Virtual Study

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PHYSICS

GRADE 9

Prepared by: Virtual Study

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Contents

UNIT 1

Physics and Human Society

1.1 Definition and Nature of Physics

What is physics?

The word physics is derived from the Greek word **phusis**, meaning nature. Hence, physics is a branch of natural science aimed at describing the fundamental aspects of our universe.

Physics enables you to understand the working principles of cars, airplanes, space-rockets, refrigerators, radios, televisions, etc. as well as many of your daily utensils and tools.

Importance of physics

- Physics explains physical phenomena such as the difficulty of walking on a smooth plane, and why an electric fan rotates etc.
- Physics helps you discover some of the unknown parts of nature and makes you familiar with the modern world.
- Physics helps you to understand some concepts in other subjects like: Biology, Chemistry, Geology, Astronomy, etc.

Studying physics helps you understand concepts, relationships, principles and laws of nature.

Note: A person who studies physics is called a physicist.

1.2. Branches of Physics

Mechanics: Mechanics is the branch of physics which deals with the motion of an object without or with the reference of force. Mechanics can be further divided into two branches namely quantum mechanics and classical mechanics.

Quantum mechanics: deals with the behavior of smallest particles like neutrons, protons, and electrons,

Classical mechanics: is the branch that deals with laws of motion of forces and physical objects

Acoustics: Acoustics is the branch of physics which deals with the study of sound and its transmission, production, and effects.

Optics:Optics is the branch of physics which deals with the behavior, propagation, and properties of light.

Thermodynamics: Thermodynamics is the branch of physics which deals with thermal energy and the transfer of heat.

Electromagnetism: is the branch of physics which deals with the study of electromagnetic force like electric fields, light, magnetic fields, etc. There are two aspects of electromagnetism which are "electricity" and "magnetism"

Nuclear physics: is the branch of physics which deals with the structure, properties and reactions of the nuclei of atoms.

Astrophysics: Astrophysics is a science that employs the methods and principles of physics in the study of **astronomical objects** and phenomena.

1.3. Related fields of physics

- Chemistry: Chemistry deals with the interactions of atoms and molecules. However, it is rooted in atomic and molecular physics.
- **Engineering**: Most branches of engineering also apply physics. For example, in architecture, physics is at the heart of determining structural stability, acoustics, heating, lighting, and cooling for buildings.
- **Geology**: Parts of geology, the study of nonliving parts of Earth, rely heavily on physics; including radioactive dating, earthquake analysis, and heat transfer across Earth's surface.
- Biophysics: Biophysics applies principles and methods used in physics to study

biological phenomena.

• Geophysics: Geophysics applies the principles and methods of physics to the study of the Earth.

• Medical Physics: Diagnostics and medical therapy, such as x-rays, magnetic resonance imaging (MRI), and ultrasonic blood flow measurements involves principles of physics.

1.3 Historical Issues and Contributors

Galileo Galilei (1564-1642): Galileo Galilei was an Italian astronomer, physicist and engineer who studied the **solar system** and the **universe** using a telescope.

Isaac Newton (1643- 1727). Isaac Newton was an English mathematician, physicist, astronomer,Isaac Newton developedthe **laws of motion** and **gravity**

Michael Faraday (1791-1867): Michael Faraday was an English scientist. He contributed to the study of **electromagnetism** and **electrochemistry**. His main discoveries include the principles underlying electromagnetic induction, diamagnetism and electrolysis. In general Michael Faraday changed the world with magnet

James Prescott Joule(1818-1889): James Prescott Joule is an English physicist,. Joule studied the nature of **heat**, and discovered its relationship to mechanical **work**. This led to the law of conservation of energy. Joule's work helped lay the foundation for the first of three laws of thermodynamics that describe how energy in our universe is transferred from one object to another or transformed from one form to another.

Marie Curie(1867-1934) Marie Curie, was a Polish-born French physicist and chemist who conducted pioneering research on radioactivity. She discovered elements **polonium** and **radium**

Albert Einstein (1879- 1955): Albert Einstein was a German-born theoretical physicist. Einstein is known for developing the theory of **relativity** and the theory of **quantum mechanics**

Willebrod Snell: developed the law of refraction of light

Daniel Bernoulli: developed Bernoulli principle and kinetic theory of gases

Thomas Young: developed theory of light

Unit summary Questions

1. The Greek word 'phusis' for nature is appropriate in describing the field of physics. Which one of the following is the best answer for this?

(a) Physics is a natural science that studies life and living organisms on habitable planets like Earth.

(b) Physics is a natural science that studies the laws and principles of our universe.

(c) Physics is a physical science that studies the composition, structure, and changes of matter in our universe.

(d) Physics is a social science that studies the social behavior of living beings on habitable planets like Earth.

2. A moving car suddenly comes to a rest after applying brakes. Which branch of physics do you think is appropriate to explain this phenomenon?

(a) Mechanics

(b) Acoustics

(c) Electromagnetism

(d) Nuclear physics

(e) None of the above

3. Which of the following is not one of the branches of physics?

(a) Thermodynamics

(b) Optics

(c) Classical physics

(d) Evolution

4. Which of the following is not a historical contributor in physics?

(a) Willebrod Snell

(b) Daniel Bernoulli

(c) Thomas Young

(d) Charles Darwin

5. Which of the following institution/project does not apply the principle of physics?

(a) Ethiopian Aviation Industry

(b) Grand Ethiopian Renaissance Dam (GERD)

(c) Quality and Standard Authority of Ethiopia

(d) Ethiopian Radiation Protection Authority

(e) None of the above

6. Which branch of Physics is most important when studying the nature and behavior of light? (a) Quantum Mechanics

(b) Nuclear Physics

(c) Optics

(d) Thermodynamics

7. Galileo's famous experiment at the leaning tower of Pisa demonstrated that

(a) What goes up must come down

(b) All objects fall to earth at the same rate, regardless of their mass

(c) Heavier object falls faster than lighter object of the same size

(d) Gravity does not act on a falling object

Unit 2

Physical Quantities

physical quantities are any phenomenon that can be quantitatively described using mathematical tools.

Ex: time, distance, temperature, mass etc…

2.1 Scales, Standards, Units (prefixes)

In general there are four data measuring scales. These are nominal scales, ordinal scales, interval scales and ratio scales

Nominal scale: Nominal scales: are used for labeling variables without any number value. For nominal scales there is no inherent quantitative difference among the categories. Examples are: gender (male, female), hair color (black, brown), primate, religion….

Ordinal scales: are rank-order observations. For this type of scale, there is an underlying quantitative measurement on which the observations differ.

Example: class rank, horse race,

Interval scales: have a constant interval but lack a true zero point. For this type of scale, one can add and subtract values on an interval scale, but one cannot multiply or divide units.

Examples: temperature in degree Celsius or Fahrenheit, grade levels, age, income….

Ratio scales: have the property of equal intervals but also have a true zero point. As a result, one can multiply and divide as well as add and subtract using ratio scales. Units of time (second, minute, hour), length (centimeter, meter, and kilometer), weight (milligram, gram, kilogram), volume (centimeter cube) and temperature in Kelvin Scale are ratio scales.

Key Concept: scale is a set of numbers, amounts, etc., used to measure or compare the level of something.

Class activity

Are scales involving division of two ratio scales also themselves ratio scales? Discuss in small groups?

Yes, example: acceleration is the ratio of velocity to time, but velocity itself is the ratio of displacement to time

In group observe measurement activities in the surrounding (home, local market and work places) for two days and prepare a report on the what, the where, and the how of the measurements observed.

Answer: for length measurement: hand span, cubit, foot span, pace

For weight: tin can and feresula

Standards : is a reference used to calibrate measurements and reproduce the same value of measured quantities

A standard should be defined as:

- It must be readily accessible and possesses some property that can be measured reliably.
- Measurements taken by different people in different places must yield the same result.

ACTIVITY 2.3: Six grade 9 students in different parts of Ethiopia are given the same object and measured its mass in the same unit as shown in Table below. Discuss whether the measurement has a standard or not regardless of personal errors.

No.	Name of student	Place	Measured value
1	Student A	Place A	1.6 unit
2	Student B	Place B	2.1unit
3	Student C	Place C	2.5unit
4	Student D	Place D	3unit
5	Student E	Place E	1.1unit
6	Student F	Place F	3.5unit

Answer: No, the measurements are not standard. For the measurements to be standard, measurements taken by different students in different places must yield the same result

Class activity 2.4: what is the need for standards and discuss the negative consequences of using non- standard measurements?

Answer: standard measurement is needed to make the result reliable, accurate and the same ignoring personal errors.

Negative consequences of using non-standard measurements are different results and inaccuracy among measured values.

Length: Meter is the international system (SI) unit for length.

NB: meter (m) is defined as a distance traveled by light in vacuum during a time of

1 299792458 seconds

Mass:kilogram (kg) is the international system (SI) unit of mass.

Time:second is the SI unit of time

NB: The second (s) is defined as 9 192 631 770 times the period of vibration of radiation from the cesium-133 atom

Standard units: are conventional units which are used to measure physical quantity scientifically.

Scientific Notation Scientific notation is a way of writing numbers that are too large or too small to be conveniently written as a decimal. This can be written more easily in scientific notation, In the general form: $d \times 10^n$

Where,

D= the decimal number between 0 and 10

n= exponent

example : $0.005*10^{4}= 50$

$3.24*10^{-3}=0.00324$

Exercise 2.4: Write 0.000001256 in scientific notation to 3 decimal places?

Answer: $1.26*10^{-6}$

How many significant figures are in 7800?

Answer: 2

Because zeros at the end of the number are not significant numbers

Significant figures

In a number,

Each non-zero digit is a significant figure. E.g 8543 (four significant figures)
Zeroes are only counted if they are between two non-zero digits or are at the end of the decimal part.

For example, the number 2000 has 1 significant figure (the 2), but 2000.0 has 5 significant figures

Prefix

Prefixes are words or letters written in front that change the meaning.

Ex: 1 kg= 1000 g=1×103 g. We can replace the 10^{3} with the prefix "k"(kilo)

Prefix	Symbol	multiplier	Exponent
Tera	T	1000000000000	10^{12}
Giga	G	1000000000	10^{9}
Mega	M	1000000	10^{6}

Kilo	K	1000	10^3
Hector	H	100	10^2
Deka	Da	10	10^1
Deci	D	0.1	10^{-1}
Centi	c	0.01	10^{-2}
Milli	m	0.001	10^{-3}
Micro	µ	0.000001	10^{-6}
Nano	n	0.000000001	10-9
pico	p	0.000000000001	10^{-12}

Unit prefix: is a letter or a syllable which is written directly before a unit name with no space.

Scientific notation: a system in which numbers are expressed as products consisting of a number between 1 and 10 multiplied by an appropriate power of 10.

In a number, each non zero digit is a significant figure.

Example: 1543; has four significant figures

2.2 Measurement and Safety

Measurement is the process of comparing an unknown quantity with another quantity of its kind (called the unit of measurement). The measurement process has three key elements:

• The physical quantity to be measured.

• The necessary measuring tools.

• Units of measurements used (standard units).

Mass: is a basic physical quantity. It is defined as the amount of matter contained in a body**Length**: Length is one of the fundamental (basic) physical quantities which describe the distance between two points. The SI unit of length is meter (m).

Non SI units of length are millimeter (mm), centimeter (cm) and kilometer (km).

Time:Time is the basic physical quantity. It describes the duration between the beginning and end of an event. The SI unit of time is second (s).

Non SI units of time are: minute, hour, day, week, month and year

Note: Every physical quantity can be represented by its numerical value and unit.

Example: if The length of a table is 3m, 3 is the magnitude, and meter is the standard unit (SI) of the length

2.3 Classification of Physical Quantities

Physical quantities: Aphysical quantity is anything that you can measure. For example, length, temperature, distance and time are physical quantities.

Physical quantities are classified in to two.

Fundamental physical quantities: Fundamental or basic physical quantities: are physical quantities which can be measured directly. They cannot be described in terms of other physical quantities. The units used to measure fundamental quantities are called fundamental units(basic units).

Fundamental physical quantities	Symbol	Basic unit	Symbol
Length	l	meter	m
Mass	m	kilogram	kg
Time	t	second	s
Temperature	T	kelvin	K
Current	I	ampere	A

Amount of substance	n	mole	m
Luminous intensity	I_v	candela	cd

Derived physical quantities: Physical quantities which depend on one or more fundamental quantities for their measurements are called derived physical quantities. The units of derived quantities which depend on fundamental unitfor their measurement are called derived units.

Example: Area, volume, density, and speed are some examples of derived physical quantities.

Derived physical quantities	symbol	Formula	unit	Symbol of the unit
Speed	v	Distance/time	meter/second	m/s
Density	ρ	Mass/volume	Kilogram/meter cube	Kg/m^3
Acceleration	a	Velocity/time	Meter/second square	m/s^2
Force	F	Mass*acceleration	Newton (N)	$Kg*m/s^2$
Work	W	Force*displacement	Joule (j)	$Kg*m^2/s^2$
Pressure	p	Force/area	Pascal (pa)	$Kg/m*s^2$

Scalar and vector quantities

Scalar quantities: A scalar quantity is a physical quantity which has only magnitude but no direction. Examples: distance, mass, time, temperature, energy etc

Example: 3m(only magnitude)

Vector: A vector quantity is a physical quantity which has both magnitude and direction.

Examples: displacement, acceleration, force, etc.

Example: 50 km/h to east (includes magnitude and direction)

50km/h= magnitude,

East= direction

2.4 unit conversion

Example 2.1 The distance between two houses is 200 meter. What is the distance in:

a) centimeter

b) kilometer

c) millimeter

Given: *l*= 200 m

Solution:

1 m = 100 cm

200m= ?

l= (100cm*200m)/1m= 20,000cm

1m=0.001km

200m= ?

l=(200m*0.001km)/1m= 0.2km

1m=1000mm

200m=?

l= (200m*1000mm)/1m=200,000mm= $2*10^5$mm

LengthUnit conversions

1kilometer (km) = 1000 meter (m)

1meter (m) = 100 centimeter (cm)

1meter (m) = 1000 millimeter (mm)

1centimeter (mm) =10millimeter (mm)

1meter (m)=0.001kilimeter (km)

1cm= 0.01 meter (m)

1 millimeter (mm) = 0.001meter(m)

Exercise

1. Which one of the following is a suitable unit to measure the distance between the Earth and the Moon?

(A) mm(B) km (C) cm(D) m (E) all

2. Which one of the following is a suitable unit to measure the diameter of electric wire?

(A)mm

(B) km

(C) cm

(D) m

(E) all

3. A hydrogen atom has a diameter of about 10 nm.

(a) Express this diameter in meters.

(b) Express this diameter in millimeters.

(c) Express this diameter in micrometers.

Solution:

10 nm $=1*10^{-9}$ m

10 nm$=1*10^{-5}$ mm

10 nm $=1*10^{-2}$ μm=0.01μm

The relationship between the SI units and non SI units of mass are;

1 kilogram (kg) = 1000 gram g)

1 gram (g) = 0.001 kilogram (kg)

1 milligram (mg) = 0.001 gram(g)

100 kilogram (kg) = 1 quintal

1000 kilogram (kg) =1 tonne

Example 2.2 In one of the pans of a beam balance the masses 1.5 kg, 500 g, 250 g, 25 g and 0.8 g are placed to measure the mass of unknown object. What is the mass of an object in gram and kilogram on the other side of the pan if they are in balance?

Given: m = 1.5 kg, 500 g , 250 g , 25 g , 0.8 g ,

Required: Total mass in g and Kg Solution:

Total mass =sum of masses in the pan

First convert the masses given in kilogram to gram and add all the quantities on the pan

1.5kg= 1500gram

Mass in gram= 1500+500+250+25+0.8= 2275.8 gram(g)

1000 g= 1 kg

2275.8 g=?

(2275.8 g*1kg)/1000 g =2.2758 kg

The relations between different units of time are:

1 minute = 60 seconds

1 hour = 60 minute

1 day = 24 hours

1 week = 7 days

1 month = 30 days

1 year = 365.25 days

Example 2 Express the following times in seconds.

a) 2 hours

b) 0.5 hour

c) 3/5 hour

Solution

1 hr = 3600 s

2 hr =?

= (2 hr *3600 s)/1 hr = 7200 s

1 hr = 3600 s

0.5 hr =?

= (0.5 hr * 3600 s)/1 hr = 1800 s

C) 1 hr = 3600 s

3/5 hr = ?

(3/5 * 3600 s)/1 hr = 2160 s

Exercise 2.9

1. How many hours, minutes and seconds are there in a day

Solution

1 day = 24 hr

(1 day/24 hr) * 1 hr/60 min = 1 day/1440 min

So, 1day = 1440 min

(1 day/ 1440 min)/ 1 min/60 s = 1 day/ 8640 s

So, 1 day = 86400 s

End of Unit Questions and Problems

Part I. multiple choice

1. Which one of the following scale allows addition, subtraction, multiplication and division?

(a) Nominal scale

(b)Ratio scale

(c) Ordinal scale

(d) Interval scale

2. Which one of the following is NOT a fundamental physical quantity?

(a) Temperature ((b)density c) time (d) mass

3. The SI standard of time is based on:

(a) The daily rotation of the Earth

(b) The yearly revolution of the Earth about the sun

(c) 9 192 631 770 times the period of vibration of radiation from the cesium-133 atom.

(d) A precision pendulum clock

4. Which one of the following method provides a more reliable measurement of time in daily life activities?

(a) Looking the rotation of stars in the sky

(b) Using a digital watch

(c) Looking the position of shadows of trees

(d) Looking the position of the sun on the sky

5. Which one of the following pair of physical quantities has the same unit?

(a) Displacement and distance

(b) Mass and force

(c) Speed and acceleration

(d) Volume and area

6. Why are fundamental physical quantities different from derived physical quantities?

(a) Fundamental physical quantities are derived from derived physical quantities.

(b) Derived physical quantities are derived from fundamental physical quantities.

(c) Derived and fundamental physical quantities have no relation.

(d) All are answer

7. Which quantity is a vector?

(a) Energy

(b) Force

(c) Speed

(d) Time

8. Which one of the following lists is a set of scalar quantities?

(a) Length, force, time

(b) Length, mass, time

(c) Length, force, acceleration

(d) Length, force, mass

Part II: Write true if the statement is correct and false if the statement is wrong.

Candela is a derived physical quantity

Answer: false, candela is a fundamental (basic) unit of luminous intensity

The unit of force can be derived from the units of mass, length and time

Answer: True

For a very large or very small numbers prefixes are used with SI units.

Answer: True

4. Scalar quantity can be described by its magnitude and direction

Answer: false

Part IV: Workout problems

If the area of a single ceramic is 0.25 m^2, how many ceramics are used to cover a floor of a classroom whose area is $40m^2$

Solution

Given : $0.25\ m^2$ = 1 ceramic

$40\ m^2$= ?

Total ceramic = ($40\ m^2$* 1 ceramic)/ $0.25\ m^2$ = 160 ceramics

. The distance between Sun and the Earth is about 1.5 × 1011 m. Express this distance using prefix

Solution

$0.15*10^{12}$ Tm

Unit 3

Motion in a Straight Line

3.1 Position, Distance and Displacement

Frame of reference: is a set of coordinates that can be used to determine positions of objects.

Motionis the change in the position of the object with respect to a fixed point as the time passes

Note :A body is said to be at rest in a frame of reference when its position in that reference frame does not change with time.

Position:is a measurement of a location, with respect to some reference point (usually an origin)

For one-dimensional motion, we often choose the x axis as the line along which the motion takes place. Positions can therefore be negative or positive with respect to the origin of the x-axis.

Distance (S): Distance travelled is a measure of the actual distance covered during the motion of a body. In other words, distance is the total path length traveled by the body.

Note: distance is a scalar physical quantity. The SI unit of distance is meter.

When an object moves, it changes its position. This change of position in a certain direction is known as displacement. A displacement is described by its magnitude and direction.

Note: displacement a vector quantity

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

$\Delta \vec{S}$ = a change in displacement

$\vec{S}f$ = final position of an object

$\vec{S}I$ = initial position of an object

Difference between distance and displacement

table

Distance	Displacement
It is the length of path travelled by an object in a given time.	It is the shortest distance between the initial and final positions.
It is a scalar quantity	It is a vector quantity.
It depends on the path followed by the object.	It depends o the initial and final positions of the object, but not necessarily on the path followed
It can be more than or equal to the magnitude of displacement	Its magnitude can be less than or equal to the distance.

Exercise

1. What is the distance around a standard football field?

2. Is distance a positive or negative quantity?

Solution

The minimum length of a standard football field is 100 m and the maximum length is 110 m

The minimum width of a standard football field is 64 m and the maximum width is 75 m

Therefore; the minimum distance is: 2* 100+ 2*75= 350 m

The maximum distance = 2*110+2*75 = 370 m

Distance is a positive quantity

Activity 3

Three students walked on a straight line. The first student walked 200 m to the right from a reference point A, then returned and walked 100 m to the left and then stopped. The second student walked 200 m from point A to the right, then returned and walked 300 m to the left and stopped. The third student walked 200 m to the right from point A, then returned and walked 200m to the left and stopped at point A. Discuss in groups about the total distance and displacements of the first, the second and the third student.

Answer: the displacement of the first student is 100 meters to the right of point A. The displacement of the second student is 100 meters to the left of point A.

The third student returned back to his initial position and has zero displacement.

Example 3.1a cyclist rides 3 km west and then turns around and rides 2 km east.

(a) What is her displacement?

(b) What distance does she ride?

(c) What is the magnitude of her displacement?

Solution: To solve this problem, we need to find the difference between the final position and the initial position while taking care to note the direction on the axis.

a) Displacement: The rider's displacement is $\Delta\vec{S} = \vec{S}f - \vec{S}i$ = 2 km east- 3 km west =1 km west. The displacement is negative if we choose east to be positive and west to be negative.

b) Distance: The distance traveled is 3 km + 2 km = 5 km.

c) The magnitude of the displacement is 1 km.

Exercise . What is the displacement if the final position is the same as the initial position?

Answer: if the final and initial positions are the same, the displacement is **zero**

Exercise : Given the following values for the initial position Si and final position S f , check whether the value of the net displacement is positive or negative.

a) S f = (5,0) and Si = (−1,0)

b) S f = (10,0) and Si = (−15,0)

c) S f = (6,0) and Si = (4,0)

As the direction of motion is on the X- axis, the Y coordinate is zero,

Solution: net displacement is the change in the final and initial positions

A) $\Delta\vec{S}$ = positive because $\vec{S}_f > \vec{S}_i$

B) $\Delta\vec{S}$ = negative because $\vec{S}_f = 10$, $S_i = 15$(west)

C) $\Delta\vec{S}$ = Positive because $\vec{S}_f = 6$, $S_i = 4$

3.2 Average Speed and Instantaneous Speed

- Speed is a quantity that describes how fast a body moves.
- Speed is the rate at which an object changes its location.
- Speed is a scalar quantity because it has a magnitude but no direction.
- it depends on the time interval of motion. Its symbol is v.
- speed is the distance covered by a moving body per unit time.

The SI unit of speed is meter per second (m/s). Other units of speed include kilometer per hour (km/h) and miles per hour (mi/h).

The mathematical equation used to calculate speed is:

Speed= distance/ time

V= s/t

Average speed: is defined as the total distance travelled divided by the total time it takes to travel that distance:

Average speed= total distance covered/total time taken

Instantaneous speed: The speed at any specific instant is called the instantaneous speed.

$V_{ins}=\Delta s/\Delta t$ as $\Delta t \rightarrow$

Example

A car covers a distance between two towns which are 80 km apart. If it takes the car 1hr and 30 minutes to travel between the two towns, calculate the average speed of the car in m/s.

Solution:

S= 80 km, t= 1 hr & 30 min = 1.5 hr

V_{av}= s/t = (80 km/1.5 hr) * (1000m/km * 1hr/3600sec)= 14.81 m/s

Example How far does a student walk in 1.5 hrs if her average speed is 5 m/s?

Given;

V_{avg} =5 m/s

t= 1.5 hr =5400 s

solution

v_{avg} =s/t

s= v_{avg}*t = 5 m/s * 5400 s =27000 m

3.3 Average Velocity and Instantaneous Velocity

- Velocity is the rate of change of displacement.
- Its symbol is v (with arrow on the head)
- Its SI unit is m/s

Average velocity is the total displacement of a body over a time interval.

$\vec{v}av=(\vec{S}f-\vec{S}i)/(tf-ti)=\Delta\vec{S}/\Delta t$

Instantaneous velocity of a body is its velocity at any time t.

Exercise Does the average speed the same as the magnitude of the average velocity? Explain.

No, average speed and the magnitude of average velocity are not the same since speed and velocity are not the same. Speed is a scalar while velocity is a vector

Note: For uniform motion, average velocity and the instantaneous velocity are the same

Example a student attained a displacement of 360 m north in 180 s. What was the student's average velocity?

Solution:

Total displacement, $\Delta\vec{S}$ = 360 m north

Total time, Δt = 180 s

$\vec{v}_{av} = \Delta\vec{S}/\Delta t = 360/180 = 2$ m/s north

Example 3.6 A bus moving along a straight line towards west covers the following distances in the given time intervals. Calculate the average velocity of the bus for each time interval.

S in km:	20	60	100	140
t in hour:	0	1	2	3

Solution: By computing the displacement of the bus for each time interval, we can calculate the average velocity of the bus as follows. Between $t_0 = 0$ and $t_1 = 1$ hr

$\Delta\vec{S}_1 = \vec{S}_1 - \vec{S}_0 = 60$ km $- 20$ km $= 40$ km

$\vec{v}_1 = \Delta\vec{S}_1/\Delta t_1 = 40$ km/1 hr $= 40$ km/hr

$\Delta t_2 = 2$ hr- 1hr= 1hr (between $t_2 - t_1$)

$\Delta\vec{S}_2 = \Delta\vec{S}_1 = \vec{S}_2 - \vec{S}_2 = 100$ km $- 60$km $= 40$ km

$\vec{v}_2 = \Delta\vec{S}_2/\Delta t_2 = 40$ km/ 1hr $= 40$ km/hr

between $t_3 = 3$ hr and $t_2 = 2$, $\Delta t_3 = 3-2 = 1$ hr

$\Delta \vec{S}3 = \vec{S}2 - \vec{S}2$ = 140 km −100 km = 40 km

$\vec{v}3 = \Delta \vec{S}3/\Delta t_3$ = 40 km/ 1hr= 40 km/hr

Therefore, for each time interval, the average velocity of the car is constant. This implies that the car is undergoing uniform motion.

3.4 Acceleration

Acceleration is the rate of change of velocity.

It is a vector quantity

Decelerating motion: is a motion when the final velocity of a body is less than the initial velocity.

Deceleration is a negative acceleration
SI unit = m/s^2

$\vec{a}_{av} = (v_f - v_i)/(t_f - t_i)$

a_{av} = average acceleration

v_f= final velocity

v_i= initial velocity

t_f= final time

t_i= initial time

Exercise

If the initial and final velocities of a car are the same, what will be its acceleration?

Is the direction of the acceleration always in the direction of the velocity?

Answer: Zero, because, $v_f = v_i$

No, because it can be in the opposite direction of motion when deceleration (negative acceleration) occurs.

Example A train moving in the east direction accelerates from rest to 36 km/h in 20 s. What is the average acceleration during that time interval?

Given: $\vec{v}_i = 0$, $\vec{v}_f = 36$ km/h, $\Delta t = 20$ s,

Required: $\vec{a}_{av}$=?

Solution

First convert the velocity in to km/s = 36 km/hr = 36km/hr* 1hr/3600s =0.01 km/s

$\vec{a}_{av} = (\vec{v}_f - \vec{v}_I)/\Delta t = (0.01\text{km/s} - 0\text{ km/s})/20\text{ s} = 0.0005\text{km/s}^2 = +0.5\text{ m/s}^2$ east

Note: the plus sign in the answer indicates that the acceleration is to the right. So, acceleration is in the same direction as the change in velocity.

Example 3.8 a car travelling at 7.0 m/s along a straight road accelerates 2.5 m/s 2 to reach a speed of 12.0 m/s. How long does it take for this acceleration to occur?

Given: $v_i = 7.0$ m/s, $v_f = 12.0$ m/s, $a_{av} = 2.5\text{ m/s}^2$

Required: Δt =?

$\Delta t = \Delta v/a_{av} = (12\text{ m/s} - 2.5\text{ m/s})/2.5\text{ m/s}^2 = 2$ s

3.5 Uniform Motion

Uniform motion is the motion of an object along a straight line with a constant velocity or speed in a given direction

In a uniform motion, an object travels equal distances in fixed intervals of time.

3.6 Graphical Representation of Motion

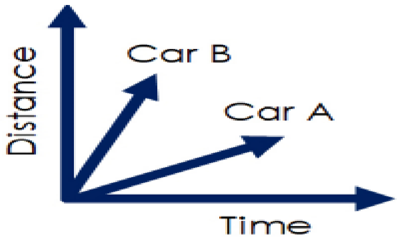
The uniform rectilinear motion has the following properties:

The acceleration is zero (a=0) because neither the magnitude of the velocity nor its direction changes.

On the other hand, the average and instantaneous velocities have the same values at all times.

3.6 Graphical Representation of Motion

Exercise 3.12 Consider the following S-t graph of two cars in motion on a straight line as shown in Figure 3.8. Which car is moving faster and why?



figure

Answer: car B is moving faster because it has steeper slope

The slope of a position-time graph represents the average velocity of an object.

Slope = vertical increase/horizontal increase.

Slope= Δy/Δx

Example: Displacement vs time

Position vs. time	
Time (s)	Position (m)
0	0
1	5
2	10
3	15
4	20
5	25
6	30

Solution:

slope= Δs/Δt, take any two points along the straight line

slope= (5-0)/(1-0) = 5 m/s

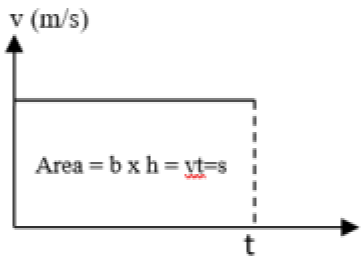
Note: displacement versus time graph represents velocity

Velocity- Time Graph

The slope of a velocity-time graph represents the acceleration of an object
In a uniform motion, the v-t graph is a horizontal line velocity is constant at any given time.
The area under the v-t graph in a uniform motion represents the distance covered by the object.

The slope of a velocity-time graph in a uniform motion is zero

Area = b × h = v t = s, which is equal to the distance covered by the object.



slope = $\Delta v/\Delta t = 0$

Figure

End of Unit Questions and Problems

Part I: Conceptual questions and workout problems

1. How are average velocity and instantaneous velocity related in a uniform motion?

Answer: In uniform motion, velocity is constant. This means that the average and instantaneous velocity is the same.

2. What does the area under velocity against time graph describe in a uniform motion?

Answer: distance

3. If the slope of the graph is zero in a distance against time graph, what can one conclude about the motion of the body?

Answer: the body is at rest

7. A car moves with a steady speed of 60 km/hr for 2 hours between two towns A and B. If the average speed of the car for the round trip is 50 km/hr, then compute the speed of the car when it moves from B to A

Given required: 1. Speed (v) from B to A =?

Speed from A to B = 60 km/hr

Time taken from A to B = 2 hr

Average speed for the round trip = 50 km/hr

Solution:

Distance covered from A to B= 60 km/hr *2 hr= 120 km

Total distance for the round trip =120 km *2= 240km

Total time for the round trip= s/v_{avg} =240 km/ 50 km/hr = 4.8 hr

$V_{BA}= S_{BA}/t_{BA}=$

$S_{BA} = S_{AB}$ = 120 km

$t_{BA}= t_{tot}-t_{AB}$ = 4.8- 2= 2.8 hr

$V_{BA}= S_{BA}/t_{BA}$= 120 km/2.8 = 42.86 hr

10. An airplane lands with an initial velocity of 70.0 m/s and then decelerates at 1.50 m/s^2 for 40 s. what is its final velocity

Given: V_i = 70 m/s

t= 40 s

A = -1.5 m/s^2 (deceleration)

Solution

a= Δv/Δt =(vf-vi)/tf-ti =(vf- 70)/40-0 = -1.5

vf-70 = -60

vf = 10 m/s

12. An athlete swims from the north end to the south end of a 50.0 m pool in 20.0 s and makes the return trip to the starting position in 22.0 s

(a) What is the athlete's average velocity for the first half of the swim?

(b) What is the average velocity of the athlete for the second half of the swim?

(c) What is the athlete's average velocity for the round trip?

Given

displacement north to south = south to north = 50 m

time taken for the north to south trip= 20 s time taken for the south to north trip = 22 s

solution

V_{av} = 50 m/20 s = 2.5 m/s
V_{av}= 50 m/ 22 s = 2.27 m/s
Zero. Because the athlete returns to the same point and thus the displacement is zero and if the displacement is zero the velocity is zero as well

Part II: Multiple choice questions

13. A train is traveling on a straight track at a constant speed. In 80 seconds it covers a distance of 2400 meters. What is the speed of the train?

a) 30 m/s (b) 40 m/s (c) 60 m/s (d) 100 m/s

Given: distance(s) = 2400 m

time(t) = 80 s

required = speed (v)=?

Solution : speed (v) = s/t= 2400 m/80 s =30 m/s

15. A car accelerates from rest to a speed of 20 m/s in 10 seconds. What is the acceleration of the car during this time interval?

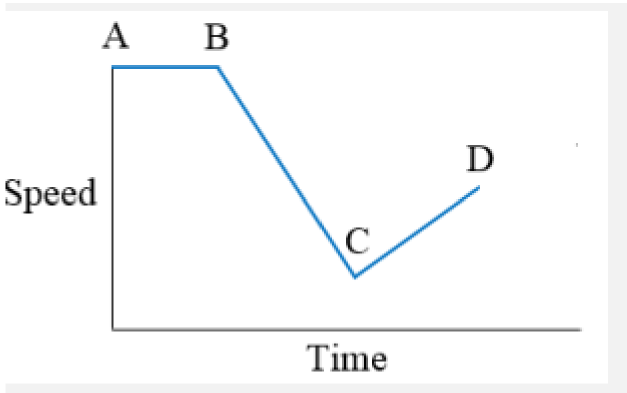
(a) 1m/s^2 (b)2m/s^2 (c) 0.5m/s 2 (d) 5m/s^2

given: Vi =0

ti= 0 solution: aav = (vf – vi)/tf-ti = (20 -0)/(10-0) Vf = 20 m/s

tf = 10 s aav= 2m/s^2

16. The following figure shows the speed versus time graph of a car moving in a straight line. Between which two points is the car experiencing uniform motion?



(a) Between B and C

(b) Between C and D

(c) Between A and B

(d) Between B and C, C and

Solution: in a uniform motion the speed is constant at any intervals of time

Unit 4

Force, Work, Energy and Power

4.1 The Concept of Force

A force is a push or a pull exerted on a body that changes the state of motion of the body

Force can change the velocity of a body or cause deformation by changing its shape or size. It is a vector quantity.
The SI unit of force is Newton and is represented by N

Examples of force: frictional force, normal force and the force of gravity

Contact and Non-Contact Forces

<u>Contact forces:</u>Forces that involve physical contact between objects are called contact forces

Examples:Applied forces, normal forces, frictional forces, and spring force

<u>Non- contact forces:</u>forces that do not involve physical contact between objects are known as non-contact forces.

Examples: magnetic force and gravitational force

Weight: is the magnitude of the gravitational force acting on a body.

Measured in Newton
The gravitational force is directed towards the center of the earth.

4.2 Newton's Laws of Motion

<u>Newton's First Law of Motion</u>: It states that a body continues to be in its state of rest or of uniform motion in a straight line unless it is acted on by unbalanced force

- it is called the law of inertia
- inertia is the tendency of an object to resist any attempt to change its velocity

Mass: is a measure of the resistance of an object to change in its state of motion.

Note: Objects with large masses have large inertia and are more resistant to changes in their state of motion.

<u>Newton's Second Law of Motion</u>: states that the acceleration of a body is directly proportional to the net force acting on it and inversely proportional to the mass of the body.

Newton's second law of motion describes force mathematically as:

Where $\vec{F}$ is the force acting on the body, m is the mass of the body, and $\vec{a}$ is the acceleration when acted on by the force $\vec{F}$.$\vec{F} = m\vec{a}$

1 N = 1kg m/s^2

<u>Gravitational force</u>:(F_g) is the force acted on the falling object

$F_g = m*g$

F_g= gravitational force

m = mass of the object

g = gravitational acceleration

Note: This force is directed towards the center of the earth. Fg is also called weight of the object. Weight of a body is represented by 'W

W = m*g

Example A force of 10N acts on a block of mass 2kg resting on a smooth horizontal surface. What is the acceleration of the block?

Given: F = 10 N, m = 2 kg

Required: The acceleration 'a' of the block

Solution; F = m*a

a= F/m= 10 N / 2 kg = 10 kgm/s^2/2 kg = 5 m/s^2

Example 4.2 a force of 100N acts on a certain object and accelerates it by 2ms/s^2 in the direction of the force. What is the mass of the object? Given: F = 100N, a = 2m/s 2

Required: mass (m)

Solution

F = m*a

a = F/m = 100 N/2 m/s^2 =100 kgm/s^2 /2 m/s^2 = 50kg

Example what is the weight of a body of mass 10kg on the surface of the earth? Given: m = 10kg

Required: weight 'W'

W= m*g = 10kg* 9.8 m/s^2= 98 N

Newton's Third Law of Motion: states that every action has an equal and opposite reaction. The action and reaction forces are equal in magnitude but opposite in direction and they act on different objects.

Action force: is the force you act on the car (F_{12})

Reaction force: is the force the car acts back on you (opposite force) = F_{21}

F_{12}= -F_{21}

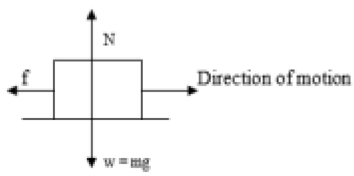
F_{12}= 100 N andF$_{21}$=-100 N

Forces of Friction: is a resistance force acted by a rough surface on the body moving over the surface.

Friction forces are classified in to two

Static friction: is a kind of friction that exists between two surfaces in contact when one body tends to slide over the other without moving. It requires large force to overcome this friction.

Kinetic friction: is the friction between two contacting surfaces when one of them slides over the other or when one body rolls over the other. Its effect on motion is less than that of the static friction



The force of friction is directly proportional to the normal force

4.4 The Concept of Work

Work is the product of a force and the magnitude of displacement in the direction of the force.

Work is a transfer of energy from one object to another through the force.

Force does work on an object when the object is displaced in the direction of the applied force.

Work is a scalar quantity. The SI unit of work is a Newton-meter (N m) which is called Joule (J).

W = F*S

F = force

S= displacement

Example a boy pushed a box by a force of 60 N through a displacement of 12 m on a horizontal surface. How much work is done by the boy? Assume the force is parallel to the direction of displacement of the box.

Given: F = 60 N S = 12 m required = W

Solution: W = F*S = 60 N *12 m = 720 Nm = 720J

Example how much vertical force is required to lift a load vertically to a height of 3 m, if the work done is 600 J?

Given: W = 600JS = 3 m

Solution: W = F*S

$F = W/S = 600\ J/3\ m = 600\ kgm^2/s^2/3\ m = 200\ kgm/s^2 = 200N$

Energy: is the capacity to do work

It is a scalar quantity.
Its S.I unit is Joule (J) similar to that of work.

Kinetic energy

Kinetic energy (E_K) is the form of mechanical energy possessed by an object due to its motion. For example, a rolling ball, a moving car, or a thrown stone possess kinetic energy due to their motion.

The kinetic energy of an object depends on:
Mass
speed

Kinetic energy = 1/2 ×mass× (speed)^2 ⇒ $Ek = 1/2\ mv^2$

Kinetic energy is a scalar quantity and can be described only by its magnitude. Its SI unit is Joule (J) $1J = 1kgm2\ /s^2$

Example A 200 g ball is thrown at a speed of 20 m/s. What is the kinetic energy of the ball?
Given: m = 200g, v = 20m/s required :E_K

Solution: $E_K = ½ * 0.2kg *(20m/s)^2 = 40kgm^2/s^2 = 40J$

Exercise 4.5

For a fixed speed, if the mass of the ball is doubled, what will be its kinetic energy?

2. For a fixed mass, if the speed of the ball is doubled, what will be its kinetic energy?

3. For a fixed mass, if the speed of the ball is tripled (3 times), what will be its kinetic energy?

Solution:

$E_{K1} = 1/2\ mv^2$, if the mass is doubled$m_2 = 2m_1$, $m_1 = m$

$E_{K2} = 1/2\ (2m_1)v^2 = 2(1/2mv^2) = 2E_K$

So, the kinetic energy will be doubled.

$E_{K1} = 1/2mv^2$, if the speed is doubled, $v_2 = 2v$
$E_{K2} = 1/2m(2v)^2 = 1/2m(4v^2) = 4\,(1/2mv^2) = 4E_K$

So, the kinetic energy will be quadrupled

If the speed is tripled,(3 times), the kinetic energy will be nine times

Example 4.7 How fast must a 1 kg ball move in order to have a kinetic energy of 50 J?

$E_K = 1/2mv^2$

$50J = ½*1kg*v^2$

$V^2 = 2*50kgm^2/s^2/1kg = 100m^2/s^2$

$V = \sqrt[2]{100} = 10m/s$

Gravitational Potential Energy

Potential energy is the stored energy in an object by a virtue of its position or its configuration. There are two types of potential energy

Gravitational potential energy
Elastic potential energy
<u>Gravitational potential energy</u>: is the energy of an object held in a vertical position due to the force of gravity working to pull it down. The gravitational potential energy depends the height and mass of an object.
The heavier the object and higher it is above the ground, the more potential energy it holds.

EP = mass* gravitational acceleration* height $\Rightarrow E_p = mgh$

Exercise 4.7

1. Object A has twice the mass of object B. If object B is 4 m above the floor and object A is 2 m above the floor, which one has greater potential energy?

2. If both objects in the question above were lowered by 1 m, would they still have the same ratio of potential energies that they had in their original positions? Explain your reasoning

1. Given: h_A = 2m, h_B = 4m , m_A = $2m_B$, h_B=4m

Solution: E_{PA}= m_Agh_A= $2m_Bg$(2m) =($4m_Bg$) m

E_{PB} = m_Bgh_B = m_Bg(4m) =($4m_Bg$) m

Object A and object B have the same potential energy (E_{pA} = E_{PB})

Given: m_A = $2m_B$, h_A =1m, h_B = 3m
Solution:
E_{PA} = m_Agh_A = $2m_Bg$(1m) = ($2m_Bg$) m
E_{PB} =m_Bgh_B = m_Bg(3m) = ($3m_Bg$) m

Potential energy of object B is greater than object A (E_{PA}> E_{PA})

Example 4.9 how high should an object of mass 5 kg be lifted in order to have energy of 1000 J? (Use the acceleration due to gravity g = 10 m/s^2)

Given: m = 5 kg ,Ep = 1000 J, g = 10 m/s 2 Required: h =?

E_P= mgh

h=E_P/mg = 1000 kgm^2/s^2/5kg*10m/s^2 = 20m

The sum of kinetic and potential energies is known as Mechanical energy. Thus, we can express mechanical energy as: Mechanical Energy = Kinetic Energy + Potential Energy

4.6 Power

Power is the rate at which work is done or the rate at which energy is being transferred

Power= $\frac{\text{work done}}{\text{time taken}}$= $\frac{\text{energy transferred}}{\text{time taken}}$

$$P = \frac{W}{t} = \frac{E}{t}$$

Power is a scalar quantity like work and energy.
The SI unit of power is J/s (Joule/second) which is called watt (W).
1 w is the power developed when one Joule (1J) of energy is transferred in one second (1 s).

1 W = 1J/s

Example 4.10If a car used up to 1500 J of energy in 5 seconds, what is the power developed by the car

Given: E = 1500J, t = 5s

Solution: P= E/t = 1500j/5s = 300J/s = 300W

Example What is the power of a water pump that can lift 500 liters of water through a vertical height of 10 meter in 5 seconds (Take g = 10 m/s 2)? .

Given: Volume(v) =500 liter = 0.5 m^3 , t= 5 s, h= 10m, density(water)= 1000kg/m^3

Solution: m = density* volume =0.5m^3* 1000kg/m^3 = 500kg

$P= E_P/t = mgh/t = (500kg*10m/s^2*10m)/5s= 10J/s =10kw$

End of Unit Questions and Problems

Part I: Short answer questions

3. What are the action and reaction forces involved when you walk on a surface?

Answer:. If you take the force that your feet exert on the surface as an action force, the reaction force is the force that the surface exerts back on your feet

6. A certain force F accelerates a 25 kg object by 4m/s^2. Calculate the magnitude of the force F.

Given: m= 25kg, a= 4m/s^2required: F

F= m*a = 25kg*4m/s^2 = 100N

What is the weight of a 250 kg object on the surface of the moon? Theacceleration due to gravity on the surface of the moon is one-sixth of that on the surface of the earth.

Given: m= 250kg, $g_{moon} = 1/6(g_{earth}) = 1/6(9.8m/s^2)=1.6m/s^2$

Required= weight(w)

$W= mg_{moon} = 250kg*1.6m/s^2= 400N$

Part II: Multiple choice questions

1. Which of the following units belongs to work?

A. kg m/s^2

B. N/m
C. kg m^2/s^2
D. N/m2
2. A box is pulled from point A to point B by a force of 10 N. If the distance between the points is 6 m, what is the work done?
A. 6 J
B. 10 J
C. 60 J
D. 100 J
3. Which one of the following objects DOES NOT have gravitational potential energy?
A A bottle on the surface of a table
B. A ball on the level ground
C A stone on the roof of a house
D. A fruit on a branch of a tree

4. A loader lifts a 500 kg stone at a height of 8 m in 2 seconds. The power developed by the loader is (take g = $10 m/s^2$)

A. 5000 W
B. 20000 W
C. 40000 W
D. 80 000 W
P= $mgh/t = (500kg*10m/s^2 *8m)/2\ s = 20000W$
Part III: Workout Problems
1. A physics student does a work on a 2.5 kg curling stone by exerting 50 N of force horizontally over a distance of 2 m. Calculate the work done by the student on the curling stone.
Given: m = 2.5 kg, F= 50 N, s=2 m
Required: work(W)=?
Solution: w = F *S = 50 N *2 m = 100 Nm =100J

2. Calculate the kinetic energy of the following objects.

(a) A man weighing 50 kg running at a speed of 20 m/s

(b) A 200 g of bullet fired at a speed of 300 m/s

(c) A car of mass 1000 kg travelling at 80 meter per second

Answers:

Given: m= 50kg, v_f =20m/s, required: k_E =?

Solution: $k_E = ½*mv^2$ =1/2*50kg*(20m/s)^2= 10000kgm^2/s^2=10KJ

Given: 200g =0.2kg, v=300m/s, required: k_E =?

K_E = ½*m*v^2 = ½*0.2kg*(300m/s)^2 = 9000kgm^2/s^2= 9kJ

Given: m =1000kg, v= 80m/s, required: k_E=?
K_E = ½*m*v^2 = ½*1000kg*(80m/s)^2 = 3200000kgm^2/s^2 =3200KJ= 3.2MJ

3. Calculate:

(a) The potential energy of 10 kg stone placed at a height of 10 m above the ground.

(b) The position of the 10 kg stone if it possesses a potential energy of 400 J.

Given: m= 10kg, h= 10m. g= 9.8m/s, required: E_P =?
Solution: E_P = mgh = 10kg*9.8m/s^2*10m= 980kgm^2/s^2=980J
E_P= mgh….solve for 'h'
h=E_P/mg = (400kgm^2/s^2)/(10kg*9.8m/s^2)= 4.08m
A crane is capable of doing 1.5×105 J of work in 10 seconds. What is the power of the crane in watts?

Given: work (W) =1.5*10^{5}J, t =10s, required: power(P) =?

Solution: P =W/t =1.5*10^{5}J/10s = 1.5*10^4 w =15kw

Unit 5

Simple Machines

Simple Machines and their Purposes:

Definitions:

- Simple machine is any device which helps us to do work more easily.
- A simple machine is a device that requires a single force to do mechanical work.
- Simple machines are energy transferring devices. Actually machines do not create energy or change one form of energy into another. They simply transfer mechanical energy involving a small force into mechanical energy involving a large force.

The purpose of simple machines is to make mechanical work easier by:

- **Changing the direction of force**: When you raise a flag on a flagpole you pull down on a rope wrapped around a pulley to raise the flag up.
- **Changing the distance of effort (to multiply speed or distance):** Imagine you need to move a heavy box up to the second floor of a building. It would be easier to carry it up an inclined plane (like a set of stairs) than to throw it straight up. But as you move the box up the stairs, it travels a longer distance than if you threw it straight up.
- **Changing the strength of a force (to multiply force) :** You can apply a weak force to pull the bottle opener up over a long distance and it exerts a short but strong force on the bottle cap.

Exercise

What is the purpose of using a fixed single pulley to take water from a deep well?

Answer: to change the direction of force

What is the purpose of using an inclined plane to raise different objects in the truck?

Answer: to multiply force

What is the purpose of using a bicycle instead of walking or running on feet?

Answer: to multiply the speed

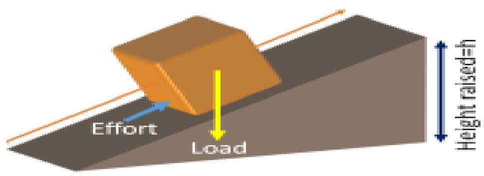
Effort (F): is the force exerted on a simple machine (a fixed pulley, an inclined plane, etc.) or a compound machine (e.g. a bicycle) by an external body like a human being.

Work input = effort×distance moved by effort

Load (L): is a force exerted by a simple machine (a fixed pulley, an inclined plane, etc.) or a compound machine (e.g. a bicycle) on an object to be lifted or moved. A machine also provides a work output; this may be used to move a load.

Work output = load×distance moved by load

In an inclined plane a small effort is used to lift the heavy load. Hence the inclined plane is used to multiply a force. In other words, it is a force multiplier



inclined plane

5.2 Classification of Simple Machines

Simple machines are categorized into two groups:

Inclined planes
Ramp or inclined plane
Wedge
screw
Levers
- Lever
- Wheel & Axle
- Pulley

Note: Every simple machine will fit into one or more of the following categories.

1. Force multipliers: these are simple machines designed so that the load is greater than the effort. This is only possible if the load moves through a smaller distance than the effort.

2. Speed multipliers: these are simple machines designed so that the distance moved by the load is greater than the distance moved by the effort in the same time.

Direction changers: these are machines designed so that the load is moved in different direction to the effort

5.3 Mechanical Advantage, Velocity Ratio and Efficiency of Simple Machine

Mechanical Advantage (M.A)

Mechanical advantage: the ratio of the load and the effort.

Note: . When a machine turns a small input force into a larger output force, we say that the machine gives us a mechanical advantage

Mechanical advantage (M.A) = Output force /input force = load/ effort

Exercise

Explain about the mechanical advantage of a simple machine.

Answer: the ratio of output force to input force is called the mechanical advantage of a simple machine.

What is the actual mechanical advantage?

Answer: The actual mechanical advantage is the ratio of output force to input force.

$(MA)actual = F_L/F_E$

3. What is the ideal mechanical advantage?

The ideal machine transfers all the energy, so the output work is equal to the input work.
WO = WI

$Wo = F_L*S_L$, $Wi = F_E*S_E$

$MA = F_L/F_E = S_E/S_L$

Exercise The hammer produces an output force 15 times greater than the force you apply to it (the input force). What is the mechanical advantage of hammer?

Given: FL = 15FE

Solution: MA = FL/FE = 15FE/FE =15

Note: Machines with a mechanical advantage greater than 1 are force multipliers because the load is greater than the effort.

There are two kinds of mechanical advantages.

- Actual mechanical advantage (AMA)
- Ideal mechanical advantage (IMA)

Actual mechanical advantage: compares the force you get out (load) with what you put in (effort).

Ideal mechanical advantage: is the mechanical advantage if there were no energy losses (e.g. no losses due to friction etc.).

Exercise 5.6

Complete the following table

Load (N)	M.A	Effort (N)
	3	600
40		160
	0.5	480
900	0.3	
2000		500

Use the formula: MA= FL/FE, and find the required

Load(F_L)	MA	Effort (F_E)
1080	3	600
40	0.25	160
240	0.5	480
900	0.3	3000
2000	4	500

Velocity Ratio (V.R): The term velocity ratio describes the ratio of the distance moved by the effort to the distance moved by the load.

$$V.R = S_E/S_L$$

Velocity ratio has no units. If the V.R is 3 then the effort has to move three times as far as the load. i.e $S_E = 3S_L$

Similarly if the V.R is 0.5 then the effort moves half as far as the load (or the load moves twice as far as the effort. i.e = $S_L = 2S_E$

Exercise 5.7: Velocity ratios

Complete the following table

Distance moved by effort	V.R	Distance moved by the load
0.2	4	
0.8		2
6	0.6	
	0.3	6
12	2	

Distance moved by effort	V.R	Distance moved by load
0.2	4	0.05
0.8	0.4	2
6	0.6	10
1.8	0.3	6
12	2	6

use the equation $V.R = S_E/S_L$

Exercise What is the purpose of a machine if:

1. V.R < 1 ?

2. V.R > 1 ?

Solution:

1. If V.R < 1, the distance moved by the load is greater than the distance moved by the effort. So the simple machine is a distance multiplier or a speed multiplier.

2. If V.R > 1, the distance moved by the load is less than the distance moved by the effort. So the simple machine is a force multiplier.

Efficiency of Machines : Describes how good a machine is at transferring the input energy to useful output energy.

Efficiency is the ratio of power output to power input.

Efficiency (η) is the ratio between the work output and the work input.
It is expressed as percentage by multiplying by 100.

Note: There is no a machine that can produce more work than the amount of work that is put into a machine. Machines waste energy due to friction between their moving parts. As the result the efficiency of a machine is less than one.
Examples: turbine, compressors etc…

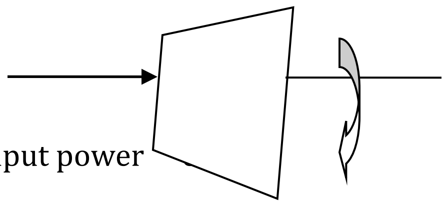


fig1. Turbine (fluid machine)
When a machine provides an increase in force, there must always be a decrease in the distance the force moves.

Efficiency (η) = $\frac{Power\ output}{power\ input} = \frac{work\ output}{work\ input}$

Efficiency can also be expressed in terms of M.A and V.R.

Efficiency (η) = $\frac{Work\ outpout}{Work\ input} = \frac{Load*distance\ moved\ by\ load}{Effort*distance\ moved\ by\ effort}$

Where;

Load/effort = M.A,

Distance moved by load/ distance moved by effort = 1/V.R

$\eta = \frac{MA}{V.R}$

Example

A simple machine provides a work output 80 J for every 400 J of work input.

a) What is the efficiency of a simple machine?

b) What will be the work output of this simple machine if 2000 J of work goes to a machine?

Solution:

Given: work input =400J required: η =?
work output = 80J

solution: $\eta = \frac{Work\ outpout}{Work\ input}$ = 80J/400j = 0.2 = 20%

Given: Work input = 2000J required: work output=?

η = 20%

solution: $\eta = \frac{Work\ outpout}{Work\ input}$

work output = η*work input = 0.2*2000J = 400J

Exercise

The efficiency of a machine is 0.75 (or 75%). What is the physical meaning of this statement?

Solution: η = 75% means, 75% of the work input to the machine is obtained as a useful work output. The remaining 25% of the work input has been lost in overcoming the friction.

Exercise

1. What is the efficiency of a machine with M.A = 3 and V.R = 6?

Solution: $\eta=\frac{M.A}{V.R}$ = 3/6*100%= 50%

What you conclude if M.A = V.R? Write your conclusion in a piece of paper and present it to the whole class.
Solution: if M.A=V.R, then η=1, this means the machine is 100% efficient and it converts the work input to the machine completely to work output and there is no energy loss due to friction.

Levers

The term lever originates in France, 'levier' means 'to raise'. Lever is a rigid bar of a wood or metal which is free to turn about the supporting point which is called fulcrum (F). Lever also consists of effort point (E), load point (L) and fulcrum (F).

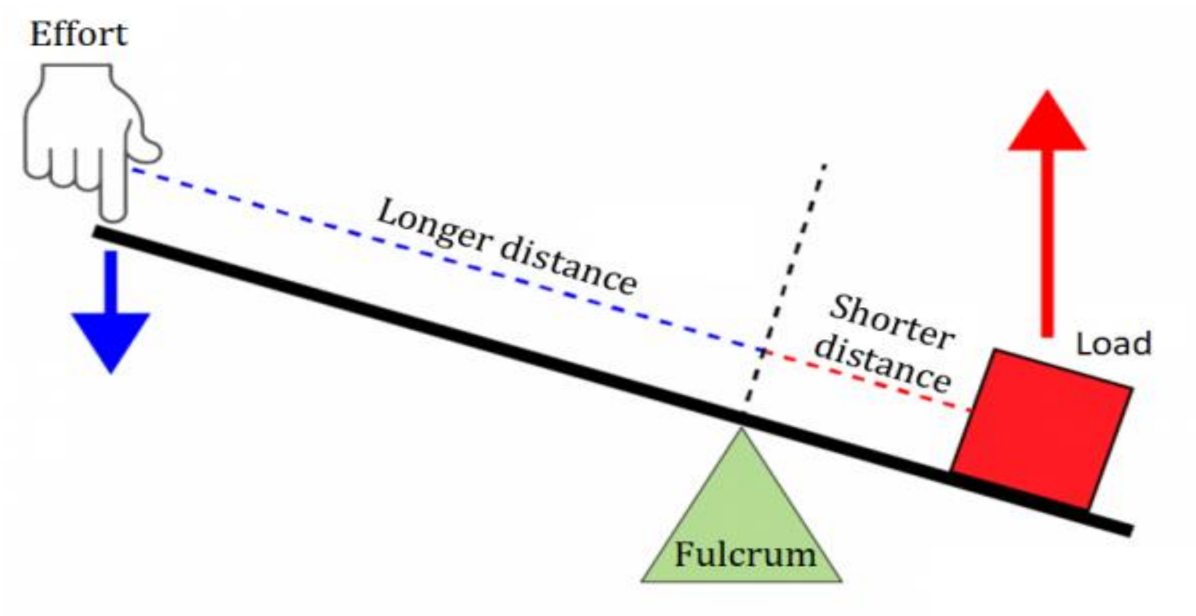


Figure 5.11 Feature of lever.

Lever consists of three parts namely: effort point (E), load point (L) and fulcrum (F). Fulcrum: the pivot point of a lever.

Load arm: the part of the lever that extends from the fulcrum to the mass being moved.

Effort arm: the part of the lever that extends from the fulcrum to where the force is applied.

Different Classes of Levers

There are three different classes of levers depending on the relative position of fulcrum.

1. **First-Class Lever**:

The fulcrum is always located between the load and the effort.

Examples: seesaw, scissors, a crow bar.

IMA can be greater than one, equal to one, or less than one.

2. **Second class lever**: the load is placed between the fulcrum and the effort.

Example: wheelbarrow

3. **Third class lever**: the effort is applied between the fulcrum and the load.

Examples of third class levers are: a fishing pole, a pair of tweezers, an arm lifting a weight, a pair of calipers, a person using a broom, a hockey stick, a tennis racket, a spade, or a shovel.

IMA is always less than one.

M.A, V.R, and Efficiency of Levers

The mechanical advantage of lever is the ratio of load to effort

M.A $= \frac{Load}{Effort} = F_L/F_E$

Note: in levers the forces are **turning** rather than **moving**. Therefore; the equation for V.R is somehow different. As a system is rotating, we do not use the distance moved by the force.

$V.R = \frac{\text{Distance from the effort to the fulcrum}}{\text{Distance from the load to the fulcrum}} = d_E/d_L$

Note: If there are no energy losses, the ideal mechanical advantage is equal to the velocity ratio.

IMA = V.R = d_E/d_L

Example

A load of 200 N is lifted by applying a force of 80 N on the lever. If the load is 10 cm from the fulcrum and the effort is 40 cm from the fulcrum, calculate:

a) The V.R of the lever

b) The M.A of the lever

c) Efficiency

Given: Load (F_L) = 200 d_L = 10cm

Effort (F_E) = 80 d_E = 40cm

Solution:

V.R = d_E / d_L = 40cm/10cm = 4
M.A = 200N/80N = 2.5
η = M.A/V.R = 2.5/4*100% = 62.5%

Inclined Plane, Wedge and Screw

Inclined Plane

- It is a sloping surface that connects two points together.
- An inclined plane is another name for a ramp.
- A screw and a wedge are made up of two inclined planes.
- The longer the distance of the ramp, the easier it is to do the work, however, it takes a much longer time to do the work. An inclined plane is another name for a ramp. The object is lifted to a height h by sliding it up the length of the slope l.

$$M.A = \frac{Load}{Effort} = \frac{L}{E}$$

$$V.R = \frac{Distance\ moved\ by\ effort}{Distance\ moved\ by\ load} = \frac{Length\ of\ inclined\ surface}{height\ of\ inclined\ plane} = l/h$$

Exercise 5.12

1. Calculate the velocity ratio (V.R) of:

(a) A slope of length 30 m that raises an object to a height of 5 m.

(b) A slope that makes an angle of 37^0 to the horizontal and raises an object to a height of 60 m.

2. A slope of length 40 m raises an object to a height of 8 m above the ground. An effort of 80 N is needed to push a 240 N object up the inclined plane.

Calculate: (a) M.A

(b) V.R

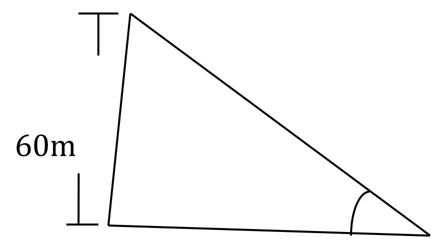
(c) Efficiency

Solution

1)

a) V.R = l/h = 30m/5m= 6

b)



$\sin(\varnothing) = \frac{opposite}{hypotnus}$,

opposite = h= 60m

Hypotenuse = l =?

$\varnothing = 37^0$

Sin $(37^0) = h/l = 60m/l$

$0.6 = 60m/l$

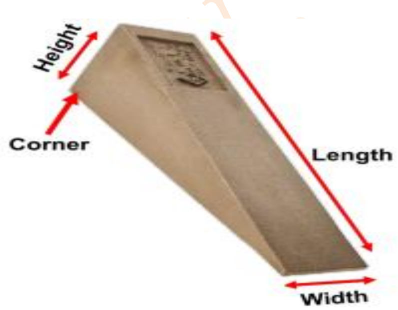
l= 60m/0.6 = 100m

V.R = l/h = 100m/60m = 1.66

2) Solution: M.A= L/E = 240N/80N = 3

V.R =l/h = 40m/8m = 5

η = M.A/V.R = 3/5*100% =60%

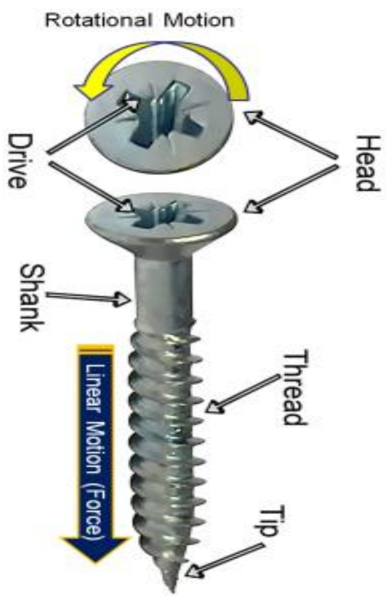


<u>Wedge</u>: Wedges are used to separate two objects or split objects apart. Examples of wedges include knives, nails, axes and spears.

M.A = $\frac{Load}{Effort} = \frac{L}{E}$

The velocity ratio of a wedge is the ratio of the penetration length (l) of a wedge and the thickness of the wedge (t)

V.R = $\frac{Penetration\ length}{thickness}$ = l/t



η= M.A/V.R = $\frac{L*t}{E*l}$

Screw: The term screw refers to any cylinder with helical thread around it. It includes nuts and bolts. It is used to hold objects together, to dig into the ground and to bore through rocks.

pitch (p): is a separation distance between the threads in one turn of the screw

length: is equal to the circumference of the screw shaft

M.A =$2\pi r/p = \pi d/p$,

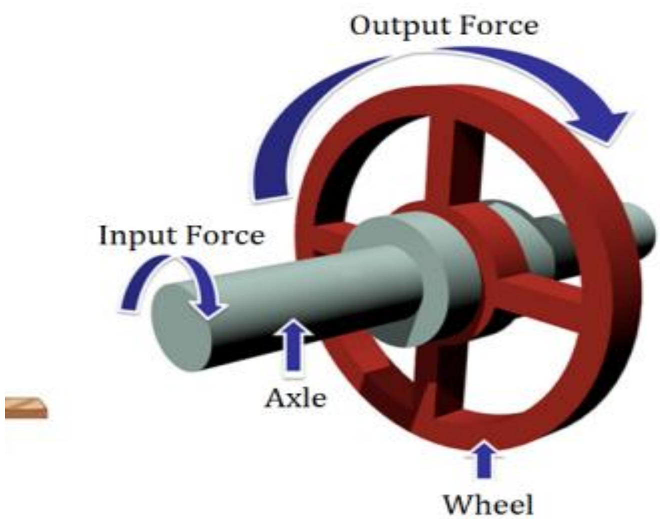
r= radius of the screw shaft

d= diameter = 2*r

M.A= $\pi d/P$

Wheel and axle: is comprised of a large wheel secured to a smaller wheel which is called an axle.

The input force is used to turn the wheel and the output force is exerted by the axle. Because the wheel is larger than the axle, the mechanical advantage is greater than one. So the output force is greater than the input force
A wheel with a rod, called an axle, through its center lifts or moves loads.
The axle is a rod that goes through the wheel. This lets the wheel turn.
The wheel and axle can be used as a tool to multiply the force you apply or to multiply the distance traveled



There are two basic types of wheel and axle in simple machines.

1. **A machine where the force is applied to the axle**. Applying a large force to the axle makes the wheel go faster. The mechanical advantage is less than one and the output force is less than the input force. Everyday examples of this type of wheel and axle include:

• Bicycle • Car tires • Electric fan

2. **A machine where the force is applied to the wheel**. When you apply a small force to the wheel, it travels a longer distance and creates a stronger force on the axle. In this method the effort (input force) has to move a long distance, whereas the load (output force) moves a small distance. This is because the circumference of the wheel is much larger than the circumference of the axle. This is helpful to lift large loads. Everyday examples of this type of wheel and axle include:

• Screwdriver • Drill • Windmill • Water wheel • Doorknob • skateboard

AMA $=\frac{L}{E}$

V.R $= \frac{Distance\ moved\ by\ the\ effort}{distance\ moved\ by\ the\ load} = \frac{R}{r}$

R = radius of the wheel

r = radius of the axle

If there is no energy losses, V.R = M.A = I M A = $\frac{R}{r}$

Exercise 5.15

The diameter of the wheel is 20 times greater than the diameter of the axle. What is the mechanical advantage of this wheel and axle system?

Given: $R_{Wheel} = 20r_{axel}$

Solution: M.A = $R_{Wheel}/r_{axel} = 20r_{axel}/r_{axel} = 20$

The pulley system

There are different kinds of pulleys.

They are: 1. Fixed pulley 2. Movable pulley 3. Compound pulley

Pulley: is a circular body (wheel) with groove surface and is free to rotate about its center

fixed pulley: comprises a fixed axle with the rope looped over the top.

A fixed pulley is used to change the direction of the force.

The advantage of the fixed pulley is that no need to pull or push the pulley up and down.

The disadvantage is the effort is greater than the load

fixed pulley

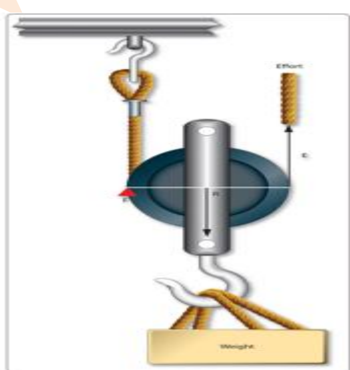
Movable pulley: Is a pulley where the axle is free to move up and down.

Applying an effort to the other end of the rope will effectively provide about 2 times a force.

A movable pulley has a V.R = 2. That is in order to lift the load 1m you would have to pull 2 m of the rope through the pulley.

The main disadvantage of a movable pulley is that you have to pull or push the pulley up or down.

The main advantage of a movable pulley is that you use less effort to pull the load



Movable pulley

Note: for both fixed and movable pulley, the M.A is less than the velocity ratio due to the presence of friction. i.e M.A < V.R

compound pulley: is the combination of a fixed and a movable pulley. This is sometimes called a block and tackle.

The main advantage of this pulley is that the amount of effort is less than half of the load.
The main disadvantage is it travels a very long distance.
M.A, IMA&V.R of a pulley

AMA=load/effort and V.R = IMA= N (number of sections of ropes used to lift the load)

End of Unit Questions and Problems Part I:

Multiple choices

1. Which one is NOT correct about simple machine?

a) Machines help us to make work easier

b) Machines create energy to help us

c) Machines act as force multipliers

d) Machines act as speed multipliers

2. Which one of the following is the purpose of a simple machine?

a) Increasing volume

b) Changing mass

c) Multiplying energy

d) Multiplying force

3. If a machine raises a load to height of 8 m when effort is moved by 2m, then the machine is

a) Distance multiplier

b) Force multiplier

c) Both force and speed multiplier

d) Direction changer

4. An effort of 30 N is applied on a machine to raise a load of 150 N. By how much does the machine multiply the force?

a) 3 b) 5 c) 7 d) 95.

5. A machine used 50 N effort through a distance of 8 m in order to lift a load of 100 N through a distance of 4 m. What is the efficiency of the machine?

a) 70% b) 80% c) 90% d) 100%

Solution M.A = Load/Effort = 100N/50N =2

V.R = S_E/S_L = 8m/4m = 2

η = M.A/V.R = 2/2*100% = 100%

Part II: II. Write true if the statement is correct and false if the statement is wrong.

1. In real world there is a machine which is 100% efficient. False

2. Efficiency is the ratio of work input to work output. False

3. A fixed pulley is used to multiply a force. False

4. Wedge is a double inclined plane. True

5. The separation between each thread in the screw is known as a pitch. True

Part III: Work out

A simple wheel and axle is used to lift the bucket of water out of a well. The radii of the wheel and axle are 30 cm and 5 cm respectively.
Determine:
a) The velocity ratio
b) The effort required to lift a load of 40 N assuming no energy losses.
c) The efficiency if the actual effort required is 20 N

Given: R_{wheel} =30cm , r_{axel} = 5cm required =V.R =?

Solution: V.R =: R_{wheel}/ r_{axel} = 30cm/5cm = 6

Given: load(L) =40N, required: effort(E)

If there is no energy loss, then M.A=V.R

Load/effort = S_E/S_L = L/E = 6

E =L/V.R = 40N/6 = 6.67N

Given: effort(E) = 20N , V.R = 6, load(L) = 40N

η= M.A/V.R

M.A = L/E = 40N/20N = 2

η= M.A/V.R =2/6*100% = 33.33%

2. A block of weight 6000 N is pushed up the slope by a force of 300 N. Assume there is no energy losses. Determine:

a) The actual mechanical advantage

b) The velocity ratio

c) The length of the slope if the height of the slope is 10 m

Given: Load = 600N, Effort= 300N

Solution:

AM.A= load/effort = 6000N/300N = 20
Since there is energy loss, V.R=AM.A = 20
V.R = *l/h,*
20N= l/10m, l= 20*10m =200m

3. A 12 cm long and a 3 cm wide wooden wedge is pushed into a soft wood block. Calculate:

a) The velocity ratio of the wedge. b) The load on the soft wood if the effort applied is 20 N (assume there is no energy losses).

Given: length (l) =12cm, thickness (t) = 3cm

Solution:
V.R = l/t = 12cm/3cm = 4
AM.A = V.R = 4 (No energy loss)
AM.A = 4 =F_L/F_E
= F_L/20N, F_L = 4*20N = 80N
What is the mechanical advantage of a lever that can lift 100 N load with an input force of 20 N?
Given: F_E= 20N, F_L= 100N
Solution: M.A = F_L/ F_E= 100N/20N =5

5. A single movable pulley is being used to move a 140 N load. The pulley is a little dirty, so it adds another 5 N of frictional force. a) Can this load be moved with a 75 N input force? Explain your answer. b) Would a single fixed pulley work? Explain your answer.

Given: The total load= 140 N (Actual weight) + 5 N (d i r t on pulley) ⇒FL = 145 N

F E = 75 N

a) Yes, the load can be moved by a movable pulley because the movable pulley multiplies the applied force twice.

b) No, the fixed pulley changes only the direction and it is impossible to lift 145 N load by applying a 75 N force i.e. for fixed pulley the effort is greater than the load

Part IV:

Short answer questions

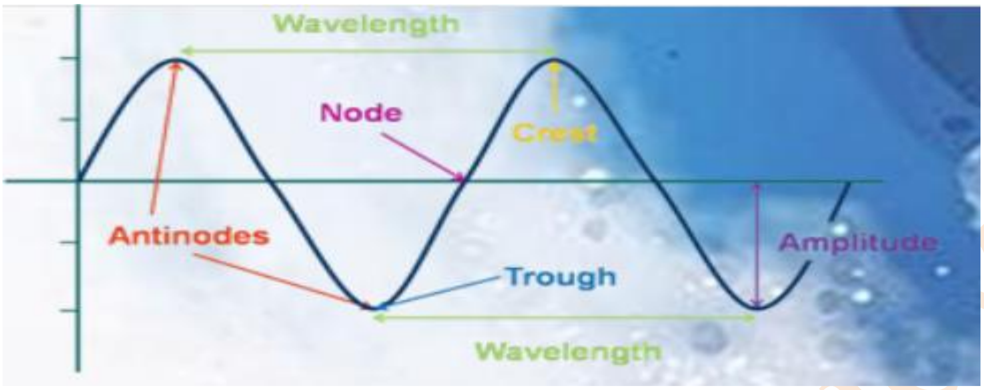
List six types of simple machines

Answer: (inclined plane, wedge, screw, lever, wheel and axle, and pulley)

For every simple machine AMA< IMA. Why? Explain it.
AM.A < IM.A. This is because there are energy losses due to friction in real application of simple machines.

Unit 6

6.1 Mechanical Oscillation and Sound Wave



Oscillation: is the movement of particles back and forth about a fixed point.

Wave: is a disturbance that moves from its source accompanied by transfer of energy

Common characteristics of waves

Rest position: Rest position is the undisturbed position of particles or fields when they are not vibrating.

Displacement: Displacement is the distance that a certain point in the medium has moved from its rest position.

Trough: Trough is the lowest point below the rest position. Crest: Crest is the highest point above the rest position.

Period (T): Period, denoted by symbol T, is the time for one complete cycle of the periodic motion. It is also defined as the time taken for one complete wave to pass a given point

Frequency (f): Frequency, denoted by symbol f, of a wave is defined as the number of complete waves passing a given point per unit time. The higher the frequency, the greater the number of waves per second. A common unit for frequency is one cycle per second. This is defined as one Hertz (Hz). 1Hz=1 cycle/s.

Amplitude (A): Amplitude is defined as the maximum displacement from equilibrium position. Amplitude is denoted by the symbol A and measured in meters (m).

Wave speed (v): Wave speed is defined as the distance the wave travels in one second. It is denoted by the symbol v and like all speeds it is measured in meter per second.

Wavelength (λ): Wavelength is defined as the distance between identical points on adjacent waves. For example, the distance between two adjacent crests or troughs of a wave is one wavelength. Wavelength is denoted by Greek letter λ (lambda).

$f = 1/T$ or $T = 1/f$

In terms of wavelength and frequency, wave speed can be written as,

wave speed = frequecy×wavelength ⇒ $v = \lambda \times f$

6.2 String, Pendulum and spring

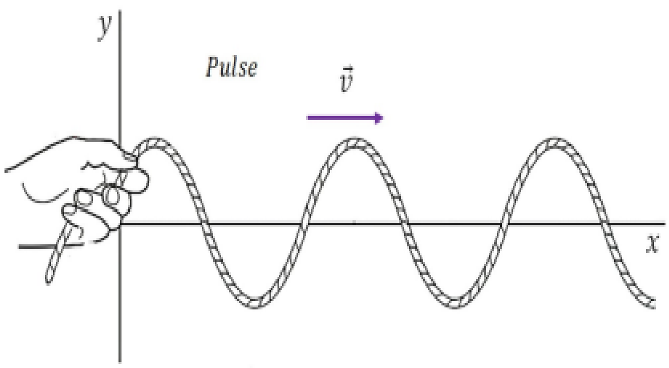


Figure: string wave

The pulse moves horizontally along the string
Particles of the string moves up and down at right angles to the horizontal motion of the pulse (wave).

Periodic motion: A motion that repeats itself over and over is referred to as periodic motion.

Examples: The beating of your heart, the ticking of a clock, and the movement of a child on a swing and simple pendulum

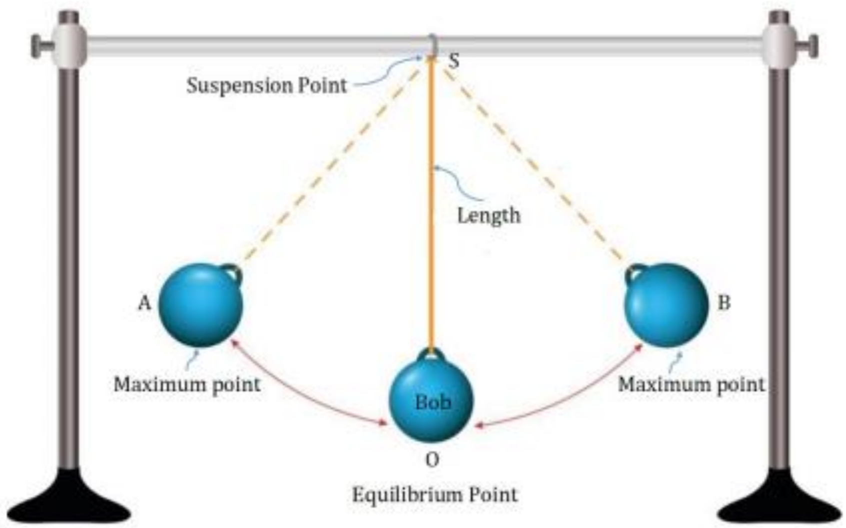


Figure: simple pendulum

Note: If the pendulum is displaced from equilibrium, it swings back and forth, and its motion is periodic

T = $2\pi\sqrt{l/g}$

Note: the period of pendulum is dependent on the length and gravity

L: is the length of the simple pendulum

g: is the acceleration due to gravity

Example 6.1

What is the period of a simple pendulum with length 50 cm? Use the acceleration due to gravity g = 9.8m/s 2

Given: L = 50 cm = 0.5m, g = 9.8m/s 2

Required: T =?

Solution: T= = $2\pi\sqrt{l/g}$ =$2\pi\sqrt{(0.5m/9.8m/s^2)}$ =$2\pi\sqrt{\frac{5}{(49*2)}}$ s =$\frac{2\pi}{7}*\sqrt{\frac{5}{2}}$ s $\frac{2*3.14}{7}$=*1.58 s

=1.42s

Example

A simple pendulum has a length of 100 cm and oscillates periodically with a period of 0.65π s at a certain place. What is the value of the acceleration due to gravity at that place?

Given: L = 100 cm = 1m, T = 0.65π Required: T =?

Solution: $T = 2\pi\sqrt{l/g}$

0.65π s = 2 $\pi\sqrt{1m/g}$ ....square both sides

$0.4225\ \pi^2\ s^2 = 4\ \pi^2 m/g$

$g == 4\ \pi^2 m/0.4225\ \pi^2\ s^2 = 9.47\ m/s^2$

The simple spring

Restoring force: the force exerted by the spring to return to its equilibrium position(x=0)

$F_{rest} = -k*x$

F_{rest}= restoration force

K = proportionality constant called spring constant or stiffness of the string

X= displacement of the spring

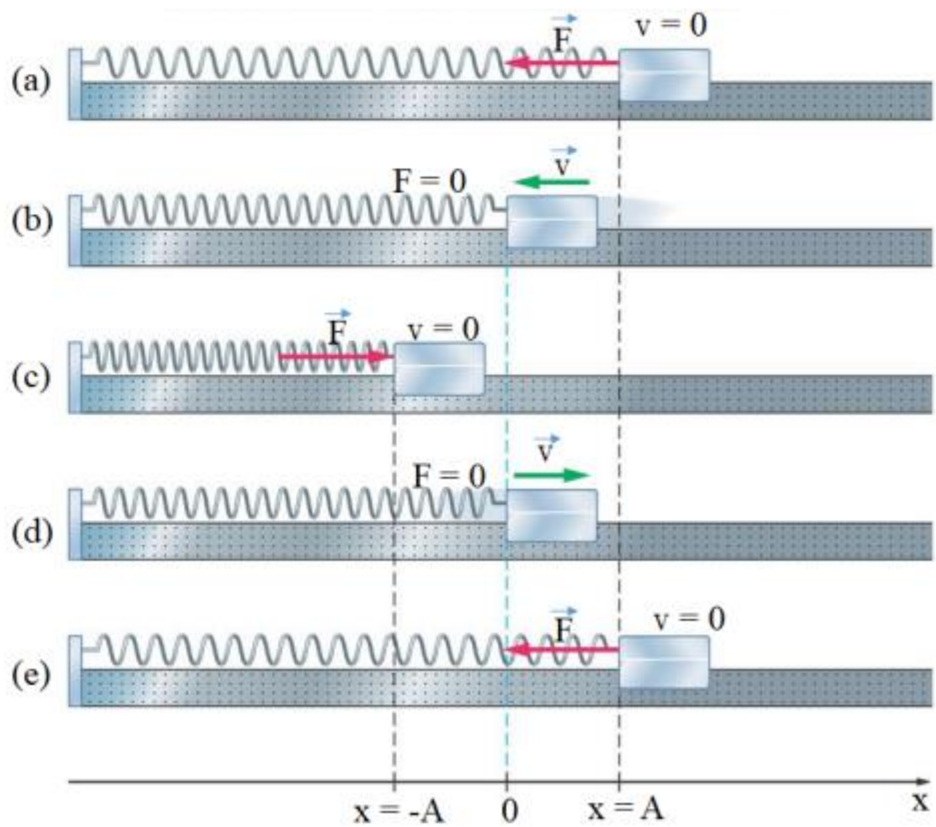
Hooke's law: states that the restoring force acts opposite to the displacement of the object (described by the negative sign)

$F_{app} = k*x$,

F_{app}: is the applied force on the spring

- If **k** is large, then the spring is **stiff** and produces a **lot of force** for a small displacement.
- If **k** is small, then the spring is said to be **loose** and doesn't pull back with much force(produces **small restoring force**)
- The spring constant k can be measured by applying a force (F_{app}) and measuring how much the spring stretches (x).

Then k = F_{app}/x and has units of force/distance (N/m).



(a) The mass is at rest position and at its maximum positive value of x. Its velocity is zero, and the force on it points to the left with maximum magnitude.

(b) The mass is at the equilibrium position of the spring. Here the speed has its maximum value, and the force exerted by the spring is zero.

(c) The mass is at its maximum displacement in the negative x direction. The velocity is zero here, and the force points to the right with maximum magnitude.

(d) The mass is at the equilibrium position of the spring, with zero force acting on it and maximum speed.

(e) The mass has completed one cycle of its oscillation about x = 0.

In one full cycle after being released from a non-equilibrium position, the displacement of the object:

• decreases as it returns to equilibrium

• reverses and increases as it moves away from equilibrium in the opposite direction

• decreases as it returns to equilibrium

• increases as it moves away from equilibrium towards its starting position.

The period of an object of mass m attached to a spring of spring constant k is given by:

$T=2\pi\sqrt{m/k}$

Note: the period of an object with mass 'm' *attached on the spring is dependent on;*

- ✓ *Te mass of the object*
- ✓ *The spring constant*

Exercise

A block of mass 4kg is connected to the free end of a spring and undergoes periodic motion with period of $\frac{\pi}{10}$S. Compute the spring constant of the spring in N/m

Given: mass(m) = 4kg required: spring constant: k

Period(T) = $\frac{\pi}{10}$s

Solution: $T=2\pi\sqrt{m/k} = \frac{\pi}{10}\,s = 2\pi\sqrt{4kg/k}$……*square both sides*

$\Pi^2/100\ s^2 = 4\ \pi^2 * 4kg/k$

K= 1600N/m

Example

6.3 A block of mass 2kg is connected to the free end of a spring with a spring constant of 200 N/m. Compute the period of the block.

Given: m = 2kg , K = 200N/m Required: T =?

Solution: $T = 2\Pi\sqrt{m/k} = 2\Pi\sqrt{2kg/200N/m} = 2\Pi\sqrt{2kg/200kgm/ms^2} = 2\Pi/10\ s = \Pi/5\ s$

6.3 Propagation of Waves and Energy Transmission

Mechanical waves: are waves that require material medium for their propagation.

- ✓ Mechanical waves travel through a material as a vibration of the particles of the material (water, wood, air, etc.). It is these vibrations that form the wave.
- ✓ All mechanical waves require a medium to travel through.

Examples: sound waves, water waves, waves in strings, etc

Electromagnetic waves*:* are waves that do not require material medium for their propagation.

- ✓ Electromagnetic waves do not require a medium to travel through.
- ✓ They are comprised of vibrating electric and magnetic fields and there are no particle vibrations at all.
- ✓ Electromagnetic waves travel through a vacuum.

Examples: light, radio waves, x-rays etc.

Waves are classified in to two based on the direction of propagation of the wave and the direction of vibration of particles of the medium

1. ***Transverse wave***: is a wave where the direction of propagation of the wave is ***perpendicular*** to the direction of vibrations of particles of the medium. In other words, in transverse waves, the directions of the particles' vibrations are at right angles to the direction of energy transfer (wave movement).

   Examples: all electromagnetic waves, waves on strings etc

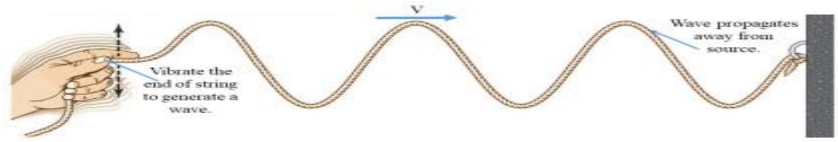


Figure: Example of transverse wave on a string

2. ***Longitudinal wave***: the direction of propagation of the wave (the direction of energy transfer) is ***parallel*** to (in the same direction as) the direction of vibrations of particles of the medium. This means, the vibrations are forward and backward along the wave.

   Examples: sound waves, pressure waves, etc.

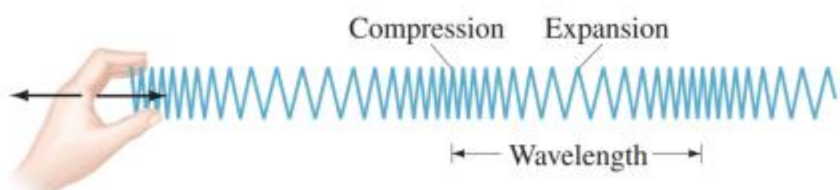


Figure: longitudinal wave

- ✓ Propagation of longitudinal waves results in the areas of compressions and rarefactions.

Compression: refer to regions where the particles are pushed together

Example: crest

Refraction: refer to regions where the particles move apart

Example: trough

6.4 Sound Waves

<u>Sound:</u> *is* the vibrations that travel away from the source of disturbance

- ✓ Sound carries energy and loses its energy as it travels

<u>Production and Propagation of Sound</u>

- ✓ sound travels through any material medium with a speed that depends on the properties of the medium

  Medium: the material through which the sound travels and reaches your ear.

Speed of Sound: *The speed of sound waves in a medium depends on:*

- ✓ ***compressibility** and **density** of the medium*

The speed of sound in air is about 331 m/s at 0^0C. The speed of sound in air, V, at any temperature T_C can be calculated as

$V = 331m/s\sqrt{(1 + T_C/273^0C)}$

Note: The speed of sound in liquids and solids is not affected significantly by the change in temperature, but affected by their body structure.

Example

What is the speed of sound in air at 20 °C? Given: Tc = 20 °C

Required: v =?

Solution: The speed of sound at temperature Tc is given by:

$V = 331m/s\sqrt{(1+T_C/273)} = 331m/s\sqrt{(1+20/273)} = 331m/s\sqrt{(1.073)} = 331m/s*1.036 = 343m/s$

Note: The transmission of sound in different substances depends on the structure of the particles in the substances. Since the particles in solids are close to each other they easily pass the sound to the next particles by collision and the sound moves faster. But in liquids and in gases, the particles are far apart and the collision between the particles takes place rarely. This is why sound travels slower in liquid than in solids and faster in liquids than in gases.

$V_{Solid} > V_{Liquid} > V_{gas}$

The speed of sound in different materials is given in Table .

S.No.	Material	Speed of sound
1	Air (0 ^{o}C)	331
2	Air(20^{0}c)	343
3	Sea water(25^{o}c)	1533
4	Water(20^{o}c)	1493
5	Iron	5950
6	lead	1960
7	Rubber	1600

Reflection, Refraction, Diffraction and Interference of Sound

Echo: is the reflection of sound from hard surfaces

Diffraction: is the change in the direction of sound wave as it passes through an opening or around a barrier in its path.

6.5 Superposition of Waves

Superposition principle: When two or more waves pass through a single point at the same time the resultant instantaneous displacement at that point is the sum of the displacements that would be created separately by each wave, taking signs in to account. This principle is known as the superposition principle

Note: Superposition is also known as Interference

- Interference can be either constructive or destructive depending on the phase between the interfering waves
- **Two waves** are said to be **in phase** when corresponding points of each wave reach **maximum** or **minimum** displacements **at the same time**

Constructive interference: When two periodic waves with the same frequency and wavelength travel in the same direction in phase, their resultant wave is more amplified and we can say that the two waves interfere constructively.

Destructive interference: when two periodic waves with the same frequency and wavelength travel in the same direction, but out of phase, the resulting wave is diminished (or may be zero) in amplitude. In such a case the two waves interfere destructively

Standing Waves: is the superposition of two identical waves travelling in opposite directions in the same medium.

Antinodes (A): The positions in the medium at which maximum displacement occurs

Nodes(N): positions with zero displacement

Note that:

• The distance between adjacent antinodes is equal to $\lambda /2$

• The distance between adjacent nodes is equal to $\lambda /2$

- The distance between a node and an adjacent antinode is $\lambda/4$.

6.6 Characteristics of Sound Waves

Sound cannot travel through a vacuum. The movement of molecules of a medium is essential for the propagation of sound waves.

The characteristics of sound are:

Pitch: The pitch of a sound depends on the frequency of the sound wave. The higher the frequency of the sound waves, the higher their pitch. In higher pitch sounds, the particles vibrate more often past their equilibrium position per second

Loudness: The loudness of a sound depends on the amplitude of the sound wave.

- If the amplitude is greater, the sound is louder.
- In louder sounds, the particles move further from their equilibrium position.
- The loudness of a sound is measured in decibel (dB).

sound pollution: Exposure to elevated sound that may lead to adverse effects in humans or other living organisms.

- Health effects of sound pollution: **hypertension**, **hearing loss**, **sleep disturbances**, etc. A noise becomes harmful when it exceeds 75 dB and painful above 120 dB. **Timber (Quality)**: The same note played on different instruments sounds distinctly different. Timber or quality is the property of tone that distinguishes it from another tone of the same pitch and intensity but produced by different sources. Quality does not mean good or bad, it just refers to the difference in sound.

End of Unit Questions and Problems

Part I: Conceptual questions and workout problems

1. Calculate the period of a simple pendulum of length 4m.

Given: $l = 4m$, $g = 10m/s^2$, required: $T=?$

Solution: $T = 2\Pi\sqrt{(l/g)} = 2\Pi\sqrt{(4m/10m/s^2)} = 3.97s$

2. An object of mass 2kg is attached to one end of a spring of spring constant 800N/m. If the object is undergoing periodic motion on a smooth horizontal surface, what is the period of oscillation?

Given: $m = 2kg$, $k = 800N/m$, required: $T=?$

Solution: $T = 2\Pi\sqrt{(m/k)} = 2\Pi\sqrt{(2kg/800N/m)} = 2\Pi\sqrt{(2kg/800kgm/\ m\ s^2)} = 0.314\ s$

3. Explain the difference in the speed of sound:

(a) between solids, liquids and gases

Solution $V_{SOLID} > V_{LIQUID} > V_{GAS}$

(b) Between warm air and cold air

Solution: The speed of sound in warm air is greater than that in cold air

4.In which type of wave are the vibrations parallel to the direction of wave propagation?

Give at least two examples for such type of wave.

Solution: Longitudinal waves.

Examples of longitudinal waves include: sound waves and pressure waves,

5. An electromagnetic wave has a wavelength of 10 nm. Calculate its frequency

Given: wave length (λ) $=10nm$, *V(speed of light) = 300,000km/s =* $3*10^8 m/s$

$f= v/\lambda = 3*10^8 m/s/10*10^{-9} m= 3*10^{-16}/s =3*10^{-16} Hz$

7. Two identical waves of amplitude 4cm meet. What will be the amplitude of the combined wave at a point where:

(a) they interfere constructively?

(b) They interfere destructively?

Given: amplitude of each wave = 4cm

Solution: a)= 8cm(sum of the two constructive interfering waves)

b) = 0 (difference of the two destructive waves)

9. Sound travels along a steel rod of length 4m in a time of 0.0008 s. What is the speed of sound in the steel?

Given: wave length (λ) = 4m, time period (T) = *0.0008s*, *required: wave speed* (v)=?

Solution: $v= \lambda/ T$ = 4m/0.0008 s = *5000 m/s*

10. Calculate the speed of sound in air at 30 degree Celsius.

$V= 331m/s\sqrt{(1+T_C/273)} = 331m/s\sqrt{(1+30/273)} = 331m/s*1.05=348.7m/s$

11. Suppose a man stands at a distance from a cliff and claps his hands. He receives an echo from the cliff after 2 seconds. Calculate the distance between the man and the cliff. Take the

speed of sound to be 343 m/s

Given: period (T) =2s, *v= 343m/s, required:* λ

$V = \lambda/T$

$2 * \lambda = V * T$ ....because the distance is the total distance from and to the source

$\lambda = (V * T)/2 = (343m/s*2s)/2 = 343m$

12. A ship is sailing in a part of the sea where seabed is 500m below the ship. The ship uses SONAR to detect the seabed. How long will it take a pulse of sound to travel to the seabed and return to the ship. Use speed of sound in sea water to be 1500m/s.

Given: λ *= 500m, v= 1500m/s, required: period (T)=?*

$\lambda = V * T$

$T = \lambda / V = 500m/1500m/s = 1/3\ s = 0.33\ s$ *(for travelling to the sea bed)*

*The total time taken(T)=2*0.33=0.67 s*

Part II: Multiple Choice Questions

13. With reference to waves, a disturbance is:

(a) an oscillation produced by some energy that creates a wave.

(b) the resistance produced by some particles of a material.

(c) the number of oscillations per unit time

(d) the constructive or destructive interference of waves.

14. What is the period of a wave with a frequency of 2 Hz?

(a) 1 s (b) 4 s (c) 0.5 s (d) 2 s

15. What kind of interference occurs between two identical waves moving in opposite

directions?

(a) Constructive interference

(b) Destructive interference

(c) Both constructive and destructive interference

(d) Neither constructive nor destructive interference

16. Diffraction is

(a) The constructive interference of two waves of the same frequency travelling in the same direction

(b) The change in direction of waves as they pass through an opening or around a barrier in their path

(c) The change in the direction of waves as they pass from one medium to another

(d) The a change in the direction of waves when they bounce off a barrier

17. A closed organ pipe has

(a) a node at the closed end and an antinode at the open end

(b) an antinode at the closed end and a node at the open end

(c) a node at each end

(d) an antinode at each end

18. The loudness (or intensity) of a sound wave is related to its

(a) frequency

(b) wavelength (c) amplitude (d) period

Unit 7

Temperature and Thermometry

7.1 Temperature and Our Life

Temperature:

Definitions:

- ✓ Temperature is the degree of hotness or coldness of a body.
- ✓ Temperature is the average kinetic energy of the particles on a body.

Note: Human beings are comfortable with temperature between 18 ^oC and 22 ^oC, particularly referred to as room temperature.

Temperature of the environment affects:

- ✓ Humanbeing's clothing,
- ✓ eating habit,
- ✓ health and
- ✓ economy

The temperature difference from the pole to the equator depends on:

- ✓ the Sun's energy
- ✓ the energy retained in Earth's system.
  - ❖ The equator zone: the hottest zone
  - ❖ The polar zone: the coldest zone
  - ❖ Temperate zone: moderate temperature

7.2 Extreme Temperature Safety:

- ❖ Average normal temperature of human body is 37^oc

High environmental temperatures is dangerous to human body.

- ❖ In the range of 90^oc and 105^oF (32^oC and 40^oC) leads to heat cramps and exhaustion.

- Between 105°c and 130°F (40°c and 54°C) leads to heat exhaustion.
- An environmental temperature over 130°F (54°C) leads to heat stroke

Note: The natural warming of the Earth that results from when the greenhouse gases in the atmosphere such as **carbon dioxide**, **methane**, **nitrous oxide**, **water vapor** and **fluorinated gasses** trap heat from the sun is called greenhouse effect.

7.4 Measuring Temperature with Different Thermometric Scales

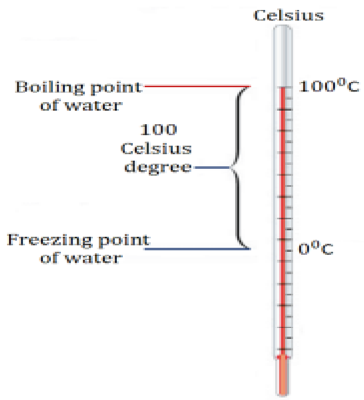
Thermometer: is a device used to measure the temperature of a body. It measures temperature in degrees.

Thermometer works as the substances (mainly mercury or alcohol) inside the tube of a thermometer undergoes some changes (expansion or contraction) when heated or cooled.

Types of temperature scales

- Centigrade (Celsius) scale
- Fahrenheit scale
- Kelvin scale

✓ In designing a thermometer, two temperatures of a body are marked on it as fixed points. These are the **lower fixed point** (melting point of ice) and the **upper fixed point** (boiling point of water) at sea level.



Celsius scale: a temperature scale where the freezing point of water is fixed at 0 degrees and the boiling point is at 100 degrees.

Fahrenheit scale: a temperature scale where the freezing point of water is fixed at 32 degrees and the boiling point is at 212 degrees.

Kelvin scale: a temperature scale that uses absolute zero as one of its fixed points. T
Absolute zero: the temperature at which a substance has no thermal energy

Exercise

1. What is the temperature of the melting point of ice?

Answer: 0^0c= 32^0F=273.15K

2. What is the temperature of the boiling point of water at sea level?

Answer: 100^0C=212 ^{0}F=373.15k

<u>Types of Thermometers and Their Use</u>

Liquid Thermometers

1. Mercury Thermometer: uses the expansion of mercury due to change in temperature.
   - ✓ It measures temperature between -30 degree Celsius and 300 degree Celsius.
2. Alcohol thermometer: uses the expansion of alcohol due to change in temperature.
   - ✓ It is used to measure temperature from -115 ^{0}C to 78.15 ^{0}C.

3. Resistance Thermometer: resistance thermometer uses the **resistance** of the wire or the substance to determine the temperature of the substance by placing he resistance thermometer in thermal contact with the substance and measuring the resistance of the wire

- ✓ Electrical resistance thermometers are often made from **platinum** wire,
- ✓ It measures temperature in the range of 270°C to +700°C.

4. Thermocouple uses **voltage** as the thermometric property. It measures temperatures as high as 2300°C or as low as -270°C.

- ✓ Often made of copper and constantan (a copper-nickel alloy).

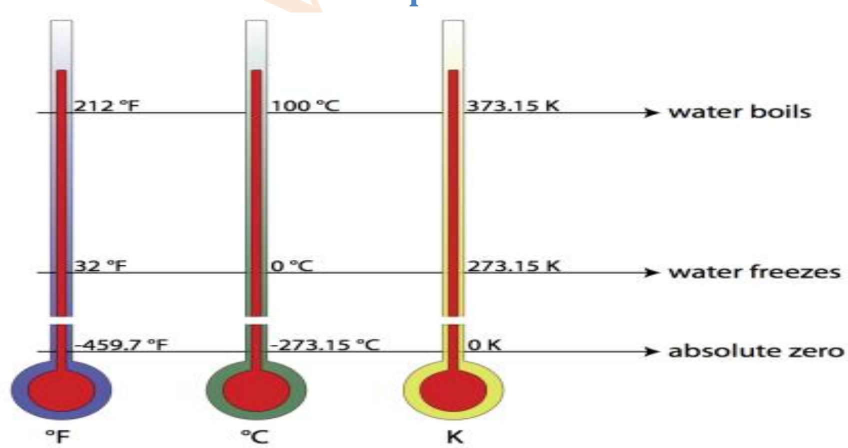
5. Thermistor: is a resistance thermometer, or a resistor whose resistance is dependent on temperature. The term is a combination of 'thermal' and 'resistor'. It is made of metallic oxides

There are two types of thermistors:

1. Negative Temperature Coefficient (NTC): when the temperature increases, resistance decreases. Conversely, when temperature decreases, resistance increases.
2. Positive Temperature Coefficient (PTC): When temperature increases, the resistance increases, and when temperature decreases, resistance decrease

6. Radiation Thermometer: uses the **electromagnetic** radiation from a body to be measured.

7.6 Conversion between Temperature Scales



Temperature conversion between Degree Celsius and Fahrenheit Scale

Exercise : Using the fixed points from Figure 7

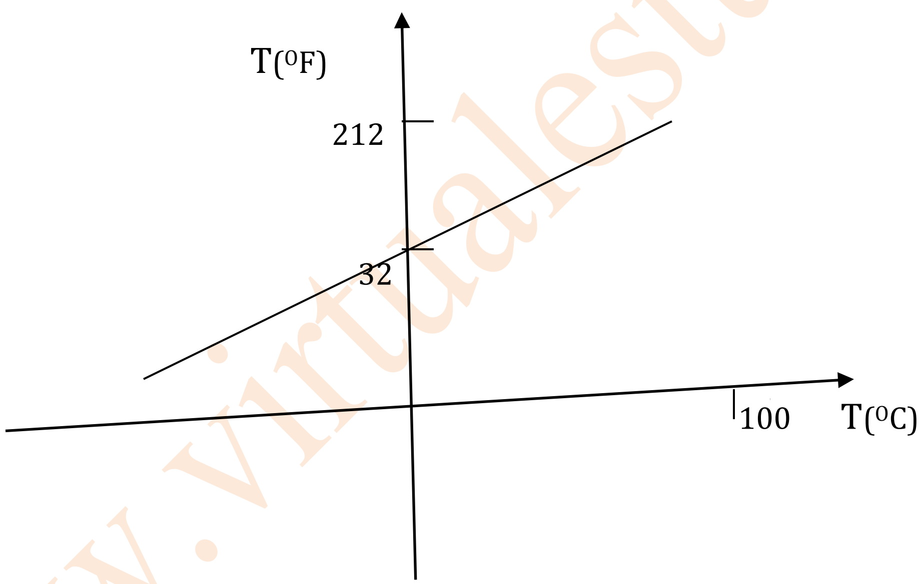
1. Derive the formula to convert temperature in Celsius scale to Fahrenheit scale.
2. Derive the formula to convert temperature in Fahrenheit scale to Celsius scale.

Given: fixed points of water (freezing point and boiling point)

Freezing point of water = $0^{o}C$ ($32^{o}F$)

Boiling point of water= $100^{o}C$ ($212^{o}F$)

Solution: drawing a graph using coordinates ($0^{o}C$, $32^{o}F$), ($100^{o}C$, $212^{o}F$)



Given:

The graph gives a linear equation of the form: $y = mx + b$,

y=T_F (temperature in degree Fahrenheit)

x= T_C (temperature in degree Celsius)

b= y-intercept

m= the slope of the equation

From the above graph the y-intercept, b =32 ^{0}F

Slope=$m=(y_2-y_1)/(x_2-x_1)= (212 -32) /(100-0) = 180/100 = 9/5=1.8$

$y= T_F=\frac{9}{5}T_C+32= 1.8\ T_C+32$

also solving for T_C,

$T_C=\frac{5}{9}(T_F-32)$

Example

If the temperature of the surrounding is 50 ^{0}F, what is the temperature in degree celsius?

$T_c=\frac{5}{9}(T_F-32)=\frac{5}{9}(\ 50-\ 32)\ =10\ ^0C$

Example 7.2

The temperature of a room is 20 ^{0}C. What is the temperature of the room in degree Fahrenheit?

$T_F=\frac{9}{5}T_C+32= 1.8\ T_C+32= 1.8*20+32= 68\ ^0F$

Temperature Conversion between Degree Celsius and Kelvin scale

TK = TC +273.15

TC= TK-273.15

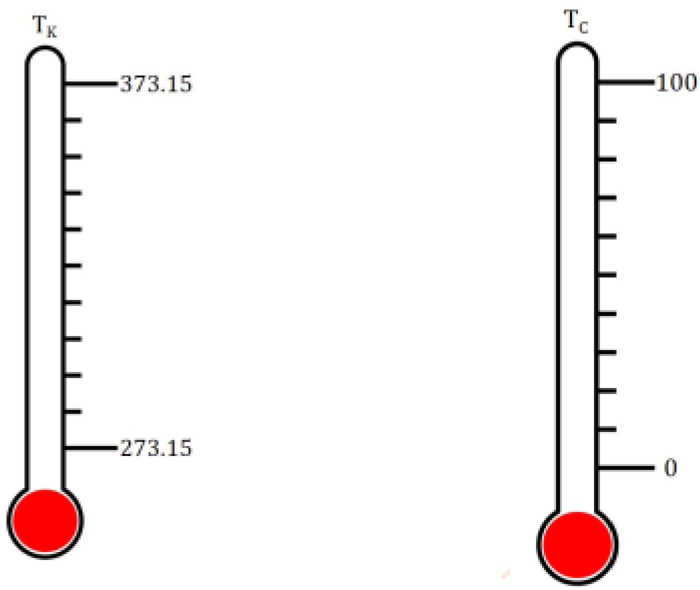
Exercise

1. The size of one Kelvin is identical to that of one Celsius degree. Discuss and reason out.

Solution: The division between the lower and upper fixed points of the Celsius temperature scale and the Kelvin temperature scale is 100. The size of one Kelvin is identical to one degree Celsius. That is the change in temperature in Celsius scale is the same as the change in temperature of the Kelvin scale.

2.What is the minimum possible temperature in nature?

Solution: The minimum possible temperature in nature is 0 K or $-273.15\,^\circ C$



Water is boiled to a temperature of 72 ^{0}C. What does a Kelvin scale read for this value? Given: TC = 72 ^{0}C Required: TK =?

Solution: $T_K = T_C + 273.15 = (72+273.15)K \therefore T_K = 345.15K$

Example 7.4

The temperature of a hot metal is 573.15 K.

What is the value of this temperature in degree Celsius scale?

Given: $T_K = 573.15K$ Required: $T_C =$

$T_C = T_K - 273.15 = 573.15 - 273.15 = 300\,^oc$

Temperature Conversion between Degree Fahrenheit and Kelvin Scale

$T_K = 0.55T_F + 255.4$, $T_F = 1.8\,T_K - 459.67$

7.7 Thermal Expansion of Materials

Thermal Expansion: is the increase in length of substances when they are heated

Different materials expand or contract at different rates. In general, gases expand more than liquids, and liquids expand more than solids.

Degree of expansion:

Gas>liquid> solid

- **Linear expansion**: the increase in length of a substance due to heating. T
- **Coefficient of linear expansion**: the increase in length of a 1 m road of a given substance when its temperature increases by 1 K.
- materials expand when heated
- Materials contract when cooled.

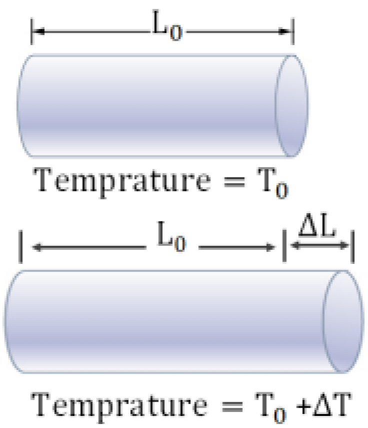


Figure when the temperature of the rod raises by ΔT, the length of the rod increases by ΔL.

Initial length of the material is L_0 at temperature T_0. When the temperature increases from T_0 to $T_0 + \Delta T$, the length becomes $L_0 + \Delta L$ where ΔT and ΔL are the magnitude of the changes in temperature and length respectively. Conversely when the temperature decreases to $T_0 - \Delta T$, the length decreases to $L_0 - \Delta L$.

$$\Delta L = \alpha L_0 \Delta T$$

Where, α is the coefficient of linear expansion and its unit is $1/^0c$

Exercise

1. What happens to the change in length of the rod if the initial length of the rod is doubled?

2. Does the coefficient of linear expansion depend on the nature of material?

Answer:

1. The change in length(ΔL) will be **doubled**
2. Yes, the coefficient of linear expansion (α) depends on the nature of materials. It is different for different materials

Substance	Coefficient of linear expansion α in $(^oC)^{-1}$
Aluminum	2.6×10^{-5}
Brass	1.9×10^{-5}
Concrete	1.2×10^{-5}
Copper	1.7×10^{-5}
Glass (common)	8.5×10^{-6}
Glass (Pyrex)	3.3×10^{-6}
Gold	1.4×10^{-5}
Iron or steel	1.2×10^{-5}
Lead	2.9×10^{-5}
Nickel	1.3×10^{-5}
Quartz (fused)	0.5×10^{-6}
Silver	1.9×10^{-5}

Table 7.3 the coefficients of linear expansion of solids.

Example a thin rod of gold has a length of 1.5×10^{-1} m at a temperature of 27 ^oC. The rod falls into a sink of hot water whose temperature is 49 ^oC. What is the change in the length of the gold rod?

Given: $L_0 = 1.5*10^{-1}$m =15cm

$T_0 = 27\ ^0C$ required: ΔL =?

$T_F = 49\ ^0C$

$\alpha = 1.4*10^{-5}\ ^0c^{-1}$

Solution: $\Delta L = \alpha * L_0 * \Delta T$

$\Delta T = T_F - T_0 = 49^0C - 27^0C = 22^0C$

$\Delta L = \alpha * L_0 * \Delta T = 1.4*10^{-5}\ ^0c^{-1} * 15cm * 22^0C = 4.62*10^{-3}cm = 4.62\times10^{-5}m$

Example

The initial length of a brass rod is 50 cm at a temperature of 25 ºC. What will be its final length when it is heated to a temperature of 70 ºC?

Given: L_0= 50cm, T_0= 25 ºC, $\alpha = 1.9*10^{-5}\ ^oC^{-1}$

T_0= 70 ºC, required: final length (L_F)= ?

Solution: $\Delta L = \alpha * L_0 * \Delta T = (L_F - L_0) = \alpha * L_0 * \Delta T$

$\Delta L = 1.9*10^{-5}\ ^oC^{-1} * 50cm\ (70\ ^oC - 25\ ^oC) = 0.043cm$

$L_F = L_0 + \Delta L$ = 50cm+0.043cm = 50.043cm

End of Unit Questions and Problems

Part I Multiple choice

1. Which of the following best defines temperature? Temperature is:

A. the degree of hotness or coldness of a body

B. the measure of the average kinetic energy of a molecule in a body

C. the measure of the total kinetic energy of a molecule in a body

D. A and B E. A and C

2. Which one of the following instruments is used to measure the temperature of a body?

A. Anemometer B. Barometer C. Hydrometer D. Thermometer

3. In constructing a thermometer it is necessary to use a substance that:

A. Expands or contracts with change in temperature

B. Remains constant while heating or cooling

C. Explode while heating

D. None of the above

4. At what temperature do the Fahrenheit and Celsius scale read the same value?

A. 40 °C, 40°F

B. -40 °C, 40 °F

C. -40 °C, – 40 °F

D. 40 °C, −40 °F

5. Room temperature is about 20 degrees on the:

A. Kelvin scale B. Celsius scale C. Fahrenheit scale D. Absolute scale

6. Thin strips of iron and zinc are weld together to form a bimetallic strip that bends when heated. The iron is on the inside of the bend because:

A. It has higher coefficient of linear expansion

B. It has higher specific heat

C. It has higher temperature

D. It has lower temperature

7. Which one of the following sets of temperatures are equivalent?

A. 50 ^{o}F, 10 ^{o}C, 283.15 K B. 68 ^{o}F, 20 ^{o}C, 341.15 K

C. 86 ^{o}F, 30 ^{o}C, 187.15 K D. None

8. An annular thin ring of aluminum is cut from the aluminum sheet as shown below. When the ring is heated:

A. The aluminum expands outward and the hole remains the same

B. The hole decreases in diameter

C. The diameter of the hole expands with the same percent as any length of the aluminum

D. Linear expansion forces the shape of the hole to be elliptical

<u>Part II: Short Answer</u>

1. What is temperature?

   Answer: Temperature is the degree of hotness or coldness of a body or the measure of the average kinetic energy of the particles in a body

2. What are the causes for the rise of temperature in our environment?

   Answer: Greenhouse gas emissions (carbon dioxide, methane, nitrous oxide, water vapor and fluorinated gasses)

3. Define absolute zero temperature.

Answer: An absolute temperature is the possible minimum temperature, 0 K on the Kelvin scale or -273.5 ◦ C in Celsius scales. (T_K =0 k, T_C= -273.1 ^{0}c)

4. What are the steam and ice points of water in Kelvin scale?

Answer: 373.15 (steam point), 273.15 K (ice point)

5. What is the lowest possible temperature in nature?

Answer: 0 K or -273.15 ^{0}C

Part III: **Workout**

1. What is the temperature in Celsius scale if the reading in Fahrenheit scale zero?

Answer: given: T_F = 0 ^{0}F required: T_C =?

Solution: $T_C = \frac{5}{9} *(T_F -32) = \frac{5}{9}*(0\ ^0F-32) = \frac{5}{9} *(-32)\ ^0C = -17.8\ ^0C$

2. The temperature of an object is 310 K. What is this temperature in Fahrenheit scale?

Given: T_K= 310 K Required: T_F =?

Solution: T_K= 0.55T_F+255.4(solve for T_F)

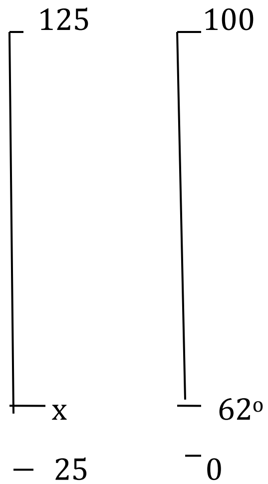
T_F =1.8T_K -459.67 =1.8*310-459.67 =98.33 ^{o}F

3. The ice and the steam points of the newly designed thermometer is 25 ^{o}X and 125 ^{o}X respectively. What value of temperature does this thermometer read for 62 ^{o}C?

   Given: T_0=25 ^{o}, T_{100} =125 ^{o}, given temperature = 62^{o}c

   Required: T_C (given scale) = ?

Solution: using reference temperature scale of water



apply temperature scale Conversion

$(125^o - 25^o)/(x^o - 25) = (100-0)/(62-0)$

$100^o/(x^o - 25^o) = 100/62$

$(x-25)*100 = (100*62)$

$x-25 = (100*62)/100$

$x-25 = 62$

$x = 62+25 = 87^oc$

4. Calculate the increase in length of a 2m copper rod that is heated from 0 ^oC to150^oC?

Given: L_0 = 2m, T_1 = 0 ^oC, T_2=150^oC, α=1.7*10^{-5} c^{-1}, required; ΔL=?

Solution: $\Delta L = \alpha * L_0 * \Delta T = 1.7*2m*10^{-5}\ c^{-1} * (150^oC - 0\ ^oC) = 0.0051m$

5. The temperature varies from 25 ^oC to 38 ^oC yearly in Afar region. A concrete side walk is constructed between two buildings when the temperature is 25 ^oC. A sidewalk consists of one concrete slab of length 3m with negligible thickness. What amount of empty space should be provided to protect the concrete from bending?

Given: T_1 =25 ^oC, T_2= 38 ^oC, L_0 =3m, α=1.2*10^{-5}c^{-1} required: ΔL =?

$\Delta L = \alpha * L_0 * \Delta T = 1.2*10^{-5}c^{-1}*3m*(38\ ^oC - 25\ ^oC) = 0.00047m$