e. AB.

If heating is further done, heat energy will start reaching the liquid. The liquid will then start expanding rapidly, according to its nature, exceeding its previous level, to reach up to level C. So the measurement of BC gives the true (real) expansion of the liquid only.

An observer present at the start and at the end will see the whole episode as just the expansion of the liquid from A to C. So AC measures the apparent expansion of the

body. Mathematically,

$$BC = AC + AB$$

Or, Real Expansion of liquid = Apparent Expansion of liquid + Vessel Expansion

Since there are two different types of expansion of liquids, their coefficients of expansion should also be defined differently.

C. Coefficient of Real Expansion 'γ_R' :

It is defined as the real increase on volume of liquid per unit original volume per unit degree rise in temperature. It is defined as:

$$\gamma_R = \frac{\text{real increase in volume}}{\text{original volume} \times \text{rise in temperature}} \quad (8.14)$$

Its unit is per degree rise in temperature i.e. $°C^{-1}$ or K^{-1}.

D. Coefficient of Apparent Expansion 'γ_A':

It is defined as the apparent increase in volume of liquid per unit original volume per unit degree rise in temperature.

$$\gamma_A = \frac{\text{apparent increase in volume}}{\text{original volume} \times \text{rise in temperature}} \quad (8.15)$$

Its unit is per degree rise in temperature i.e. $°C^{-1}$ or K^{-1}.

E. Anomalous Expansion of Water:

Liquids expand on heating except water between 0°C and 4°C. Water is unusual in its expansion characteristics. When water at 0°C is heated, its volume decreases upto 4°C and from 4°C its volume increases with the increase of temperature. This peculiar behaviour of water is called anomalous expansion of water. Due to the formation of more number of hydrogen bonds, water has anomalous expansion.

As the temperature increases from 0°C to 4°C, the density increases and as the temperature further increases the density decreases. Hence water has maximum density at 4°C.This is why ice floats on water, we can see this when we put ice cubes in water to cool it or icebergs floating in ocean.

Example 8.4 LOST DIESEL

An oil trucker loaded 37,000 L of diesel fuel with $\gamma = 9.5 \times 10^{-4}\,K^{-1}$ at Jackobabad, where on hot day the temperature is 50°C. This oil is transported to Kalam where on cold day the temperature is 0°C. What is the change in volume of diesel? How many liters did he deliver?

SOLUTION

GIVEN:

Original volume V_o = 37000 L

Coefficient of volume thermal expansion $\gamma = 9.5 \times 10^{-4}\,K^{-1}$

Change in Temperature ΔT = 0°C - 50°C = - 50°C = - 50 K

REQUIRED:

(a) Change in volume ΔV = ?

(b) Volume Delivered V_D = ?

(a) The volume of the diesel fuel depends directly on the temperature. Thus, because the temperature decreased, the volume of the fuel also decrease.

The volume thermal expansion is given by

$$\Delta V = \gamma V_o \Delta T$$

putting values $\Delta V = 9.5 \times 10^{-4}\,K^{-1} \times 37000\,L \times -50\,K$

therefore $\Delta V = -1757.5\,L = -1760\,L$ — Answer

(b) A decrease in 1760 liters is observed and the amount delivered was

$$V_D = V_o + \Delta V = 37000\,L - 1760\,L$$

therefore $V_D = 35240L$ — Answer

Assignment 8.4 CHANGE IN VOLUME OF PATROL

If patrol at 0 °C occupies 250 Liters. What is its volume at 50 °C? For patrol take $\gamma = 9.6 \times 10^{-4}\,K^{-1}$.

8.4.3 APPLICATIONS AND CONSEQUENCES OF THERMAL EXPANSION

Thermal expansion is used in our daily life. In thermometers, already we have seen the use of thermal expansion to measure temperature.

A. Railway lines:

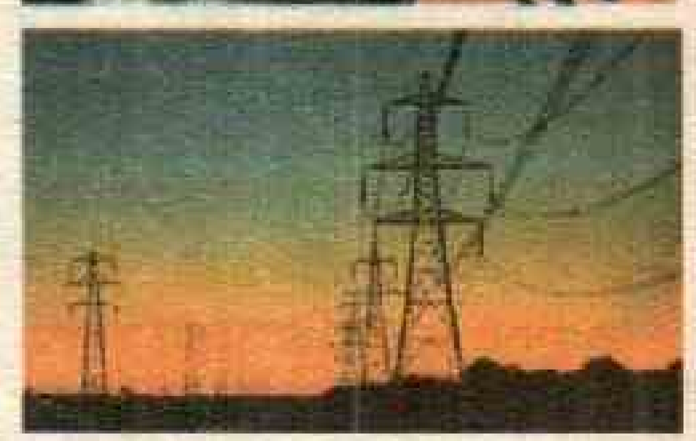
When railway tracks are laid the engineers leave a small gap between two rails as shown in figure A. If two railway tracks are laid together without any gap between them they will push against each other when they expand with the rise of temperature. This may cause them to bend as shown in figure B or tracks may also break free from one another. Such a situation will result in the derailment of the trains causing major accidents and loss of lives.

So, the railway engineers always leave a small gap between two rails to compensate for the expansion of the rails during the hot summer and contraction during cold winter.

B. Opening a tight jar lid:

When the lid of a glass jar is too tight to open, holding the lid under hot water for a short time will often make it easier to open. The top expands before the heat reaches the bottle. But even if not, metals generally expand more than glass for the same temperature change (α is greater)

C. Transmission Lines:



Transmission lines in the summer sag more as compared to winter.

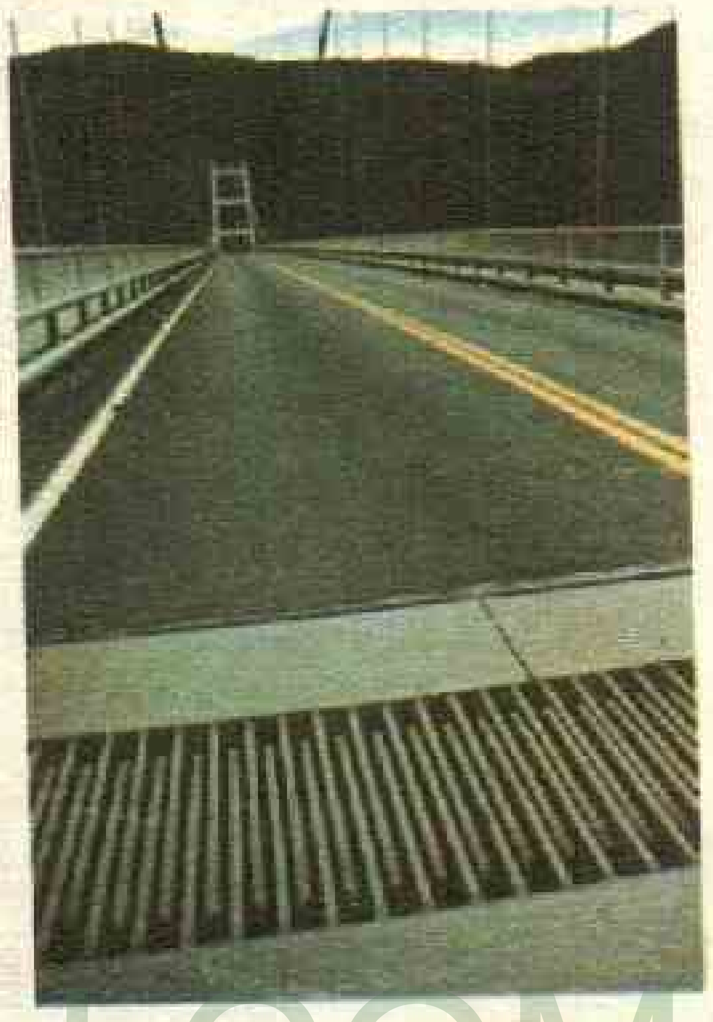
D. Shrink-fitting' of axles into gear wheels:

The axles have been shrunk by cooling in liquid nitrogen at $-196\ ^{\circ}C$ until the gear wheels can be slipped on to them. On regaining normal temperature the axles expand to give a very tight fit.

E. Expand fitting' iron ring to a cart wheel:

An iron ring can be tightly fixed into the wooden wheel of a Tonga. At room temperature, the diameter of the iron ring is slightly less than the diameter of the wooden wheel. The ring expands on heating and can be placed around the wooden wheel. When the ring comes to room temperature, it contracts and produces a tight fit.

F. Expansion Joints:



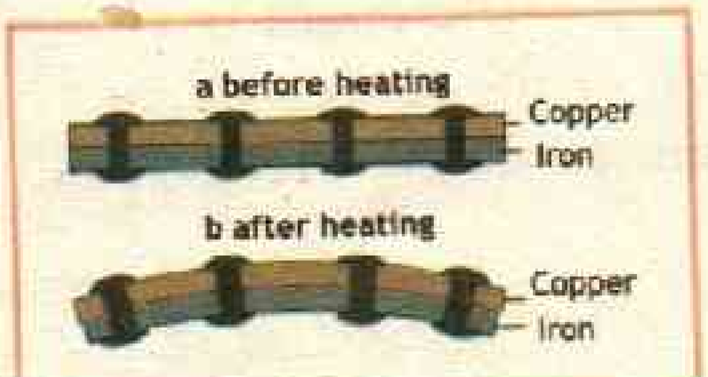
Most large bridges include expansion joints, which look rather like two metal combs facing one another, their teeth interlocking. When heat causes the bridge to expand during the sunlight hours of a hot day, the two sides of the expansion joint move toward one another; then, as the bridge cools down after dark, they begin gradually to retract. Thus the bridge has a built-in safety zone; otherwise, it would have no room for expansion or contraction in response to temperature changes.

G. Bimetallic Strip:

When the thin bimetal strip is heated, it bends because of unequal expansion of the two metals. Here brass expands more than steel when heated, making the strip bend toward the steel side.

A bimetallic strip is used to convert a temperature change into mechanical displacement. The strip consists of two strips of different metals which expand at different rates as they are heated. When their temperature increases, the unequal amounts of expansion causes the bimetallic strip to bend as shown in Figure.

For example if equal lengths of two different metals, such as copper and iron, are riveted together so that they cannot move separately, they form a bimetallic strip. When heated, copper expands more than iron and to allow this the strip bends with copper on the outside. If they had expanded equally, the strip would have stayed straight. Bimetallic strips have many uses, like fire alarm and thermostat.



8.5 HEAT CAPACITY AND SPECIFIC HEAT CAPACITY

When a substance absorbs heat its temperature rises. Conversely, when a substance loses heat, its temperature decreases. Experiments show that the thermal response of different materials to heat absorption is different. For example water requires a lot of heat to change its temperature while silver requires less heat to change its temperature. A massive body requires more heat energy to raise its temperature to a certain value than a lighter body of the same material.

8.5.1 HEAT CAPACITY (THERMAL CAPACITY)

The quantity of heat required to raise the temperature of a substance of mass (m) by 1 °C or 1 K is called the heat capacity (c_m) of that substance.

If ΔQ is the change in heat and Δ T is the change in temperature, then

$$c_m = \frac{\Delta Q}{\Delta T} \qquad (8.16)$$

The value of 'c_m' depends upon

1. The nature of the material of the substance.
2. The mass of the material of the substance.
3. The rise in temperature.

In the Standard International System the unit of heat capacity is joule per Kelvin which is expressed as $J\,K^{-1}$.

8.5.2 SPECIFIC HEAT CAPACITY (SPECIFIC HEAT)

If we take equal amounts of different substances for example copper, iron and water. Heat them for a given interval of time under the same flame so that they all absorb the same amount of heat energy from the heat source. At the end of the interval, the rise in temperature is not the same for all. It is maximum for copper, minimum for water and intermediate for iron. This shows that copper is heated quickly where as water very slowly. This means that if they are all heated so as to have the same rise in temperature, copper will need least amount of heat and the water will need the greatest amount for this purpose.

The quantity of heat required to raise the temperature of unit mass (1.0 kg) of the substance by 1 °C or 1 K is called specific heat capacity of that substance. Mathematically

$$c = \frac{c_m}{m}$$

putting value of c_m from equation

$$c = \frac{\Delta Q}{m\Delta T} \qquad (8.17)$$

The S.I. unit of specific heat capacity or specific heat is joule per kilogram per Kelvin which is expressed as $J\,kg^{-1}\,K^{-1}$.

Different substances have different specific heat. The quantity of heat needed also depends on the nature of the material; raising the temperature of 1 kilogram of water by 1 K (1 °C) requires 4190 J of heat, but only 910 J is needed to raise the temperature of 1 kilogram of aluminum by 1 K (1 °C). The specific heat of water at 15 °C is 4190 $J\,kg^{-1}\,K^{-1}$. No other substance has a high specific heat capacity and it has natural benefits in sustaining life on the planet earth.

TABLE 8.3: SPECIFIC HEATS OF VARIOUS SUBSTANCES

Materials	Specific heat $J\,kg^{-1}\,K^{-1}$
Aluminum	910
Copper	387
Glass	840
Gold	129
Iron/ steel	452
Lead	128
Silver	230
Wood	1700
Ethanol	2450
Glycerin	2410
Mercury	139
Water	4190
Air	721
Carbon dioxide	638
Oxygen	651
Steam (100°C)	1520

8.5.3 IMPORTANCE OF THE HIGH SPECIFIC HEAT CAPACITY OF WATER

The specific heat capacity of water is equal to 4190 $J\,kg^{-1}\,K^{-1}$. It has some important implications.

A. Moderate climate of sea shore:

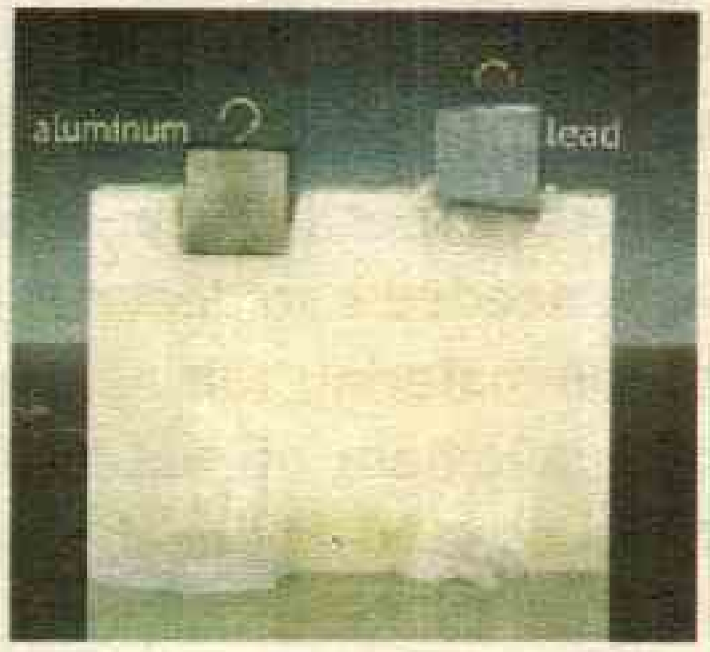
The specific heat of sand is about 800 $J\,kg^{-1}\,K^{-1}$ about. A certain mass of water needs five times more heat than the same mass of soil for its temperature to rise by 1 °C or 1 K. Hence, the land gets heated much more easily then water. Also, it cools down much easily. Hence, a large difference in temperature is formed that gives rise to land breeze and sea breeze. It keeps the climate of the coastal areas moderate. Monsoon in Pakistan is also due to the difference in temperature between the land and the surrounding sea.

B. As a coolant:

Water is used as a effective coolant. By allowing water to flow in radiator pipes of the vehicles, heat energy form such parts is removed. Thus, water extracts much heat without much rise in temperature.

INFORMATION

These two blocks of metal (aluminum on the left and lead on the right) have equal volumes. In addition, they were heated to equal temperatures before being placed on the block of paraffin wax. Notice, however, that the aluminum melted more wax—and hence gave off more heat—even though the lead block is about 4 times heavier than the aluminum block. The reason is that lead has a very small specific heat; in fact, lead's specific heat is about 7 times smaller than the specific heat of aluminum. As a result, even this relatively large mass of lead melts considerably less wax per degree of temperature change than the lightweight aluminum.



Example 8.5 AMOUNT OF HEAT TO RAISE THE TEMPERATURE OF WATER

How much heat is required to increase the temperature of 0.5 kg of water (with specific heat capacity of 4190 J kg^{-1} K^{-1}) from 10 °C to 65 °C ?

SOLUTION

GIVEN:

Mass of water m = 0.5 kg

Initial temperature T_o = 10 °C

Final temperature T = 65 °C

Rise in temperature $\Delta T = T - T_o$ = 65 °C - 10 °C = 55 °C = 55 K

Specific heat of water c = 4190 J kg^{-1} K^{-1}

REQUIRED:

Heat required, ΔQ = ?

The specific heat capacity is given by

$$c = \frac{\Delta Q}{m\Delta T}$$

or $\Delta Q = cm\Delta T$

putting values $\Delta Q = 4190\ J\,kg^{-1}\,K^{-1} \times 0.5\,kg \times 50\,K$

therefore $\Delta Q = 104750\ J$ — Answer

Assignment 8.5 SPECIFIC HEAT OF SILVER

If 117.60 J of heat is required to raise the temperature of 10 g of silver through 50 °C. Calculate the specific heat of silver.

LAB WORK

To find specific heat by method of mixture using Polystyrene cups (used as containers of negligible heat capacity.

8.6 LATENT HEAT AND PHASE CHANGE

A substance usually undergoes a change in temperature with transfer of energy (heat). In some cases, however, the transfer of energy doesn't result in a change in temperature. This can occur when the physical characteristics of the substance change from one form to another, commonly referred to as a phase change. Some common phase changes are solid to liquid (melting), liquid to gas (boiling), liquid to solid (freezing) and gas to liquid (condensation).

TID-BIT

As a thermometer comes into thermal equilibrium with an object, the object's temperature changes slightly. In most cases the object is so massive compared with the thermometer that the object's temperature change is insignificant.

Energy used to cause a phase change does not cause a temperature change. When ice melts at 0 °C it becomes water at 0 °C; when water boils at 100 °C, it becomes steam at 100 °C. The same is true in reverse: When water at 0°C freezes it becomes ice at 0 °C; when steam at 100 °C condenses it becomes water at 100 °C

The heat required to change the physical state of a substance (solid into a liquid or vapour, or a liquid into a vapour) but does not change its temperature is called latent heat of that substance.

8.6.1 LATENT HEAT OF FUSION

The amount of heat energy required to convert a given mass of a substance from the solid state to the liquid state (melt) with out any rise in temperature is called its latent heat of fusion. Liquids release the same amount of heat when they solidify (freeze).

Specific latent heat of fusion:

The amount of heat energy required to convert unit mass (one kilogram) of the solid at its melting point to liquid, (or liquid into solid) with out any change in temperature is called its specific latent heat of fusion of the solid. If 'ΔQ' is the amount of heat energy needed to melt mass 'm' of a solid to liquid (or freeze liquid to solid), then mathematically

$$\Delta Q = mL_f \qquad (8.18)$$

Where L_f is the latent heat of fusion of substance and is given as

$$L_f = \frac{\Delta Q}{m} \qquad (8.19)$$

The S.I. unit of specific latent heat of fusion is joule per kilogram which is expressed as $J\ kg^{-1}$. Different substances have different specific latent heat of fusion.

8.6.2 LATENT HEAT OF VAPORIZATION

The amount of heat energy required to convert a given mass of a substance from the liquid state to the gaseous state (boil) with out any rise in temperature is called its latent heat of vaporization. Gases release the same amount of heat when they Liquify (condense).

Specific latent heat of vaporization:

The amount of heat energy required to convert unit mass (one kilogram) of the liquid at its melting point to gas, (or gas into liquid) with out any change in temperature is called its specific latent heat of vaporization of the solid. If 'ΔQ' is the amount of heat energy needed to vaporize mass 'm' of a liquid to gas (or condense gas to liquid), then mathematically

$$\Delta Q = mL_v \quad \text{—— 8.20}$$

Where L_v is the latent heat of vaporization, such that

$$L_v = \frac{\Delta Q}{m} \quad \text{—— 8.21}$$

The S.I. unit of specific latent heat of vaporization is joule per kilogram which is expressed as $J\,kg^{-1}$. Different substances have different specific latent heat of vaporization.

8.6.3 EXPERIMENT FOR ICE - WATER PHASE CHANGE AND TEMPERATURE-TIME GRAPH ON HEATING ICE

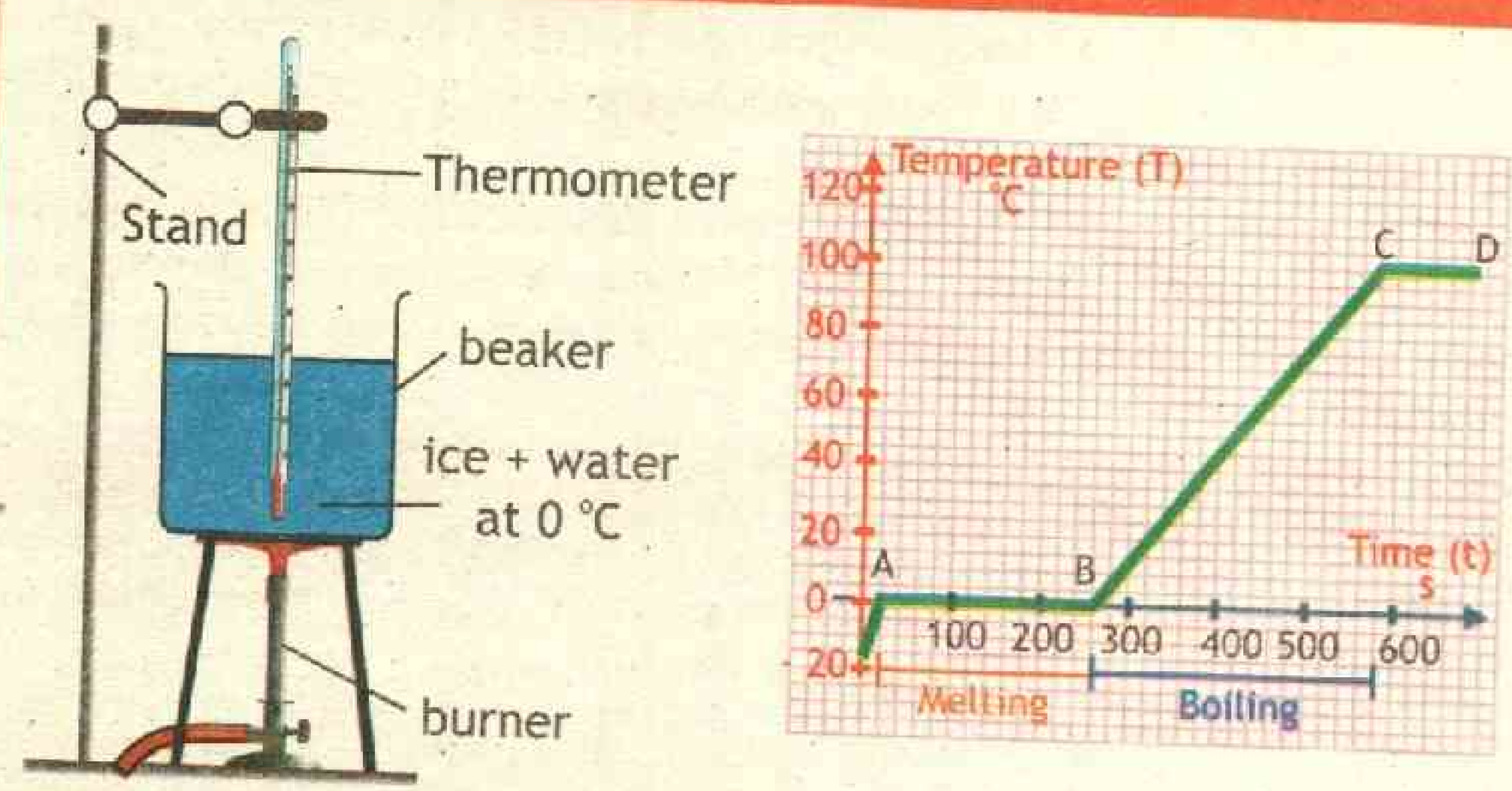
Take a beaker and place it over a stand. Put small pieces of ice in the beaker and suspend a thermometer in the beaker to measure the temperature. Place a burner under the beaker. The ice will start melting. The temperature of the mixture containing ice and water will not increase above 0°C until all the ice melts. Note the time which the ice takes to melt completely into water at 0°C. Continue heating the water at 0°C in the beaker. Its temperature will start to increase. Note the time which the water in the beaker takes to reach its boiling point at 100°C.

Draw a temperature-time graph such as shown in figure. From the graph we can see that at curve 'AB', even we were providing heat to the ice water mixture but the temperature remained constant at 0 °C. At point B, all the ice has melted to form water.

LAB WORK

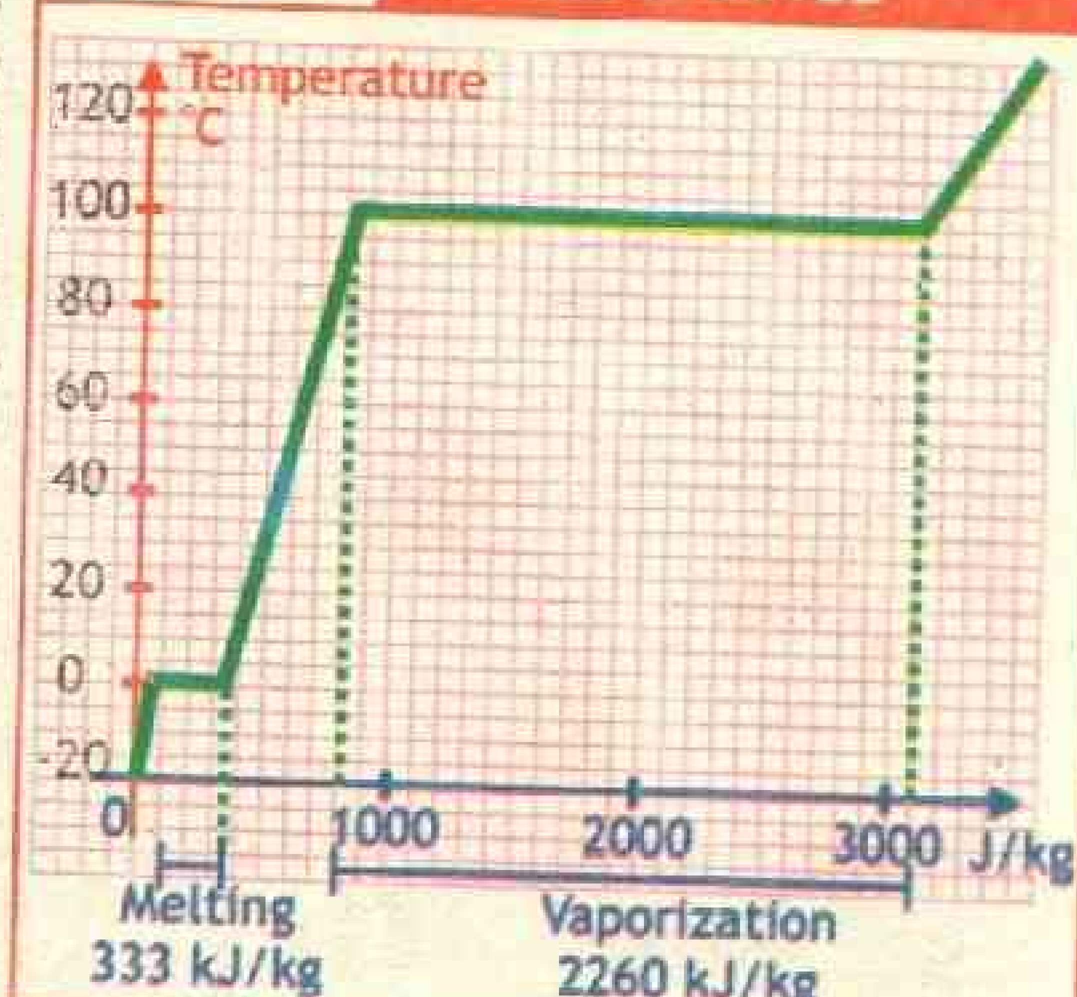
- To draw graph between temperature and time when ice is converted into water and then to steam by slow heating.
- To measure specific heat of fusion of ice.

Figure 8.8 ICE WATER PHASE CHANGE



Now, on heating beyond point 'B', the temperature of water started rising as shown by the slope line 'BC' in the graph. Since the heat absorbed during the change of state of a substance does not raise its temperature, it is called latent heat or hidden heat. The graph also shows when water is boiling and changing into steam, the temperature remains constant at 100 °C though heat is being given continuously to water. This heat which is going into water but not increasing its temperature is the energy required to convert the water from the liquid state to the vapor state. Since this heat does not show its presence by producing a rise in temperature, it is called latent heat of vaporization of water. Let us look, for example, that how much energy is needed to melt a kilogram of ice at 0°C to produce a kilogram of water at 0°C.

Figure 8.9 PHASE CHANGE



Using the equation for a change in temperature and the value for water from Table 8.4, we find that $Q = mL_f = (1.0\ kg)(334\ kJ/kg) = 333\ kJ$ is the energy to melt a kilogram of ice. This is a lot of energy as it represents the same amount of energy needed to raise the temperature of 1 kg of liquid water from 0°C to 79.8°C. Even more energy is required to vaporize water; it would take 2260 kJ to change 1 kg of liquid water at the normal boiling point (100°C at atmospheric pressure) to steam (water vapor). This example shows that the energy for a phase change is enormous compared to energy associated with temperature changes without a phase change.

The latent heat of fusion for a given substance is different from the latent heat of vaporization for that substance. Representative values for melting point, latent heat of fusion, boiling point, and latent heat of vaporization are listed in Table 8.4.

TABLE 8.4: LATENT HEATS OF FUSION AND VAPORIZATION

Material	Melting Point (°C)	Latent Heat of fusion (J/kg)	Boiling Point (°C)	Latent Heat of Vaporization (J/kg)
Helium	- 269.65	5.23×10^3	- 269	2.09×10^4
Oxygen	- 218.79	$1.38 \times \times 10^4$	-183	2.13×10^5
Water	0	$3.33 \times \times 10^5$	100	2.26×10^6
Mercury	-39	$1.13 \times \times 10^4$	357	2.93×10^5
Sulphur	119	$3.81 \times \times 10^4$	445	3.26×10^5
Lead	327	$2.45 \times \times 10^4$	1750	8.70×10^5
Aluminum	660	$3.97 \times \times 10^5$	2450	1.14×10^7
Copper	1083	1.34×10^5	1187	5.06×10^6
Silver	961	8.82×10^4	2193	2.33×10^6
Gold	1063	6.44×10^4	2660	1.58×10^6

INFORMATION

The element gallium has a heat of fusion of only 80 $kJkg^{-1}$ and a melting of 30 °C hence it melts ever when placed on palm.

POINT TO PONDER

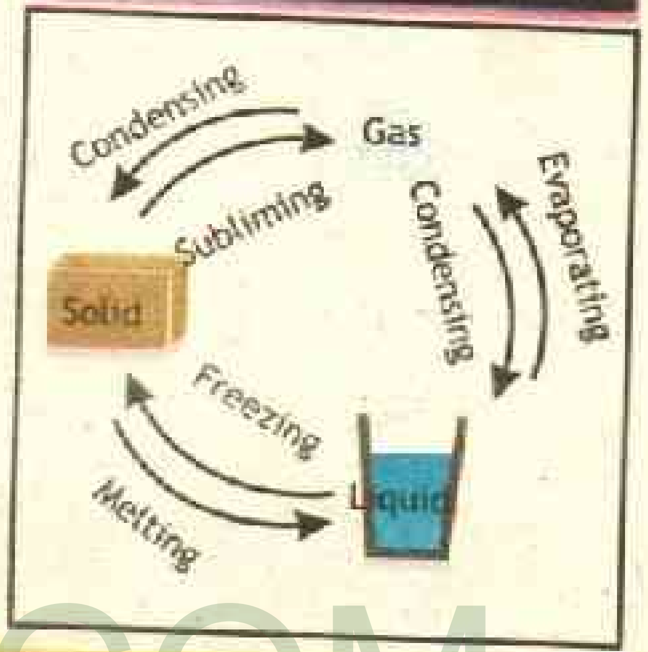
Why is a scald from steam often more serious than one from boiling water?

Steam at 100°C contains more thermal energy than water. The difference is due to the latent heat of vaporization, which for water is quite high. As the steam touches the skin and condenses, a large amount of energy is released, causing more severe burns.

It is also possible for a substance to change directly from a solid to a gas. This process is called sublimation. For example, sublimation occurs when dry ice, which is solid (frozen) carbon dioxide, changes directly to gaseous carbon dioxide without passing through the liquid state.

When a comet approaches the Sun, some of its frozen carbon dioxide sublimates, helping to produce the comet's visible tail.

The conversion between three different states of matter (solid, liquid and gas) freezing, melting, evaporating, condensing and subliming are shown in the figure.



Example 8.6 MELTING ICE

Find the amount of heat for melting the ice having mass 1.3kg at -10 °C? (Latent heat of fusion for ice $L_f = 3.3 \times 10^5$ J/kg and specific heat for ice $c = 2.2 \times 10^3$ J/kgK)

GIVEN:

Mass of ice m = 1.3 kg

Initial temperature T_o = - 10 °C

Final temperature T = 0 °C

Temperature change $\Delta T = T - T_o = 0\,°C - (-10\,°C) = 10\,°C = 10\,K$

Specific heat for ice $c = 2.2 \times 10^3$ J/kgK

Latent heat of fusion for ice $L_f = 3.3 \times 10^5$ J/kg

REQUIRED:

Heat required ΔQ = ?

We first we will provide heat to increase the temperature of the ice from -10 °C to 0 °C (melting point).

$$\Delta Q_1 = c\,m\,\Delta T$$

putting values $$\Delta Q_1 = 2200\ J\,kg^{-1}\,K^{-1} \times 1.3\ kg \times 10\,K$$

therefore $$\Delta Q_1 = 2.86 \times 10^4\ J$$

Now we will find heat required for melting ice at 0 °C, such that

$$\Delta Q_2 = mL_f$$

putting values $\Delta Q_2 = 1.3\,kg \times 3.3 \times 10^5\ J/kg$

therefore $\Delta Q_2 = 4.29 \times 10^5\ J$

Total heat required for the whole process

$$\Delta Q = \Delta Q_1 + \Delta Q_2$$

putting values $\Delta Q = 2.86 \times 10^4\ J + 4.29 \times 10^5\ J$

or $\Delta Q = 4.58 \times 10^5\ J$ — **Answer**

Assignment 8.6 EVAPORATING WATER

Find the amount of heat for evaporating 2.8 kg of water at 45 C°? (Latent heat of vaporization for water $L_v = 2.3 \times 10^6$ J/kg and specific heat of water c = 4190 J/kgK).

8.7 EVAPORATION OF LIQUIDS

We observed that water and other liquids start to boil if they are heated to their boiling temperatures. The liquid starts to transform into vapours but the change of liquids into vapours goes on even when the temperature is below the boiling point. For example, A spread wet cloth on being exposed to the air becomes dry in a short time due to evaporation of water. Water left in an open dish also disappears due to evaporation.

We know that the molecules of a liquid move with wide range of instantaneous velocities and they have different kinetic energies ranging from minimum to a very high value. Some of the molecules, having sufficient kinetic energy to overcome the forces of attraction, leave the surface of the liquid and escape out in the form of vapour. We call this escaping of the high energy molecules as evaporation.

The process by which a liquid slowly changes into its vapours at any temperature (below its boiling point) without the aid of any external source of heat is called evaporation of liquids. Experiments have shown that evaporation of liquids depends on the following factors.

A. Nature of liquid:

Liquid with low boiling points evaporates more rapidly than those with higher boiling points. For example the rate of evaporation of alcohol is higher than that of water.

B. Temperature of liquid:

Due to higher temperature, molecules of liquid at the surface will have more kinetic energy and chances of escaping will increase and evaporation will be fast. This can be seen while ironing clothes. Under a hot iron wet clothes dry out quickly as the water evaporates quickly.

C. Temperature of surrounding:

The higher the temperature of the surrounding, the higher is the rate of evaporation. It is for this reason that wet clothes dry rapidly in summer than in winter.

D. Presence of water vapour in Air:

The more the amount of water vapour present in air, the less is the rate of evaporation. It is for this reason that wet clothes dry slowly in rainy season as a lot of water vapour are present in the air.

E. Area of the exposed surface of the liquid:

Increased surface area gives the molecules a greater chance of escaping. Wet roads dry out quickly because the rain water is spread over a large area.

F. Movement of Air:

The more rapid the flow of air, the higher is the rate of evaporation. It is for this reason that wet clothes dry more rapid on a windy day compared on a calm day.

G. Dryness of Air:

Drier the air, the more rapid is the evaporation. Presence of water vapour reduces the rate of evaporation. Desert room coolers are more effective in cooling by evaporation in the dry month of June than it is in the humid month of August.

H. Air pressure on the surface of the liquid:

The lower the pressure on the surface of the liquid, higher is the rate of evaporation.

8.7.1 EVAPORATION CAUSES COOLING

When a liquid evaporates, its molecules convert from the liquid phase to the vapor phase and escape from the surface. The process that drives it is latent heat. In order for the molecule to leave the liquid surface and escape as a vapor, it must take heat energy with it. Since the molecule is taking heat with it as it's leaving, this has a cooling effect on the surface left behind. For example, spirit spilled on your palm quickly evaporates. As a result, your palm feels cold. Water evaporates much slower than ether and spirit. Evaporation of water also produces cooling. You can feel the chilling effect of the evaporation of water if you sit under a fan and wearing wet clothes. Perspiration in a human body helps to cool the body and to maintain a stable body temperature.

The kinetic theory explains the cooling caused by evaporation. During evaporation, more energetic molecules escape from the liquid surface. Molecules that remain in the liquid have lower kinetic energy. A liquid with molecules of less kinetic energy has a lower temperature. Thus evaporation produces cooling.

8.7.2 EVAPORATION VS BOILING

Vaporization (or vapourisation) of an element or compound is a phase transition from the liquid phase to vapuor. There are two types of vaporization: evaporation and boiling.

Evaporation is a phase change from the liquid phase to vapour that occurs at temperatures below the boiling temperature at a given pressure. Evaporation usually occurs on the surface. Boiling is a phase transition from the liquid phase to gas phase that occurs at or above the boiling temperature. Boiling, as opposed to evaporation, occurs below the surface.

Applications of Cooling by Evaporation:

A. Cooling by Fans:

We use fans in the hot season because the moving air increases the rate of evaporation or perspiration from our bodies. Hence we get a cooling sensation. As discussed earlier, perspiration helps in cooling the body and regulating its temperature.

B. Fever Control:

Wet towel is applied on the forehead of a person running high fever. It is because, as the water evaporates, it takes heat from the head. Thus the temperature of the head remains within the safe limits and the patient does not suffer any brain damage.

C. Refrigerator:

The Working principle of refrigerator is evaporation and compression.

There are six parts of a refrigerator.

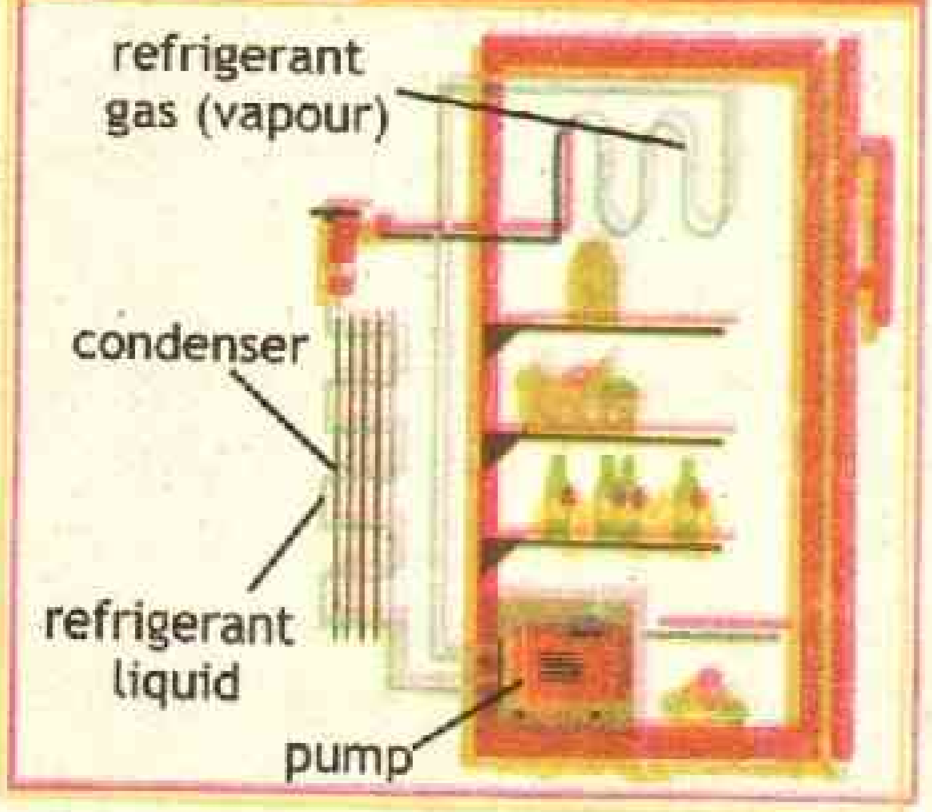
1. Heat exchanging pipes:

These coils are present on the inside and the outside of the fridge , they carry the refrigerant from one part of the fridge to another.

2. Refrigerant:

This is the substance which evaporates in the fridge causing freezing temperatures.

Figure 8.10 REFRIGERATOR



3. Expansion Valve:

The expansion valve which is made up of a thin copper coil reduces the pressure on the liquid refrigerant.

4. Compressor:

A compressor is a metal object which compresses the refrigerant thus raising the pressure and in turn the temperature of the gas.

5. Condenser:

A condenser, condenses, that is, it converts the refrigerant into liquid form, reducing its temperature.

6. Evaporator:

A evaporator absorbs the heat in the refrigerator with assistance of the evaporating liquid refrigerant.

Working:

Refrigerator has a pipe that is partly inside a refrigerator and partly outside it, and sealed so it is a continuous loop. The pipe is filled with a refrigerant. Inside the refrigerator, we make the pipe gradually get wider, so the refrigerant expands and cool as it flowed through it. Outside the refrigerator, we have a pump (compressor) to compress the gas and release its heat. As the gas flow round and round the loop, expanding when it is inside the refrigerator and compressing when it is outside, it constantly pick up heat from the inside and carry it to the outside.

Refrigerant and Environmental Concern:

The cooling effect in many refrigerators is produced by the evaporation of a volatile liquid (refrigerant) called Freon a chlorofluorocarbon (CFC) chemical.

An increasingly important environmental concern is the disposal of old refrigerators because of the chlorofluorocarbon (CFC) chemical as coolant has a property of damaging the ozone layer. Modern refrigerators usually use a refrigerant called hydrofluorocarbon (HFC), which was supposed to have zero potential to deplete the ozone layer. However in 1974 researchers predicted that emissions of HFCs could damage Earth's atmosphere by the catalytic destruction of ozone in the stratosphere. The hypothesis has been proven in 1985 by measurements which have shown the destruction of the ozone layer over Antarctica. Scientist are now looking to develop new refrigerant that is natural and have low global warming potential (GWP) and zero Ozone Depletion Potential (ODP).

KEY POINTS

Thermometry: The branch of physics which deals with the measurements of temperature is called thermometry.

Temperature: The measure of degree of hotness or coldness of a body is called temperature.

Thermometer: The device which is used to measure temperature is called thermometer.

Heat: The form of energy which is transferred from one body to another body due to the difference in temperature is called heat.

Thermal expansion: The expansion of substances on heating is called thermal expansion.

Specific Heat: The amount of heat required to raise the temperature of a unit mass of a substance by 1 °C or 1 K is called the specific heat of that substance.

Change of state of matter: Change of solid to liquid or liquid to gas and vice versa without any change in temperature is called change of state of matter or change of phase.

Fusion or melting: The process in which a solid change into liquid state with out rise of temperature by the absorption of heat energy is called fusion or melting.

Latent heat of fusion of ice: The amount of heat energy required to melt one kilogram (1 kg) of a ice at its melting point 0 °C with out any rise in temperature is called its latent heat of fusion of ice.

Boiling or vaporization: The process in which a liquid change into gaseous state with out rise of temperature by the absorption of heat energy is called boiling or vaporization.

Latent heat of water: The amount of heat energy required to vaporize one kilogram (1 kg) of a water at its boiling point 100 °C with out any rise in temperature is called its latent heat of water.

Evaporation: The process by which a liquid slowly changes into its vapours below its boiling point is called evaporation.

PROJECTS

GROUP - A

REFRIGERANT: Talk to someone who works on air conditioners or refrigerators to find out what fluids are used in these systems. What properties should refrigerant fluids have? Research the use of freon and freon substitutes. Why is using freon forbidden by international treaty? What fluids are now used in refrigerators and car air conditioners? For what temperature ranges are these fluids appropriate? What are the advantages and disadvantages of each fluid? Summarize your research in the form of a presentation or report.

GROUP - B

TEMPERATURE MEASUREMENT: Research how scientists measure the temperature of the following: the sun, a flame, a volcano, outer space, liquid hydrogen, mice, and insects. Using what you learn, prepare a chart or other presentation on the tools used to measure temperature and the limitations on their ranges. Prepare the presentation to share it with your class fellows.

GROUP - C

BIMETALLIC STRIP: What is a bimetallic strip? How it is used in thermostat? Explain the use of bimetallic strip in different equipment. Prepare a chart to be displayed in classroom.

GROUP - D

HISTORY PRESENTATION: Discuss with elder people that until refrigerators, air conditioners or even fans and electricity was limited what methods people used to cool themselves and water for their use. How they stored fruits and vegetables. Prepare a presentation for the class discussion.

GROUP - E

WRITING FOR SCHOOL MAGAZINE ON LARGE VALUES OF WATER: Water has an unusually large specific heat and large heats of fusion and vaporization. Our weather and ecosystems depend upon water in all three states. How would our world be different if water's thermodynamic properties were like other materials, such as methanol? Write an essay to be published in school magazine.

EXERCISE

MULTIPLE CHOICE QUESTIONS

Choose the best possible answer:

1. The S.I. unit of heat is
   A. J B. kg C. K^{-1} D. K
2. The S.I. unit of temperature is
   A. °C B. °F C. J D. K
3. The Fahrenheit and Celsius scale reading of temperature coincide at
   A. 0° B. - 460° C. - 273° D. - 40°
4. 310 K in centigrade scale is
   A. 37°C B. 310°C C. 63°C D. 273 °C
5. When water at 0 °C is heated, it contracts till temperature reaches
   A. 1°C B. 4°C C. 100°C D. 100 K
6. The S.I. unit of specific heat is
   A. JK^{-1} B. $JK^{-1}\ kg^{-1}$ C. $J\ kg^{-1}$ D. JK kg
7. The relation between coefficient of linear and volume expansion is;
   A. $\alpha = 3\gamma$ B. $\gamma = 3\alpha$ C. $\gamma = \alpha/2$ D. $\gamma = 6\alpha$
8. The S.I. unit of Latent heat is
   A. JK^{-1} B. $J\ kg^{-1}$ C. $JK\ kg^{-1}$ D. JK kg
9. How much heat is required to melt of 1 kg of Zink at its boiling temperature 240 °C with latent heat of $113 \times 10^3\ J\ kg^{-1}$
   A. $113 \times 10^3 J$ B. $1.13 \times 10^3 J$ C. $2.4 \times 10^5 J$ D. $2.71 \times 10^7 J$
10. The amount of heat required to raise the temperature of 1 kg of water by 1 K is
    A. 1 J B. 400 J C. 310 J D. 4190 J

CONCEPTUAL QUESTIONS

Give a brief response to the following questions.

1. Ordinary electric fan increases the kinetic energy of the air molecules caused by the fan blades pushing them means the air temperature increases slightly rather than cool the air? why use it?
2. Why are small gaps left behind the girders mounted in walls?
3. Why you should not put a closed glass jar into a campfire. What could happen if you tossed an empty glass jar, with the lid on tight, into a fire?
4. Explain why it is advisable to add water to an overheated automobile engine only slowly, and only with the engine running.
5. Explain why burns caused by steam at 100 °C on the skin are often more severe than burns caused by water at 100 °C.
6. Explain why cities like Karachi situated by the ocean tend to have less extreme temperatures than inland cities at the same latitude.
7. An iron rim which is fixed around a wooden wheel is heated before its fixture. Explain why?
8. Why is ice at 0 °C a better coolant of soft drinks than water at 0 °C?
9. Why we feel cool after perspiration?

COMPREHENSIVE QUESTIONS

Give an extended response to the following questions.

1. Explain the terms internal energy and temperature. Use kinetic theory to distinguish between heat internal energy and temperature.
2. How do we measure temperature? Explain liquid in glass thermometer.
3. What are various temperature scales. Derive mathematical expressions to convert between various scales of temperature.
4. What is meant by linear thermal expansion and volume thermal expansion of solids?
5. What is thermal expansion of liquids? Why we have real and apparent thermal expansion in liquids. Illustrate with the help an experiment.
6. Define heat capacity and specific heat capacity of a substance. Explain the importance of high specific heat capacity of water.

7. What is meant by the latent heat of fusion and latent heat of vaporization of a substance?
8. What is meant by evaporation ? On what factors the evaporation of a liquid depends. Explain how cooling is produced by evaporation. Diffrenciate between boiling and evaporation.

NUMERICAL QUESTIONS

1. Perform the temperature conversions (a) **Temperature difference in the body.** The surface temperature of the body is normally about 7 °C lower than the internal temperature. Express this temperature difference in kelvins and in Fahrenheit degrees. (b) **Blood storage.** Blood stored at 4.0 °C lasts safely for about 3 weeks, whereas blood stored at -160 °C lasts for 5 years. Express both temperatures on the Fahrenheit and Kelvin scales.
2. Consider a metre-stick composed of platinum (the coefficient of linear expansion for platinum is $\alpha = 8.8 \times 10^{-6}\ K^{-1}$). By what amount does the length of this metre-stick change if the temperature increases by 1.0 K?
3. A railway line made of iron is 1200 km long and is laid at 25°C. By how much will it contract in winter when the temperature falls to 15°C? By how much will it expand when the temperature rises to 40°C in summer? (the coefficient of linear expansion for iron is $\alpha = 12 \times 10^{-6}\ K^{-1}$).
4. The volume of a brass ball is 800 cm^3 at 20°C. Find out the new volume of the ball if the temperature is raised to 52 °C. The coefficient of volumetric expansion of brass is $57 \times 10^{-6}\ K^{-1}$.
5. What is the specific heat of a metal substance if 135 kJ of heat is needed to raise 4.1 kg of the metal from 18.0°C to 37.2°C?
6. How much heat is needed to melt 23.50 kg of silver that is initially at 25°C? (Specific Heat of silver is $c = 230\ J\ kg^{-1}\ K^{-1}$ Latent heat of fusion for silver is $L_f = 8.82 \times 10^4$).

WEB LINK

http://www.thermopedia.com/

Unit

9

TRANSFER OF HEAT

CHECK LIST

After studying this unit you should be able to:

- ✓ recall that thermal energy is transferred from a region of higher temperature to region of lower temperature.
- ✓ describe in terms of molecules and electrons , how heat transfer occurs in solids.
- ✓ state the factors affecting the transfer of heat through solid conductors and hence, define the term "Thermal Conductivity".
- ✓ solve problems based on thermal conductivity of solid conductors.
- ✓ write examples of good and bad conductors of heat and describe their uses.
- ✓ explain the convection currents in fluids due to difference in density.
- ✓ state some examples of heat transfer by convection in everyday life.
- ✓ explain insulation reduces energy transfer by conduction.
- ✓ describe the process of radiation from all objects.
- ✓ explain that energy transfer of a body by radiation does not require a material medium and rate of energy transfer is affected by:
    - Colour and texture of the surface
    - Surface temperature
    - Surface area

Heat (Q) is the thermal energy that can be transferred between two systems by temperature difference. When two bodies are at different temperatures, thermal energy transfers from the one with higher temperature to the one with lower temperature.

Heat transfer has an enormous range of application, even our survival, and comfort, depends on keeping our bodies at a constant temperature. To keep a building or a house at a comfortable temperature in winter and in summer, if it is to be done economically and efficiently, requires a knowledge of how heat travels.

A campfire illustrates the three main modes of thermal energy transfer: conduction, convection, and radiation.

9.1 CONDUCTION OF HEAT

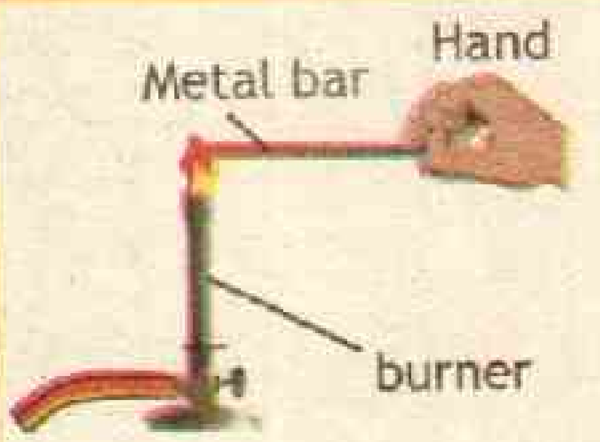
The handle of a metal spoon held in a hot tea soon gets warm. Heat passes along the spoon by conduction.

Conduction is the flow of thermal energy (heat) through matter from places of higher temperature to places of lower temperature without movement of the matter as a whole.

9.1.1 Mechanism of Heat Conduction

The mode of heat transfer by conduction can be examined with the help of a simple activity. Take an iron bar. Hold one end of the bar in the flame of a burner. After a few seconds, you will find that the other end is too hot to hold as shown in figure 9.1. How does the heat flow from the hotter to the colder end of the bar? What is the mechanism of heat transfer from one location to another?

Figure 9.1

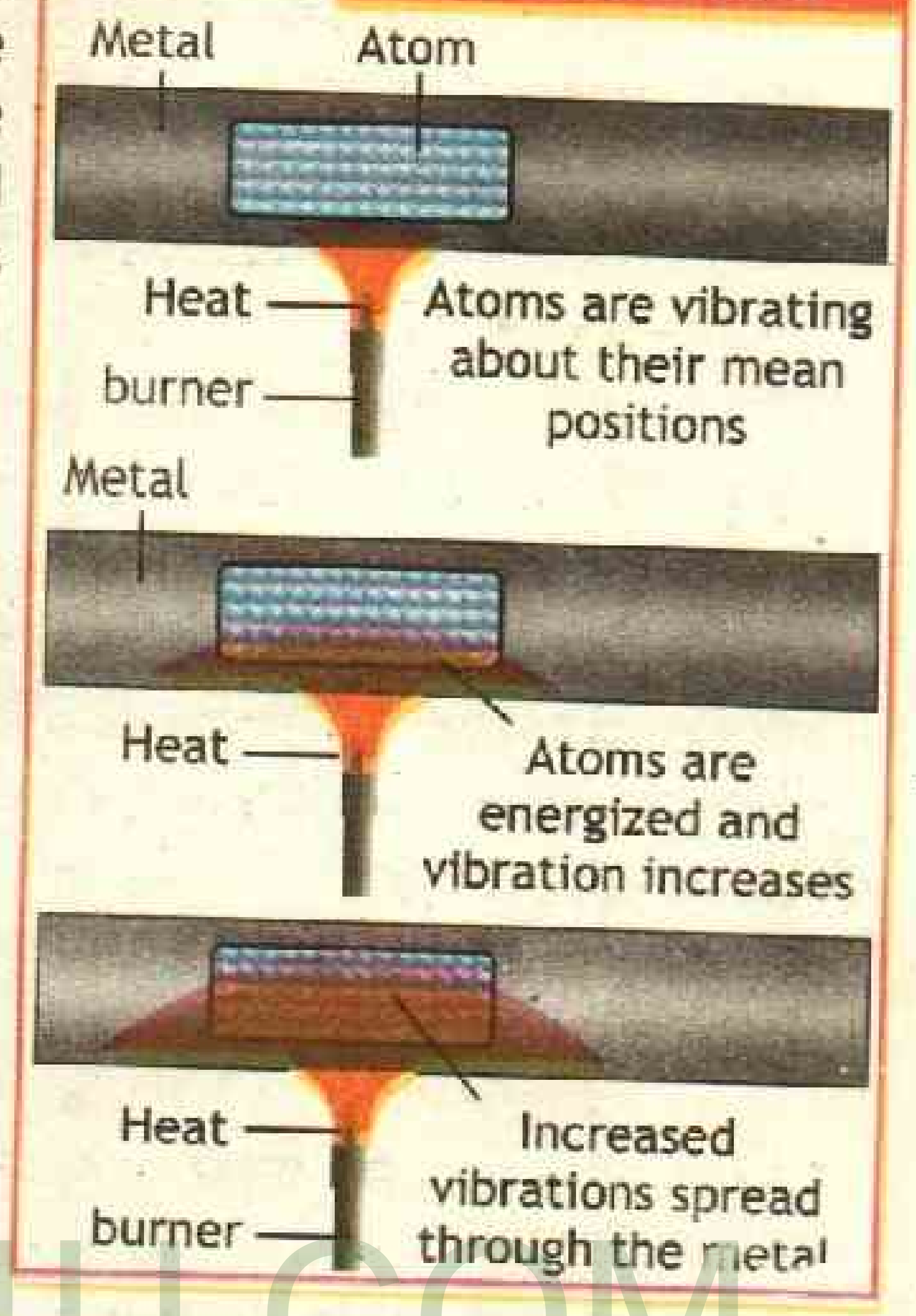


Heat Transfer Activity

The mechanism of heat conduction can be explained by the behaviour of atoms within the material. The solid iron rod is made of closely packed iron atoms. According to kinetic molecular description of matter the greater the temperature the more is the kinetic energy of atoms or molecules. The atoms in the hotter part of the rod vibrate more violently (thus possess more kinetic energy) than those in the colder part.

Initially, before the rod is inserted into the flame, the iron atoms are vibrating about their equilibrium positions. As the flame heats the rod, the iron atoms near the flame begin to vibrate with greater speeds and wider distance. These wildly vibrating atoms collide with their neighboring atoms and transfer some of their energy to these atoms. Which in turn pass thermal energy to their own neighbors and so on as shown in figure 9.2. Iron is a metal and contains a large number of electrons that are free to move through the metal called free electrons. These free electrons also play a big part in the conduction of heat. For example, when one end of the iron rod is heated, the atoms in the heated part vibrate more with greater speeds. The free electrons that collide with these atoms gain kinetic energy and move faster. They diffuse into the colder part of the metal where collisions with other free electrons and atoms occurs which result in the transfer of energy. In light of this discussion we can define the conduction of heat as that **process by which heat energy is transferred from particle to particle.**

Figure 9.2 HEAT TRANSFER BY CONDUCTION

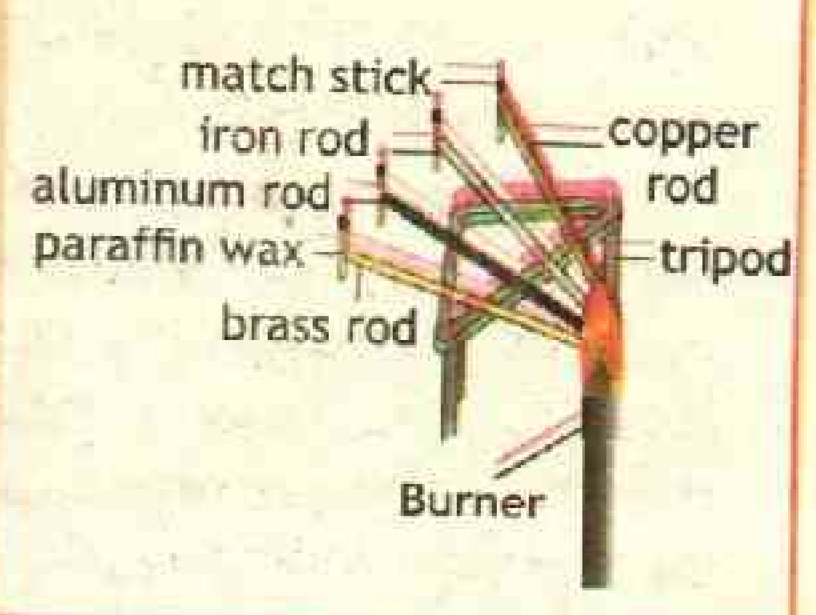


9.1.2 GOOD AND BAD THERMAL CONDUCTORS

Some materials allow heat to pass through them easily. The[illegible] are called heat conductors or good conductors. Those that do not allow heat to flo[illegible] through them easily are called heat insulators or bad conductors.

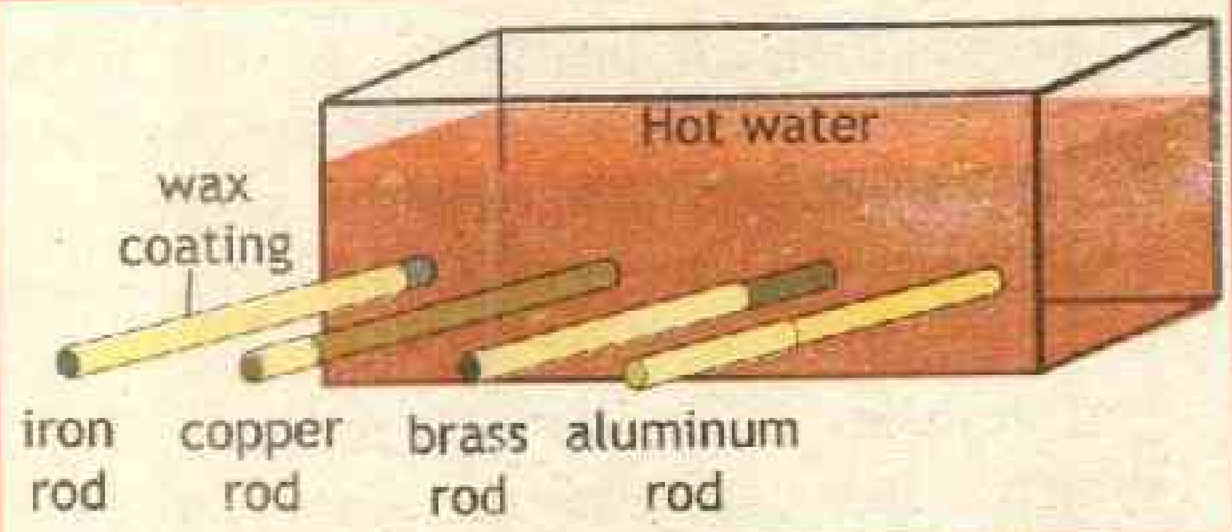
ACTIVITY 9.1 COMPARISON OF CONDUCTING ABILITY OF DIFFERENT METALS

A simple demonstration of the different conducting powers of various metals is shown in Figure. Match sticks are fixed to one end of each rod using a melted wax. The other ends of the rods are heated by a burner. When the temperatures of the far ends reach the melting point of wax, the matchsticks drop off. The match stick on copper falls first, showing it is the best conductor, followed by aluminium, brass and then iron.



Metals are the best heat conductors. Materials such as wood, rubber, plastic, paper and fiber glass are poor conductors of heat. You can sometimes tell how well something conducts just by touching it.

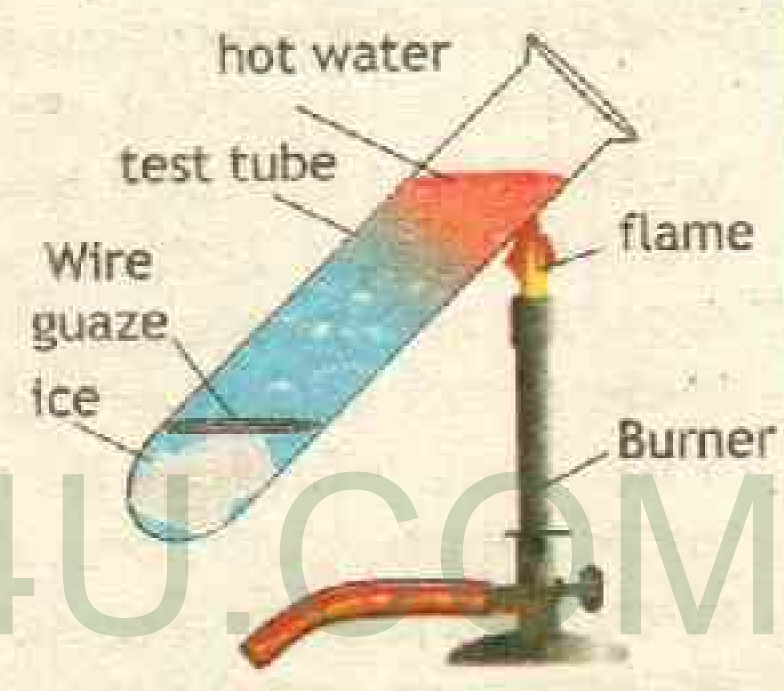
Figure 9.3 CONDUCTION



A similar activity for comparing the conducting abilities of different metals is shown in the figure. The ends of long rods of the same size but made of different metals are soldered into a tank. Initially, coat each rod with a layer of wax. Pour some boiling water into the tank.

Wait for about ten minutes or so. Wax melts to different lengths along the different rods. A greater length of wax melts on the copper rod. This shows that copper is a good conductor amongst these materials.

Activity 9.2 WATER



Water is a bad conductor of heat: The water at the top of the test tube can be boiled without making the ice melt.

Conduction occurs in all the three states of matter solids, liquids and gases. Solids conduct better than liquids. Gases are the worst conductors. As discussed earlier metallic solids are best thermal conductors. Besides the closely connected atoms, metals have free electrons. Non-metallic solids are poor conductors of heat because they do not have free electrons.

Most of the liquids are poor conductors of heat. Compared with solids, the inter-molecular distances in liquids are relatively larger and conductive collisions do not occur as often as in solids. Water is a poor conductor of heat. The poor conductivity is illustrated by the activity 9.2. Gases are the poorest of all heat conductors. In gases the separation between particles is very large. Air has about one-twentieth of the thermal conductive ability of water. Many materials such as wood, cloth, fiberglass and plastic foam etc are poor conductors because they contain tiny pockets of trapped air.

PRACTICAL APPLICATIONS OF CONDUCTION OF HEAT

The good, as well as, bad thermal conductors have many useful applications in our daily life.

A. Cooking pots and pans:

Cooking pots and pans are made of metals which are good thermal conductors. They conduct heat readily to the food inside and to spread it evenly.

B. Plastic foam:

Plastic foam and fiberglass insulators are used in the walls and ceilings of our homes to keep them cool in summer and warm in winter seasons. These materials are good insulators because they contain tiny pockets of trapped air.

C. Wire gauze:

Wire gauze is often placed over a flame to conduct heat outwards from the flame. A glass beaker can safely be heated on the gauze because this protects it from the concentrated heat of the flame.

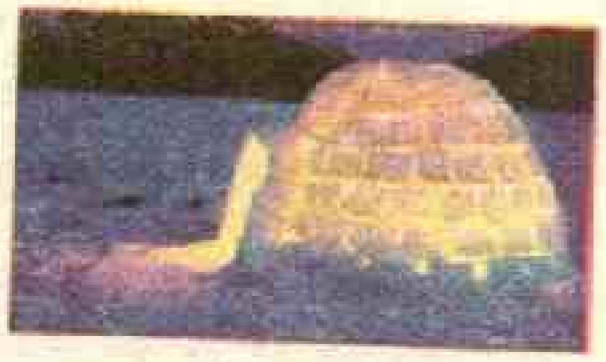
D. Pot holders and table mats:

Pot holders and table mats for hot pans are made of poor conductors such as cloth and wood. The use of poor conductors avoid burning of hands.

E. Woolen clothes:

Woolen clothes have fine pores filled with air. Air and wool are bad conductors of heat. Thus the heat from our body does not flow out and our body remains warm in winter.

F. Igloos:



Igloos type of shelter (house or hut) built of snow. Igloos are constructed from ice and snow to provide protection from wintery conditions. One reason that igloos do their job so well is that the ice and snow act as thermal insulation and minimize the loss of heat from the inside due to conduction.

G. Ice box:

Ice box has a double wall made of tin or iron. The space between the two walls is filled with cork which is the poor conductor of heat.

The cork prevents the flow of out side heat into the box, thus keeping the ice from melting.

H. Soldering:

During soldering objects are in direct contact, such as the soldering iron and the circuit board, heat is transferred by conduction.

9.2 THERMAL CONDUCTIVITY

The thermal conductivity of a substance is a measure of the ability of the substance to conduct heat energy. The rate of flow of heat through a medium depends on a number of factors.

For example consider a rod of length 'L', area of cross-section 'A'. Let the hot face of the slab be at temperature T_h and the colder face be at temperature T_c, which means $T_h > T_c$. The rate of heat flow (Q/t) across the slab depends on the following factors.

i) The difference of temperatures $T_h - T_c$ between two the two faces of the slab. The greater the temperature difference, the greater is the heat transferred per unit time across the slab.

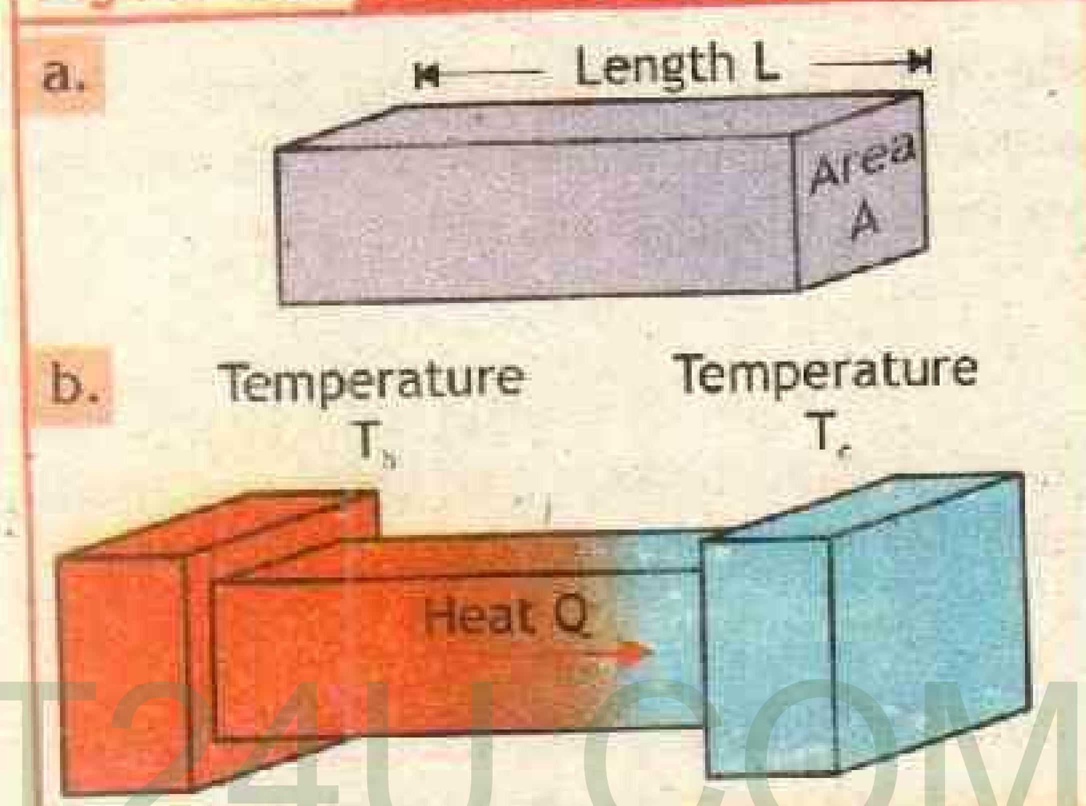
ii) Length of rod 'L' more the length, the less is the rate of flow of heat through it.

iii) The cross-section area (A). Larger cross-sectional area will allow a greater rate of heat flow.

iv) The nature or material of the slab. Mathematically,

$$\frac{Q}{t} = k \times A \times \frac{T_h - T_c}{L} \quad (9.1)$$

Figure 9.4 CONDUCTIVITY



a. A bar with cross-sectional area A and length L.
b. The bar is placed between two thermal reservoirs with temperatures T_h and T_c.

TABLE 9.1: THERMAL CONDUCTIVITIES OF COMMON SUBSTANCES

Substance	Thermal conductivity $J\,m^{-1}K^{-1}s^{-1}$
Silver	420
Copper	390
Gold	318
Aluminum	220
brass	105
Steel iron	80
lead	35

Where k is the thermal conductivity of the material of the bar. Thermal conductivity depends on the nature of the material. Such that

$$k = \frac{Q \times L}{A \times t \times (T_h - T_c)} \quad (9.2)$$

As a special case, if L = 1 m, A = 1 m^2, $T_h - T_c$ = 1 °C or 1K and t = 1s , then from Equation 9.2 we obtain k = Q. Thus the thermal conductivity k of a substance is defined as **the quantity of heat which flows through one square metre of area of the substance in one second when a temperature difference of one kelvin is maintained across a thickness of one meter.** The SI units of thermal conductivity are W $m^{-1}K^{-1}$ or J $m^{-1}K^{-1}s^{-1}$. Some typical values of thermal conductivity are listed in Table 9.1.

Substance	Thermal conductivity J $m^{-1}K^{-1}s^{-1}$
Steel (stainless)	14
Ice	2.2
Concrete brick	0.84
Glass (average)	0.8
Water	0.6
Wood	0.08-0.16
Cotton	0.08
Cork	0.042
Wool	0.04
Plastic foam	0.033
Air	0.023
Styrofoam	0.010

Example 9.1 STYROFOAM ICE BOX

A Styrofoam (k = 0.010 W/mK) ice box has a total area of 0.950 m^2 and walls with an average thickness of 2.50 cm. The box contains ice, water, and canned beverages at 0°C . The inside of the box is kept cold by melting ice. What is the rate of energy transfer in J/s if the ice box is kept at 35.0°C ?

SOLUTION

GIVEN:

Area A = 0.950 m^2

Length L = 2.50 cm = 0.0250 m;

Temperature difference $T_h - T_c$ = 35 °C - 0 °C =35 °C = 35 K

thermal conductivity of Styrofoam k = 0.010 $Wm^{-1}K^{-1}$

REQUIRED:

rate of heat transfer Q/t= ?

The rate of energy transfer is given as

$$\frac{Q}{t} = k \times A \times \frac{T_h - T_c}{L}$$

putting values $\frac{Q}{t} = 0.010 \frac{W}{mK} \times 0.950\, m^2 \times \frac{35K}{0.0250\, m}$

therefore $\frac{Q}{t} = 13.3\,W = 13.3\frac{J}{s}$ — **Answer**

Assignment 9.1 CONCRETE WALL 0.20m THICK

Find the amount of heat transferred in one hour through a concrete wall of area 6.9 m^2, and 0.20 m thick. One side of the wall is held at 20 °C and the other side is at 5 °C. The thermal conductivity of concrete is 1.3 $JK^{-1}m^{-1}s^{-1}$.

9.3 CONVECTION OF HEAT

We can warm our hands by holding them over an open flame. In this case, the air directly above the flame is heated and expands. Heat is transferred by the movement of heated particles.

The transfer of heat from one place to another by the bulk motion of fluids is called convection. Convection occurs only in fluids (liquids and gases). Convection cannot occur in solids as the atoms in a solid are located in fixed positions and cannot change place. For the same reason convection occur very easily in gases.

Activity 9.3 CONVECTION OF HEAT

Convection currents shown in water by dropping a few crystals of potassium permanganate down a tube to the bottom of a beaker of water. When the tube is removed and the beaker heated just below the crystals by a small flame, purple streaks of water rise upwards.

To understand convection, take some water in a beaker and drop in it few crystals of potassium permanganate. Heat gently the water. See how the coloured water moves. You will observe that streaks of purple coloured water begin to rise and cold water from the sides takes its place. The water will go on circulating and becomes hotter and hotter. In this way each part of water is heated in turn. The currents set up in the process are known as **convection currents.**

Figure 9.5

Convection currents are set up when a pot of water is heated.

9.3.1 MECHANISM OF HEAT CONVECTION

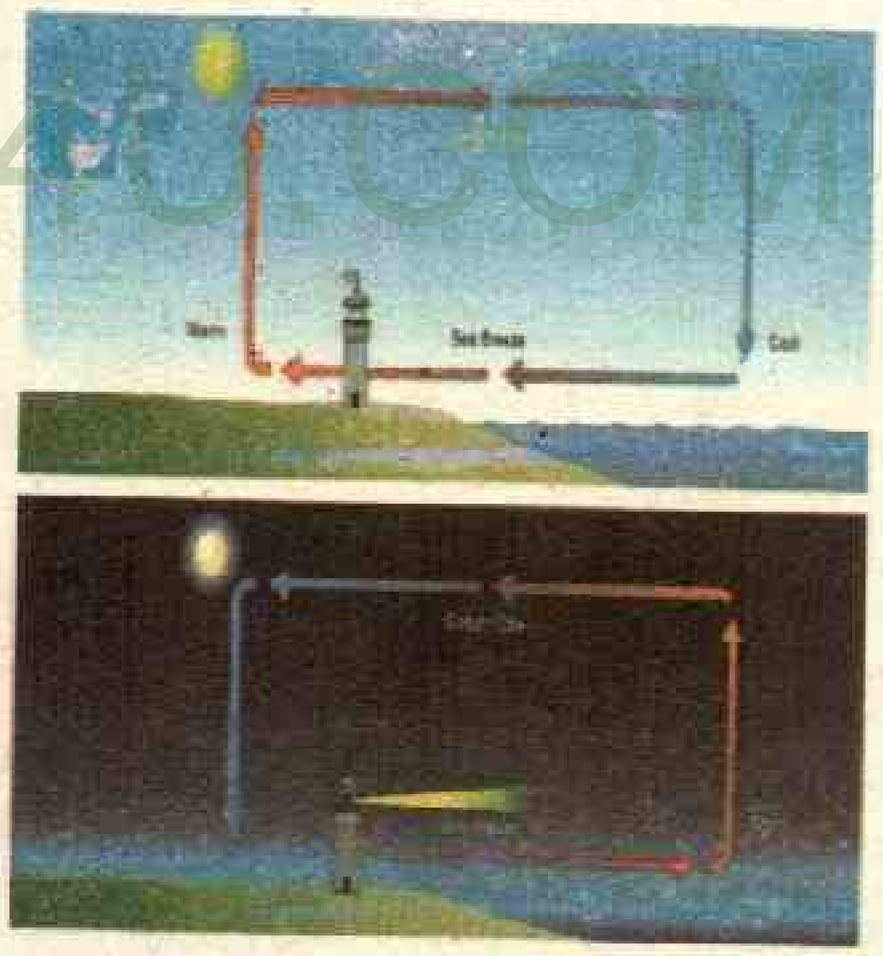
The heated portion of water at the bottom of the expands and becomes less dense. Being less dense, the warm water moves upward. It is replaced by the cold and dense water around it. The cold water flowing to the point of heating in its turn absorbs heat energy, expands and is pushed upward. Thus a continuous circulatory flow is established from the bottom to the top of the water. Black marks often appear on the wall or ceiling above a lamp. They are caused by dust being carried upwards in air convection currents produced by the hot lamp or radiator.

9.3.2 PRACTICAL APPLICATIONS OF HEAT CONVECTION

The following are few practical applications of heat convection.

A. Heating Water:

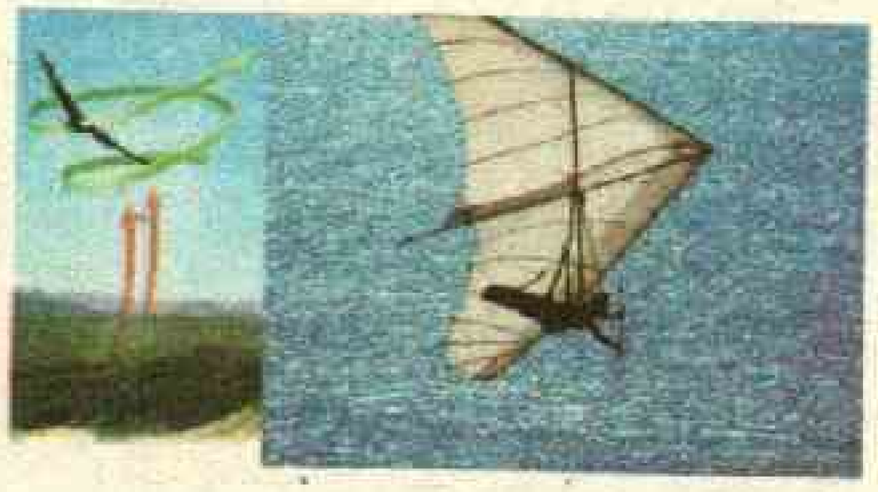
If it were not for convection currents, it will be very difficult to boil water. The lower layers of water in a electric kettle are warmed first. These heated water expands and move upward to the top because its density is lowered. Meanwhile dense cool water replaces the warm water at the bottom of the kettle so that it can also be heated.



B. Sea breeze:

Convection causes coastal breeze. During the day the land heats up more quickly than the sea. The hot air over the land rises and the cold air from the sea blows to replace it. Thus there is a sea breeze during the day. At night, the reverse happens. The land cools more quickly than the sea. The hot air over the sea rises and the cold air from the land blows to replace it. This movement of air is called the land breeze.

C. Riding on Thermals:

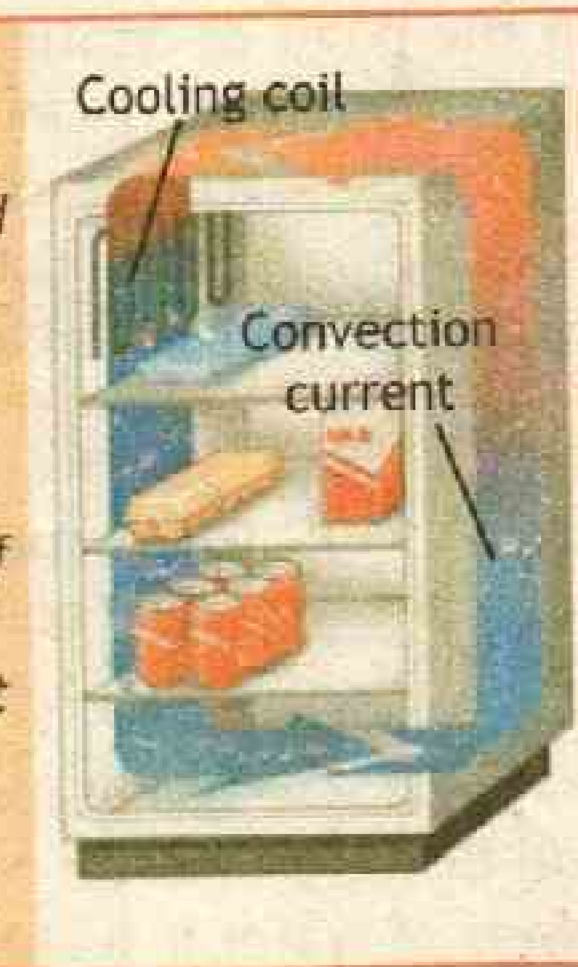


Thermals are streams of hot air rising in the sun. They are convection currents. Birds are able to fly for hours on thermals without flapping their wings. Similarly glider aeroplanes are able to rise by riding on the thermals.

D. Refrigerator:

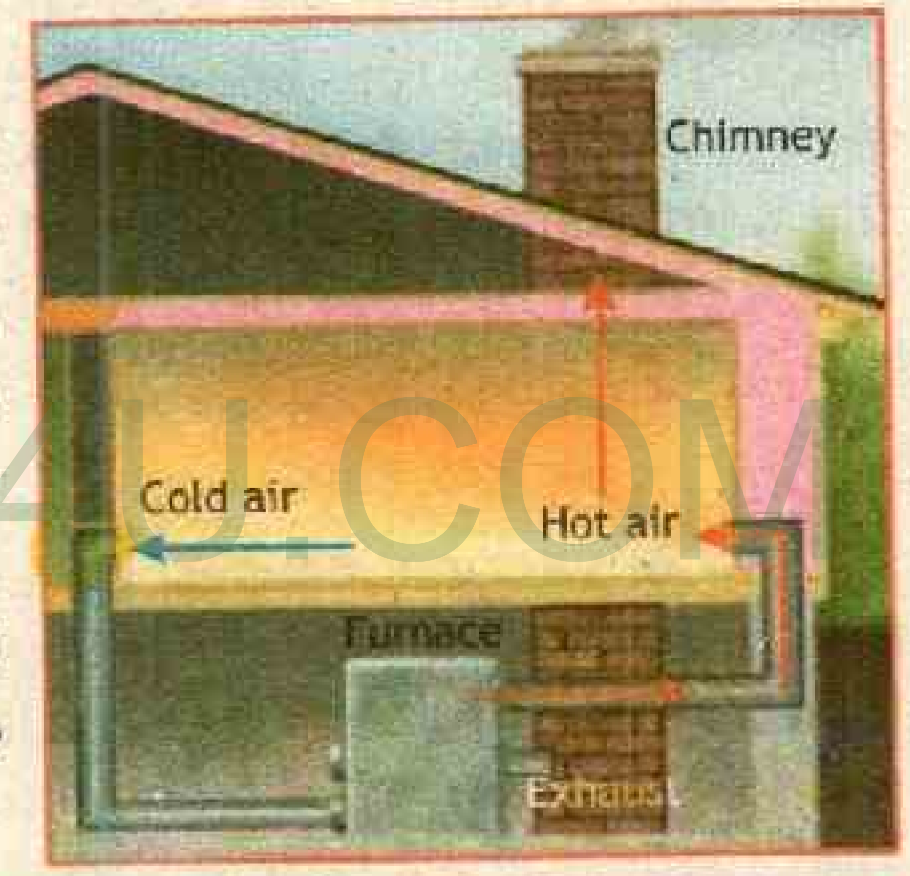
In a refrigerator, convection is used to circulate cold air around the food. Air is cooled by the freezer compartment at the top of the refrigerator. As it sinks, it is replaced by warmer air rising from the below. The circulating air carries heat energy away from all the food in the fridge.

Air cooled by the cooling coil sinks to the bottom of the refrigerat-or



E. Ventilation:

Convection currents are used in ventilation. Your classroom or the rooms in your houses have ventilators installed near the ceiling. The warm and stale air inside the room rises and escapes through the openings near the ceiling. Fresh and cold air is drawn in to the room through the doors and windows. Similarly, smoke and hot gas from the fires in houses and factories rise up and escape through the chimneys.



TID-BIT

When you light a candle, it heats the air near the flame as it burns. Because hot air is less dense—and hence more buoyant—than cool air, a circulation pattern is established with hot air rising and being replaced from below by cool, oxygenated air. Thus, convection is necessary for a candle to continue burning. When the burning candle in this jar is dropped, it suddenly finds itself in free fall—an essentially "weightless" environment where buoyancy has no effect. As a result, convection ceases and the flame is quickly extinguished as it consumes all the oxygen in its immediate vicinity.

POINT TO PONDER

Blow warm air onto your hand from your wide-open mouth. Now reduce the opening between your lips so that the air expands as you blow. Do you notice a difference in the air temperature? Why?

POINT TO PONDER

You can hold your fingers beside the candle flame without harm, but not above the flame. Why? Hot air travels upward by air convection. Since air is a poor conductor, very little heat travels sideways to your fingers.

9.4 RADIATION OF HEAT

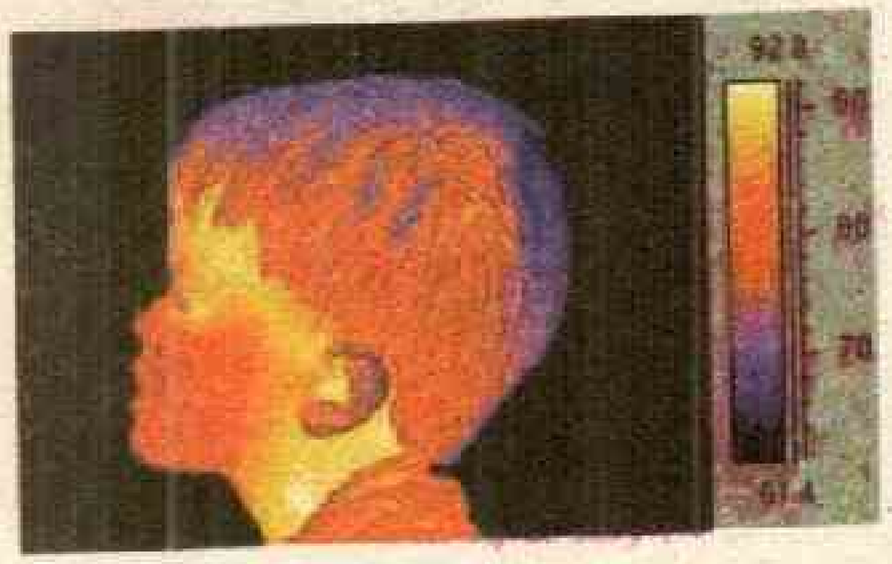
When we sit next to an open campfire, the heat from the fire does not reach us by conduction because air is a bad conductor of heat. It does not reach us by convection because hot air rises up. In this case, the heat reaches us by radiation of heat. The hot fire radiates heat rays just as light rays. When these rays fall on anything they make that object hotter.

Sun heat reaches us after passing through millions of kilometers in empty space. Sun heat also warms up anything on which it falls. Neither conduction nor convection can take place in vacuum as no material is present for the transfer of heat through conduction or convection. Sun heat reaches us by radiation of heat. Based on the above observations, we define radiation of heat as **The heat transfer from a hotter place to a colder place with or without having a material medium in between is called radiation of heat.**

Unlike conduction and convection transfer of heat by radiation, does not necessarily require a material medium.

9.4.1 MECHANISM OF RADIATION OF HEAT

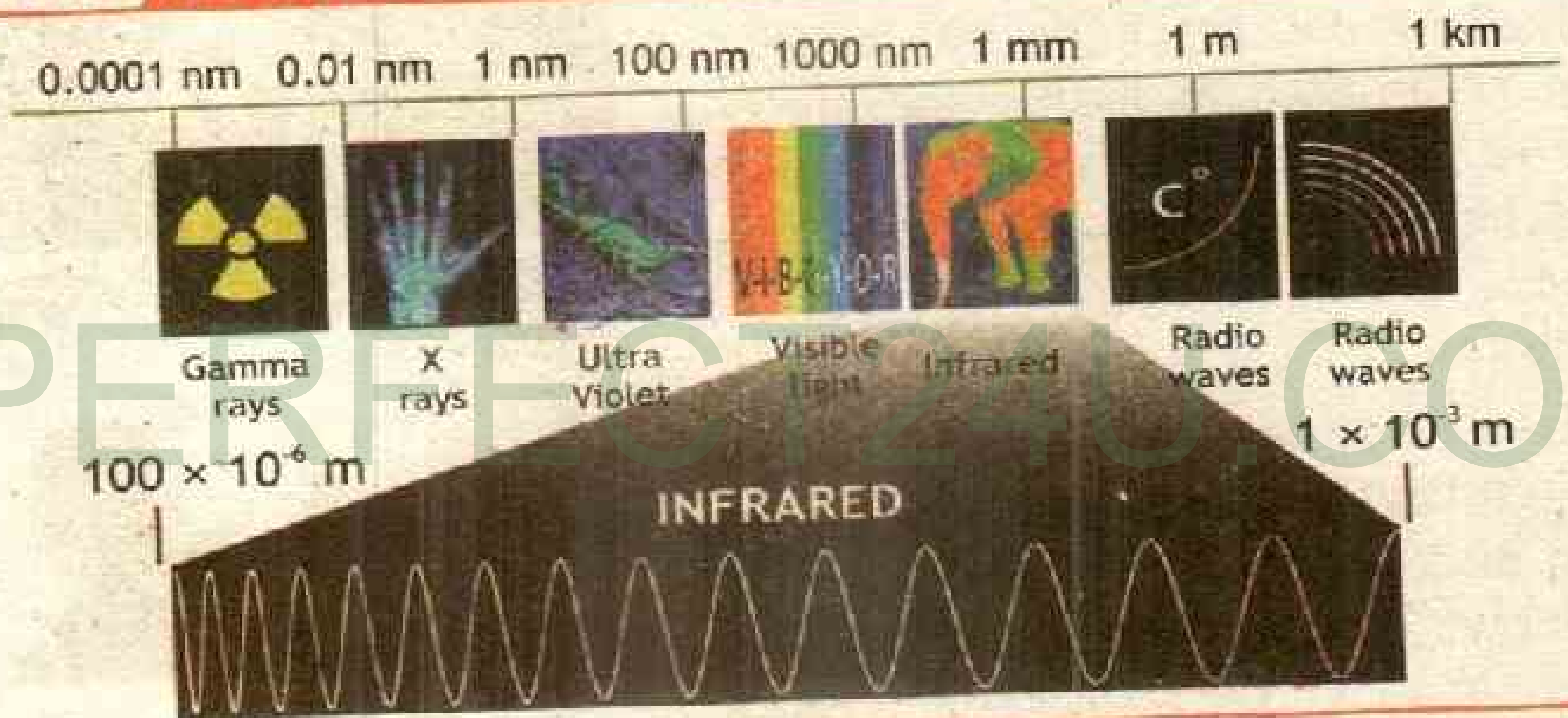
The mechanism of radiation is energy transfer by electromagnetic waves. Electromagnetic radiation comes from accelerating electric charges. On a molecular level, that's what happens as objects warm up – their molecules vibrate harder and harder, causing acceleration of electric charges which emits those radiation. Heat energy transferred through radiation is as familiar as the light; in fact, it is the light but not visible or barely visible. Electromagnetic waves (radiation) can transfer energy via vacuum or empty space as well as via a material medium like glass.



Every object around us is continually radiating, unless its temperature is at absolute zero 0 K (which is a little unlikely because you can't physically get to a temperature of absolute zero, with no molecular movement). For example a scoop of ice cream has temperature of about 237 K, therefore it radiates.

Even we radiate all the time, but that radiation isn't visible as light because it's in the infrared part of the spectrum. However, that light is visible to infrared scopes, as you've probably seen in the movies or on television.

Figure 9.6 ELECTROMAGNETIC SPECTRUM



9.4.2 GOOD AND BAD EMITTERS AND ABSORBERS

Some surfaces are better absorbers of radiation than others, a black colour absorbs most and white reflects most. A dull black kettle absorbs heat better than a silver kettle. Standing in the sun, a black car warms up more quickly than car of any other colour.

Some surfaces are better at emitting radiation than others when heated or allowed to cool. A black saucepan cools down quickly than any other. Hot water in a kettle covered with soot cools faster than a

Activity 9.4 RADIATION OF HEAT

If you hold the backs of your hands on either side of a hot copper sheet that has one side polished and the other side blackened as shown in figure, it will be found that the dull black surface is a better emitter of radiation than the shiny one.

similar kettle having shining surface.

In general a good absorber is a good radiator and a poor absorber is a poor radiator.

The rate of energy transfer by radiation is affected by:

- Colour and texture of the surface
- Surface temperature
- Surface area

White clothes are worn in hot climates because white is a good reflector and a poor absorber. Black or dark coloured clothes are worn in cold climates, because dark is a poor reflector and a good absorber.

PRACTICAL APPLICATIONS OF RADIATION OF HEAT

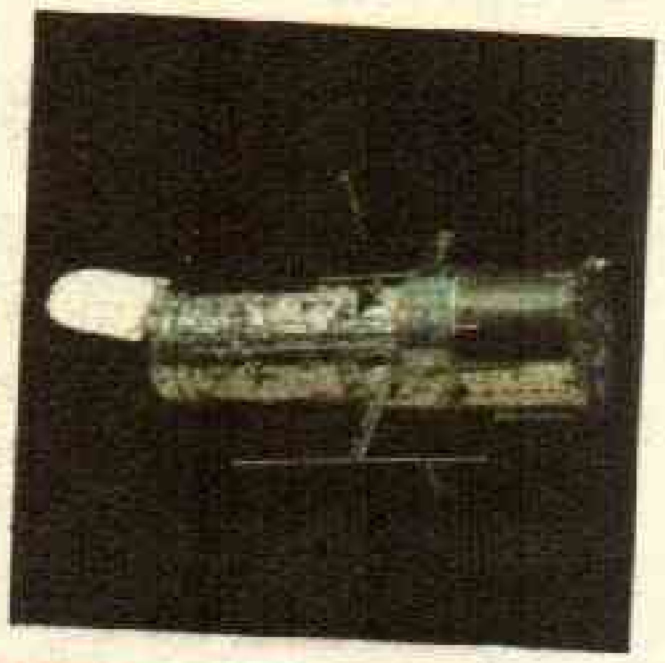
The following are few examples of radiation of heat.

A. Colouring Materials:

The cooling fins on the heat exchanger at the back of a refrigerator are painted black so that they lose heat more quickly. By contrast, saucepans that are polished are poor emitters and keep their heat longer. In general, surfaces that are good absorbers of radiation are good emitters when hot.

B. Texture of the surface:

One type of radiant barrier material, ARMA foil, produced by Energy Efficient Solutions.



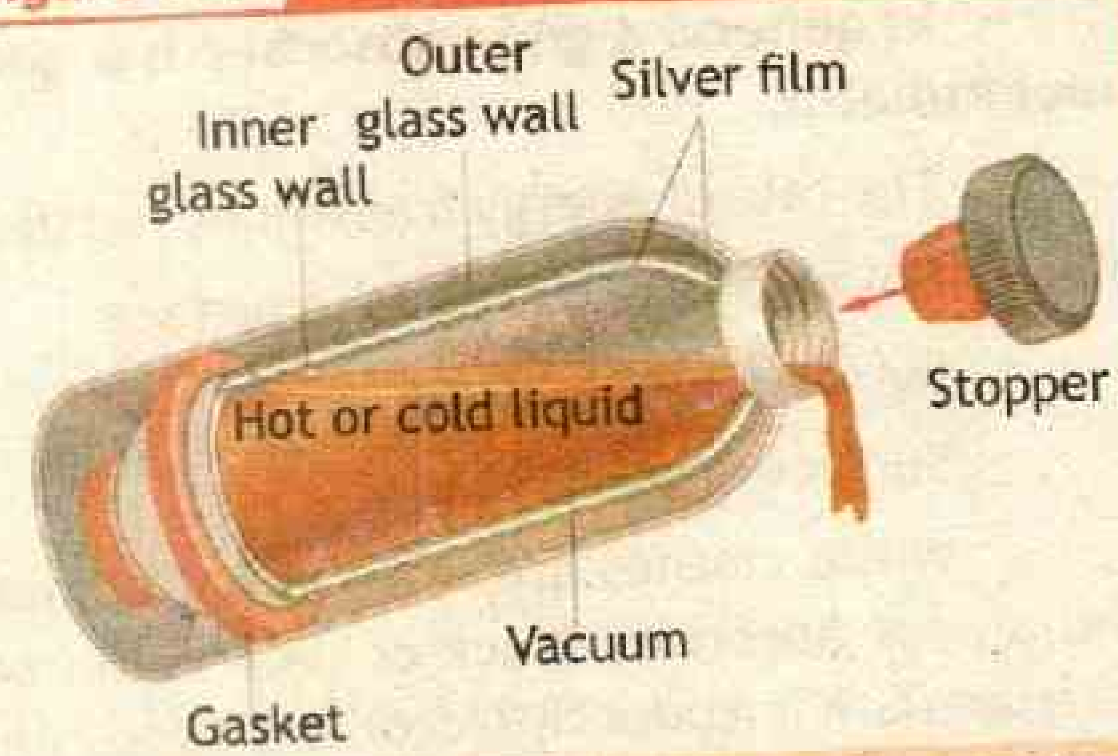
C. Satellite Protective Coating:

The highly reflective metal foil covering this satellite (the Hubble Space Telescope) minimizes temperature changes.

D. Thermos Flask:

The vessel which is used to prevent heat transfer due to conduction, convection and radiation is called thermos flask. It consists of a double - walled glass vessel silvered on the inside.

Figure 9.7 THERMOS FLASK



A thermos bottle minimizes energy transfer due to convection, conduction, and radiation.

The purpose of the slivering is to reflect all radiant heat trying to enter or leave the vessel. The space between the walls is highly evacuated (vacuum is created) to prevent convection. The glass, being a poor conductor minimizes conduction of heat as well. The heat loss through the flask is so small that a hot liquid placed in the flask will remain hot for a very long time. A cold thing placed in the flask will remain cold for a long time because flow of heat from the outside will also be very small.

9.5 GREENHOUSE EFFECT AND GLOBAL WARMING

The greenhouse effect is the process by which radiation from a planet's atmosphere warms the planet's surface to a temperature above what it would be without its atmosphere. The strength of the greenhouse effect - will depend on the atmosphere's temperature and on the amount of greenhouse gases that the atmosphere contains.

9.5.1 MECHANISM OF GREEN HOUSE EFFECT

Earth receives energy from the Sun in the form of ultraviolet, visible, and near-infrared radiation. Of the total amount of solar energy available at the top of the atmosphere, about 26% is reflected to space by the atmosphere and clouds and 19% is absorbed by the atmosphere and clouds. Most of the remaining energy is absorbed at the surface of Earth.

Figure 9.8 GREEN HOUSE EFFECT

Because the Earth's surface

is colder than the photosphere of the Sun, it radiates at wavelengths that are much longer than the wavelengths that were absorbed. Most of this thermal radiation is absorbed by the atmosphere, thereby warming it. In addition to the absorption of solar and thermal radiation, the atmosphere gains heat by latent heat fluxes from the surface.

The atmosphere radiates energy both upwards and downwards; the part radiated downwards is absorbed by the surface of Earth. This leads to a higher equilibrium temperature than if the atmosphere were absent.

9.5.2 IMPORTANCE OF GREENHOUSE EFFECT

Green house effect is important for the survival of life on earth. On Earth, an atmosphere containing naturally occurring amounts of greenhouse gases (water vapour, carbon dioxide CO_2, methane CH_4, and ozone O_3) causes air temperature near the surface to be about 33 °C (59 °F) warmer than it would be in their absence. Without the Earth's atmosphere, the Earth's average temperature would be well below the freezing temperature of water.

Human activity has increased the amount of greenhouse gases in the atmosphere leading to global warming (increase in the temperature of earth). Due to human activities in the period from 1880 to 2012, the global average temperature has increased by 0.85 °C.

The largest human influence has been the emission of carbon dioxide from factories and motor vehicles. Currently, about half of the carbon dioxide released from the burning of fossil fuels is not absorbed by vegetation and the oceans and remains in the atmosphere. Now in order to decrease global warming we have to reduce the emission of greenhouse gases and to plant more vegetation to absorb the produced carbon dioxide.

The 'greenhouse effect' of the atmosphere is named by analogy to greenhouses (a structure with walls and roof made chiefly of transparent material, such as glass) which become warmer in sunlight. However, a greenhouse is not primarily warmed by the 'greenhouse effect', because 'greenhouse effect' works by preventing absorbed heat from leaving the structure through radiative transfer, while in 'green house' warming is produced mainly by reducing convection of air. Similar effect is also observed in car parked in the hot sun with its windows closed, there is some greenhouse effect but the warming is chiefly achieved through reduction in convection.

KEY POINTS

Heat transfer: The process, in which heat travels from one place to another place because of difference of temperature, is called transfer of heat.

Conduction of heat: The particle to particle mode of heat transfer by collisions or indirect interaction is called conduction of heat.

Thermal conductivity: The thermal conductivity of a substance is a measure of the ability to conduct heat energy.

Convection of heat: The transfer of heat from one place to another by the actual motion of the heated substance is called convection of heat.

Convection currents: The currents set up in the process are known as convection currents.

Radiation of heat: The heat and energy transfer from a hotter place to a colder place with or without having a material medium in between is called radiation of heat.

Radiant energy: The energy emitted from a hotter place and carried through radiation is called radiant energy.

PROJECTS

GROUP - A

HEAT CONDUCTOR SURFACES: Choose a variety of surfaces for your ice to melt on. Compare metal, plastic, glass, and paper to see which makes a better conductor of heat. Explain your finding in form of research and present your findings in classroom.

GROUP - B

OIL AND GHEE HEAT CONDUCTION: Investigate heat transfer in any cooking process. Does cooking oil or ghee added during cooking increase the heat transfer? Do we require materials that are good conductors of heat transfer for cooking? Demonstrate your results in class in form of a presentation.

GROUP - C

INSULATING MATERIALS: Visit the market and find out the materials available for home roof and wall insulation. State the advantages of different materials over the other. Make your own suggestive material that is both good insulator and cost effective. Defend your material in front of class.

GROUP - D

GLOBAL WARMING: Write an essay on how important for us to keep the temperature of earth. What are the consequences of global warming and how we can safely overcome it.

GROUP - E

COLOR TEMPERATURE: Research books and internet to find how are the temperature measured using the color of hot objects? Write a column for school magazine.

EXERCISE

MULTIPLE CHOICE QUESTIONS

Choose the best possible answer:

1. Which of the following is the best heat conductor?
   A. aluminum B. tin C. iron D. copper
2. Identical cubes of the following materials are kept in a room at the same temperature. Which will feel coldest by touching them?
   A. Wood B. Glass C. Iron D. Styrofoam
3. The transfer of heat by convection is smallest in
   A. solids B. liquids C. gases D. none
4. One way that heat is transferred from place to place inside the human body is by the flow of blood. Which one of the following heat transfer processes best describes this action of the blood?
   A. convection B. conduction C. radiation D. none
5. The best absorber of radiation is a body whose surface is
   A. White B. Grey C. Dull black D. Highly polished

5. The mode of transfer of heat which does not require material medium is called
   A. convection B. conduction C. radiation D. none
6. Which of the following has the highest thermal conductivity
   A. water B. wood C. wool D. air
7. The temperature at which a body is not radiating any heat is
   A. 0 °C B. 0 °F C. 0 K D. all of these
8. The electrons that are free to move through the metal called
   A. lose electrons B. free electrons
   C. conduction electrons D. holes

CONCEPTUAL QUESTIONS

Give a brief response to the following questions.

1. Why white clothes are preferred wearing in summer? Explain briefly.
2. Why is the freezer compartment kept at the top of a refrigerator? Explain briefly.
3. A black car standing in the sun warms up more quickly than any other. Why?
4. Why a tile floor feels colder to bare feet than a carpeted floor?
5. How woolen sweaters keep us warmer in winter?
6. In certain places, birds can fly for hours without flapping their wings. Explain.
7. Good-quality thermos bottle is double-walled and evacuated between these walls, and the internal surfaces are like mirrors with a silver coating. How does this configuration combat heat loss from all three transfer methods and keep the bottle's contents your coffee hot?
8. A piece of wood lying in the Sun absorbs more heat than a piece of shiny metal. Yet the metal feels hotter than the wood when you pick it up. Explain.
9. Some pot handles remain cool during cooking while others become unpleasantly hot. What determines which handles remain cool and which become hot?
10. When sunlight warms the land beside a cool body of water, a breeze begins to blow from the water toward the land. Explain.

COMPREHENSIVE QUESTIONS

Give an extended response to the following questions.

1. Explain conduction of heat and its mechanism. Describe any three of its practical applications.
2. Explain thermal conductivity of a substance and its mathematical description.
3. Explain convection of heat and its mechanism. Explain any three of its practical applications.
4. Explain radiation of heat and its mechanism. Describe any three of its practical applications.
5. Discuss the greenhouse effect. Explain its importance and global warming concern.

NUMERICAL QUESTIONS

1. A person's body is covered with 1.6 m^2 of wool clothing. The thickness of the wool is 2.0×10^3 m. The temperature at the outside surface of the wool is 11° C, and the skin temperature is 36° C. How much heat per second does the person lose due to conduction? Thermal conductivity of wool is k = 0.04 W m^{-1} K^{-1}.
2. The external wall of a brick house has an area of 16 m^2 and thickness 0.3 m. The temperatures inside and outside the house are respectively 20 °C and 0 °C. Calculate the rate of heat loss through the wall. Thermal conductivity of brick is k = 0.84 W m^{-1} K^{-1}.. [533 W]
3. Window glass has thermal conductivity of 0.8 W m^{-1} K^{-1}. Calculate the rate at which heat is conducted through a window of area 2.0 m^2 and thickness 4.0 mm. The temperature inside an air-conditioned room is 20 °C. The outdoors temperature is 35°C.

ANSWERS

CHAPTER - 1

Assignment	Answer
1.1	5.98×10^{24} kg
1.2	6.048×10^{5} s
1.3	2.14×10^{-5} kg, 21.4 milligrams
1.4	5.7×10^{-2} m, 57×10^{-3} m, 57 mm
1.5	4.89×10^{8} mm
1.6	A. Vernier Caliper
1.7	200 cm^3, 2.0×10^{-4} m^3 or 0.0002 m^3

Numerical Problems	Answer
1	a. 1.0 ag, b. 3.00 Em, c. 194.6 Gm
2	0.1 nm, 10^5 fm, 10^{10} Angstrom
3	(a) 2.99792458×10^{8} m s^{-1} (b) (i) $2.997\,9 \times 10^{8}$ m s^{-1} (ii) 3.00×10^{8} m s^{-1})
4	7×10^{-9} m, 9.6×10^{7} W, 4.3×10^{-11} F, 2×10^{-3} m
5	5×10^{-12} kg, 1.39×10^{9} m

Extension Exercise	Answer
1.1	Earth moves around sun in elliptical orbit therefore the distance varies
1.2	No, we must take 365.25 days to account for leap tear
1.3	By road the distance is longer, aeroplane moves by the straight distance

CHAPTER - 2

Assignment	Answer
2.1	10.43 m/s
2.2	9 ms^{-1}, 0 ms^{-1}
2.3	0.66 m/s^2
2.4	280 m
2.5	5 m/s
2.6	- 18.5 m/s
2.7	81.6 m round off to 80 m, 4.08 s round off to 4 s

Numerical Problems	Answer
1	400 m/s^2 E
2	10 m
3	896 m/s
4	NO, 44.4 m, she will be 24.3 m past the light
5	66 m, 17 m/s
6	31.3 m/s

Extension Exercise	Answer
2.1	Speed of snail varies
2.2	WEST
2.3	41.8 m/s = 150.48 km/h which is high speed
2.4	longer runway is required for landing due to smaller deceleration

CHAPTER -3

Assignment	ANSWER
3.1	$5.83\ m/s^2$, $1.46\ m/s^2$
3.2	150 kg, 1.5×10^3 N, mass does not change it is same as 150 kg both on earth and moon
3.3	3.49 kgm/s
3.4	6000 N, 45000 N
3.5	0.6 m/s
3.6	4.5 m/s
3.7	5 N
3.8	$9.2\ m/s^{-2}$, 21 N
3.9	11 kg
3.10	1112 kg

Extension Exercise	Answer
3.1	$62.5\ m/s^2$, $2.5\ m/s^2$
3.2	No, recoil of gun will be greater than speed of bullet
3.3	$0\ m/s^2$, 9800 N

Numerical Problems	Answer
1	3560 N or 3.55×10^3 N
2	1000 N
3	-2.7×10^3 N, -1.5×10^4 N and -2.6×10^5 N
4	0.46, 0.40
5	$2.8\ m/s^2$, 42 N
6	8.44×10^4 N
7	3000 N
8	8000 N

CHAPTER - 4

Assignment	ANSWER
4.1	30 N
4.2	86 N, 8.7°
4.3	200 N
4.4	2 kg

Extension Exercise	ANSWER
4.1	No
4.2	40.8 kg, 61.2 kg

Numerical Problems	Answer
1	13 N, 7.5 N
2	160 N
3	1.5 m
4	0.6 m
5	24 N
6	294,000 Nm, 176,000 Nm

CHAPTER - 5

Assignment	Answer
5.1	2×10^{20} N
5.2	7.3×10^{22} kg
5.3	105 N, $1.62\ m/s^2$
5.4	$7.33\ m/s^2$, $0.22\ m/s^2$
5.5	6890 m/s

Extension Exercise	Answer
5.1	Only Confirmation is required

Numerical Problems	Answer
1	4.1×10^{18} N
2	$3.68\ m/s^2$ or 3.68 N/kg
3	$1.352\ m/s^2$
4	2.6×10^6 m
5	7.76×10^3 m/s
6	1.02×10^3 m/s
7	547 km

CHAPTER - 6

Assignment	Answer
6.1	2.2×10^{3} J
6.2	2400 J
6.3	490 J
6.4	9×10^{13} J
6.5	150 kJ

Extension Exercise	Answer
6.1	2.8 m/s
6.2	Variable

Numerical Problems	Answer
1	a. 6 J, b. 9.6×10^{2} J
2	3×10^{4} m/s
3	a. 0J, b. 3.7×10^{4} J
4	7500 W
5	1.06×10^{5} W
6	22 s
7	5.4×10^{6} J

CHAPTER - 7

Assignment	Answer
7.1	3600 kg/m^3
7.2	100 Pa or 100 N/m^2
7.3	10^6 Pa
7.4	3 kg/m^3
7.5	3×10^5 N/m^2

Extension Exercise	Answer
7.1	400 kPa

Numerical Problems	Answer
1	1250 Pa and 7500 Pa
2	10.. m
3	2.7×10^{3} N
4	1.11×10^{8} Pa
5	(a) 5 N (b) 5 N (c) 0.5 kg (d) 5×10^{-4} m^3 and (e) 5882 kg m^{-3}
6	150 N/m
7	1 cm

CHAPTER - 8

Assignment	Answer
8.1	− 23 °C
8.2	$2.3 \times 10-5$ °C^{-1}
8.3	0.522 cm^3
8.4	262 Liter
8.5	235.2 J/kg K
8.6	7.1×10^{6} J

Numerical Problems	ANSWER
1	a. 7 K, 13 °F b. -256 °F, 115 K
2	8.8×10^{-6} m
3	144 m, 216 m
4	1.228 cm^3
5	1700 J/kgK
6	7.1×10^{6} J

CHAPTER - 9

Assignment	Answer
9.1	2.6×10^{6} J

Numerical Problems	Answer
1	8.0×10^{2} W
2	6.1×10^{4} J
3	533 W
4	6.0 W$\times 10^{3}$ W

Glossary

Absolute Zero: The lowest temperature (-273°C) that any substance can reach. At this temperature the molecules or atoms of the substance contain no heat energy.

Acceleration: The rate of change of velocity.

Acceleration Due To Gravity: The acceleration of a freely falling body within a gravitational field close to the surface of earth its value is $10ms^{-2}$.

Artificial Satellite: Objects moving in fixed circular orbit around the earth.

Atmospheric Pressure: The pressure exerted on a body by the atmosphere due to the weight of the atmosphere. At the surface of the earth atmospheric pressure is 100 KPa / m^2.

Base Quantity: Such quantity, which can be expressed independently without the reference of any other quantity.

Base Units: The units in system international which are seven in number.

Buoyant Force: The force acting on an object due to buoyant of a liquid.

Centre Of Gravity: The point of body where its weight acts.

Centripetal Acceleration: Acceleration produced by the centripetal force.

Centripetal Force: The force, which keeps an object to move in a circular path.

Circular Motion: Motion of a body along a circular path.

Co-Efficient of Volume Expansion: Change in unit volume caused by unit Kelvin change in temperature.

Co-Efficient of Linear Expansion: Change in unit length caused by unit Kelvin change in temperature.

Component of a Vector: Such vectors when added given the resultant vector.

Conduction: Transfer of heat due to interaction of electrons or molecules.

Convention: Transfer of heat due to the movement of molecules from one place to another.

Couple: When two equal and unlike parallel forces act at different points of a body, then they constitute a couple.

Derived Quantity: Such quantity which is expressed with reference to base quantities.

Displacement: The shortest distance between two points.

Dynamics: Study of motion of bodies under action of force.

Efficiency: Ratio of output and input.

Effort Arm: The intermediate distance between fulcrum and effort.

Effort moment: Product of effort and effort arm.

Effort: Force applied on the machine.

Elastic Potential Energy: Energy of a compressed or stretched spring.

Elasticity Modulus: Ratios of stress and strain.

Elasticity: The property of the solids because of which they restore there original shape when external force ceases to act.

Energy: Ability of a body to do work.

Equllibrium: A body whose acceleration is zero.

Force: The agent that changes or tends to change the state of a body.

Friction: The force of resistance against the relative motion between two surfaces.

Fulcrum: The point around which lever revolves.

Fossil Fuels: Fuels formed over millions of year by the partial decay of the remains of living things.

Gravitational Force: Mutual force of attraction between the objects.

Gravitational Potential Energy: energy of a body due to its position in the gravitational field.

Gravitational Field Strength: The gravitational force exerted on a 1 Kg mass placed within any gravitational field.

Heat: The form of energy, which is transferred from one place to another because of difference of temperature.

Horizontal Component: The component of a vector F which is along horizontal or x-direction.

Hydraulic Systems: System that transfer forces from place to place using fluids.

Inertia: The characteristic of a body due to which it resists against any change in its state.

Insulators: Materials that prevent, or significantly inhibit, the flow of heat through them.

Joule: The unit of work in system international.

Kinematics: Study of motion of bodies without taking into consideration the mass and forces.

Kinetic Energy: Energy of a body due to motion.

Kinetic Friction: Friction during motion.

Latent Heat of Fusion: The quantity of heat required to change the state of one kilogram of a liquid to vapour or gaseous state during which its temperature remains constant.

Lever: A strong bar revolving around some point.

Light Year: The unit of distance for celestial bodies is equal to 9.46×10^{15} m.

Like Parallel Forces: Forces acting along parallel lines in the same direction.

Limiting friction: The maximum value of static friction.

Linear Motion: The motion of body along a straight line.

Load Arm: The intermediate distance between fulcrum and load.

Load Moment: Product of load effort arm.

Load: Resistance or lifted up weight.

Mass: That characteristics of a body, which determiners the acceleration produced by the application of a force.

Mechanical Advantage: Ratio of load and effort.

Mechanics: The branch of physics which deals with the study of motion of bodies is known as mechanics.

Momentum: The product of mass and velocity of a body.

Neutral Equilibrium: The condition of a body, in which its centre of gravity neither rises not becomes lower of its original position after disturbance.

Newton: The unit of force. 1 Newton is the force that gives a 1 Kg mass an acceleration of $1ms^{-2}$.

Non – Renewable Source: A source of energy that is used up faster than it can be replaced.

Orbit Velocity: A critical velocity of a satellite in order to keep on moving around the earth at a specific height.

Output: A work, which the machine does.

Physics: That branch of science, which explains the properties of matter and energy.

Power: Rate of doing work.

Proportionality Constant: Such a number, which connects two quantities to convert them in the form of an equation.

Radiation: Transfer of heat by infra red radiation requiring no medium for the transmission.

Random Motion: Motion without any consideration of time and direction.
Rectangular Components: The components of a vector which are mutually perpendicular to each other.
Resolution of a Vector: Division of a vector into its components.
Resultant Vector: Such a vector, which shows the combined effect of two or more vectors.
Rolling Friction: The friction produced during the motion of one body over the other with the help of wheels.
Scalar Quantities: Only magnitude is necessary for their representation.
Scientific Methods: Logical applications of arguments that explain a certain phenomenon.
Scientific Notion: The numbers written as power or prefix of ten in which there is only one non zero number before decimal.
Significant Figures: In a measurement, the correctly known digits and the first doubtful digit.
Simple Machine: A thing, which help in doing work more easily.
Sliding Friction: The friction between two surfaces sliding against each other.
Specific Heat Capacity: The quantity of heat, which changes the temperature of one kilogram mass by one kelvin.
Speed: Distance covered by a body in certain time.
Stable Equilibrium: The condition of a body in which it comes to its original condition after being disturbed.
Static Fraction: The force of friction arising due to applied external fore before motion.
Strain: The change in the shape of an object under the action of an external force.
Stress: Force acting on unit area of an object.
Surface Tension: The force acting along the surface of a liquid.
Tension: The force acting along string.

Thermometry: Art of measurement of temperature.
Torque: The capacity of a force to revolve a body.
Trigonometric Ratios: The rations of the sides of a right – angled triangle.

$$\sin\theta = \frac{\text{Perpendicular}}{\text{Hypotenuse}}$$

$$\cos\theta = \frac{\text{Base}}{\text{Hypotenuse}}$$

$$\tan\theta = \frac{\text{Perpendicular}}{\text{Base}}$$

Uniform Acceleration: Equal change in velocity in equal intervals of time.
Uniform Speed: Equal distances covered by a body in equal intervals of time.
Uniform Velocity: Equal change in displacement in equal interval of time.
Unlike Parallel Forces: Forces acting along parallel forces but in opposite directions.
Unstable Equilibrium: The condition of a body in which it does not come to its original condition after disturbance.
Vector Quantities: Magnitude and direction both are necessary for their representation.
Velocity: Rate of change of displacement with time.
Vertical Component: The component of a vector F which is along vertical of Y – direction.
Vibratory Motion: The to and fro motion of body about a fixed point.
Viscosity: the fractional force between the layers of a fluid in flow.
Watt: The unit of power in system international.
Weight: The force with which the earth pulls a body toward itself.
Work: The product of force and the displacement in the direction of force.
Young's Modulus: Ratio of tensile stress to tensile strain.

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Richard Wolfson

SUGGESTION FOR TEACHERS

Dear teachers, this book mainly focus on friendly and joyful learning material. An effort is made to make the book rich in tasks like assignments, projects, conceptual questions, activities, tidbit, tips, interesting information and point of ponder..

Topics: An effort is made to make students think themselves as scientists. Students' participation must be encouraged in the learning process; allow them to discuss and give them a choice to incorporate their interest. Involve students with tidbits, activities and points of ponder and share with them interesting information and tips in your classroom.

Assignments: Each topic that covers some mathematical work is assisted with relevant example and followed by an assignment task for students to workout. Some examples are even added with **extension exercise** for higher order thinking.

Projects: After each chapter you will find projects for group work by students. Divide your class in 5 groups (A, B, C, D and E) and assign tasks to them, after three to four days arrange a special class for the students to share their projects with the rest of the class.

Exercise: When the student groups are assigned different projects in the being time try to cover exercise having Multiple Choice Questions (MCQs), Conceptual Questions (CQs), Comprehensive Questions and Numerical Problems.

APPENDIX

USEFUL PHYSICAL DATA

Quantity	Value
Speed of light in vacuum	$2.997\,924\,58 \times 10^{8}$ m/s
Acceleration due to earth's gravity	9.80 m/s^2 = 32.2 ft /s^2
Universal gravitational constant	6.674×10^{-11} Nm^2/kg^2
Atmospheric pressure at sea level	1.013×10^{5} Pa
Mass of Earth	5.98×10^{24} Kg
Mass of Moon	7.35×10^{22} Kg
Mass of Sun	1.99×10^{30} Kg

FREQUENTLY USED MATHEMATICAL SYMBOLS

Symbol	Meaning
=	Is equal to
≠	Is not equal to
≤	Is less than or equal to
≥	Is greater than or equal to
α	is proportional to
Δ	the difference between two variables (e.g., Δ *T* is the final temperature minus the initial temperature)

BASIC MATHEMATICAL FORMULAS

Quantity	Formula
Area of a circle	πr^2
Circumference of a circle	$2\pi r$
Surface area of a sphere	$4\pi r^2$
Volume of a sphere	$^4/_3\,\pi r^3$
Pythagorean theorem	$h^2 = h_o^2 + h_a^2$
Sine of an angle	$sin\theta = h_o/h$
Cosine of an angle	$cos\theta = h_a/h$
Tangent of an angle	$tan\theta = h_o/h_a$

LABORATORY INSTRUCTIONS FOR STUDENTS :

Experiments in National curriculum are designed to illustrate important concept described in class. You are expected to come prepared when you arrive to laboratory to perform an experiment. The instructor at laboratory is not to perform an experiment he will be there to answer your questions, aid you in the use of equipment, discuss the physics behind the experiment and guide you in completing your analysis and write-up.

All write up should be finished in the laboratory session and handed over to the instructor for sign. Remember the neatness, organization and explanations of your measurements and calculations represent the quality of your work.

In your lab ask the instructor to provide you the materials required for practical work. Arrange them on table and examine their condition; if equipment is out of order try to replace. Apparatus requiring frequent adjustment must be placed within easy reach.

The apparatus provided for the laboratory experiment are often expensive and delicate. If a piece of apparatus is broken report to the instructor immediately.

Try to record original data and let all the group member participate in the experiment.

After completing an experiment the experimental setup must be disassembled, and turn off all the sources of water electricity and gas.

Safety: The most important thing in the laboratory is your safety and that of others. The danger increases if you have less knowledge of the equipment and procedures. If you have a question about safety you should direct it immediately to the instructor. The students in the physics lab are expected to exercise common sense judgment when working with laboratory equipment.

THE GREEK ALPHABET

Name	Capital Letters	Small Letters	Name	Capital Letters	Small Letters
Alpha	Α	α	Nu	Ν	ν
Beta	Β	β	Xi	Ξ	ξ
Gamma	Γ	γ	Omicron	Ο	ο
Delta	Δ	δ	Pi	Π	π
Epsilon	Ε	ε	Rho	Ρ	ρ
Zeta	Ζ	ζ	Sigma	Σ	σ
Eta	Η	η	Tau	Τ	τ
Theta	Θ	θ	Upsilon	Υ	υ
Iota	Ι	ι	Phi	Φ	φ
Kappa	Κ	κ	Chi	Χ	χ
Lambda	Λ	λ	Psi	Ψ	ψ
Mu	Μ	μ	Omega	Ω	ω