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UNIT1: PHYSICS AND MEASUREMENT

Introduction

Physics is an empirical study. Everything that is known about the physical world in which we live and about the principle that govern its behavior has been learned through carful observation of the phenomena of nature and generalization from these observations

ERRORS IN MEASUREMENT

1. Errors

A discrepancy is defined as the difference between two or more measured values of the same quantity. However, measurements are never exact and there will always be a degree of variance regardless of the survey instrument or method used.

- Basically Three types of errors are studied:-
  - ✓ Gross Errors
  - ✓ Systematic Errors
  - ✓ Random Errors

I. **Gross Errors** mainly covers the human mistakes in reading instruments and recording and calculating measurement results.

Example: - Due to oversight, the read of Temperature as 31.5 while the actual reading may be 21.5.

- Gross Errors may be of any amount and then their mathematical analysis is impossible. Then these are avoided by adopting two means:-
  - Great care is must in reading and recording the data.
  - Two, Three or even more reading should be taken for the quantity under measurement.

II. Systematic Errors

Systematic Errors classified into three categories:-

A. Instrumental Error
B. Environmental Errors
C. Observational Errors

A. Instrumental Errors

- ✓ These errors arise due to three main reasons.

- Due to inherent shortcoming in the instrument. If the spring used in permanent magnet Instrument has become weak then instrument will always read high. Errors may cause because of friction, hysteresis, or even gear backlash.
- Due to misuse of the instruments.
- Due to loading effects of instruments.

B. Environmental Errors

These errors are due to conditions external to the measuring device including conditions in the area surrounding the instrument.

These may be effects of Temperature, Pressure, Humidity, Dust, Vibrations or of external magnetic or electrostatic fields.

C. Observational Errors

There are many sources of observational errors:-

- ✓ Parallax, i.e. apparent displacement when the line of vision is not normal to the scale.
- ✓ Inaccurate estimate of average reading.
- ✓ Wrong scale reading and wrong recording the data.
- ✓ Incorrect conversion of units between consecutive reading

III. Random Errors

- ✓ Random (or accidental) errors are not directly related to the conditions or circumstances of the observation. For a single measurement or a series of measurements, it is the error remaining after all possible systematic errors and blunders have been eliminated.
- ✓ As the name implies, random errors are unpredictable and are often caused by factors beyond the control of the surveyor. Their occurrence, magnitude, and direction (positive or negative) cannot be predicted. Errors of this type are compensating and tend to at least partially cancel themselves mathematically. Because the magnitude is also a matter of chance they will remain, to some degree, in every measurement

Percentage error

- Percentage error = $\frac{Measured\ value - Actual\ value}{Actual\ value}$ x100%
- Error = Measured value – Actual value
- Example the density of aluminum is 2.7gram/cm^3 and its measured value 2.6gram/cm^3

Determine

A. Error (Ans = 0.1gram/cm3)
B. Percentage error (Ans = 3.7%)

2. Accuracy and Precision

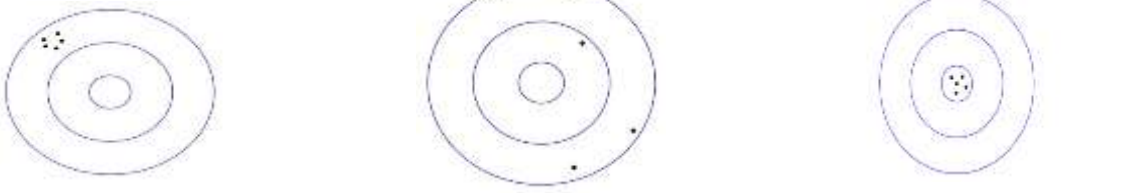
Accuracy and precision are two different, yet equally important surveying concepts.

Accuracy

- ✓ is the degree of conformity of a given measurement with a standard value or accepted value

Precision

- ✓ is the extent to which a given set of measurements agree with their mean
- ✓ or individual data are agrees with each other



Precision without accuracy ***neither precision nor accuracy*** ***Precision and accuracy***

Example

- Four students performed an experiment to measure the density of aluminum ($2.7 gram/cm^3$). Which data is accurate but not precise?

Arsema	Beza	Muse	Yafet
2.924	2.316	2.649	2.701
2.923	2.527	2.731	2.699
2.925	2.941	2.695	2.702
2.926	2.136	2.742	2.698
NA & P	NA & NP	A & NP	A & P

- Note: A & P = Accurate and Precise
- NA & P = Not accurate but Precise
- A & NP = Accurate and but not Precise

Significant figure

What is a "significant figure"?

- ✓ The number of significant figures in a result is simply the number of figures that are known with some degree of reliability. The number 13.2 is said to have 3 significant figures. The number 13.20 is said to have 4 significant figures.

- ❖ Rules for deciding the number of significant figures in a measured quantity:

A. All nonzero digits are significant:

1.234 g has 4 significant figures,

1.2 g has 2 significant figures.

B. Zeroes between nonzero digits are significant:

1002 kg has 4 significant figures,

3.07 mL has 3 significant figures.

C. Zeroes to the left of the first nonzero digits are not significant; such zeroes merely indicate the position of the decimal point:

0.001^{o} C has only 1 significant figure,

0.012 g has 2 significant figures.

D. Zeroes to the right of a decimal point in a number are significant:

0.023 mL has 2 significant figures,

0.200 g has 3 significant figures.

E. When a number ends in zeroes that are not to the right of a decimal point, the zeroes are not necessarily significant:

190 miles may be 2 or 3 significant figures; 50,600 calories may be 3, 4, or 5 significant figures. The potential ambiguity in the last rule can be avoided by the use of standard exponential, or "scientific," notation. For example, depending on whether 3, 4, or 5 significant figures is correct, we could write

50, 6000 calories as:

- ✓ 5.06×10^4 calories (3 significant figures)
- ✓ 5.060×10^4 calories (4 significant figures), or
- ✓ 5.0600×10^4 calories (5 significant figures).

Addition/Subtraction

When adding/subtracting, the answer should have the same number of decimal places as the limiting term. The limiting term is the number with the least decimal places.

- 6.22 +53.6 +53.6+45.09091 = 119.22191, round → **119.2**
- 53.6 limiting term has 1 decimal place

Multiplication/Division

When multiplying/dividing, the answer should have the same number of significant figures as the limiting term. The limiting term is the number with the least number of significant figures.

- 503.29 x 6.177 = 3108.82233 → round → **3109**
- limiting term has 4 sig figs (6.177)

Addition:

(3.131 ± 0.008 g) + (3.121 ± 0.004 g) =?

First find the sum of the values:

3.131 g + 3.121 g = 6.252 g

Next find the largest possible value:

3.139 g + 3.125 g = 6.264 g

The uncertainty is the difference between the two:

6.264 g – 6.252 g = 0.012 g

Multiplication:

(3.131 ± 0.013 g) x (6.1 ± 0.2 cm) =?

First find the product of the values:

3.131 g x 6.1 cm = 19.1 g-cm

Next find the largest possible value:

3.144 g x 6.3 cm = 19.8 g-cm

The uncertainty is the difference between the two:

19.8 g-cm - 19.1 g-cm = 0.7 g-cm

Answer: 6.252 ± 0.012 g.

Subtraction:

(3.131 ± 0.008 g) – (3.121 ± 0.004 g) =?

First find the difference of the values:

3.131 g - 3.121 g = 0.010 g

Next find the largest possible value:

3.139 g – 3.117 g = 0.022 g

The uncertainty is the difference between the two:

0.022 g – 0.010 g = 0.012 g

Answer: 0.010±0.012 g.

Answer: 19.1 ± 0.7g-cm.

Division:

(3.131 ± 0.008 g) ÷ (3.121 ± 0.004 g) =?

First divide the values:

3.131 g ÷ 3.121 g = 1.0032

Next find the largest possible value:

3.139 g ÷ 3.117 g = 1.0071

The uncertainty is the difference between the two:

1.0071 - 1.0032 = 0.0039

Answer: 1.003 ± 0.004

Scalars and Vectors

✓ Definition. A scalar quantity is defined completely by a single number,
Examples: Length, area, volume, mass, time, speed, distance etc. It has only magnitude.
✓ Definition. A vector quantity is defined by magnitude and direction,
Examples: force, velocity, acceleration, momentum, etc...
Example: 1 Force is represented by a vector; the direction of the vector describes the direction in which the force is applied, and the magnitude of the vector indicates the strength applied.

Velocity of a car is represented by a vector; the direction gives the direction of motion and the magnitude gives the speed of the car.

Note. Two vectors with the same length and same direction are equal; we do not care about their position in space.

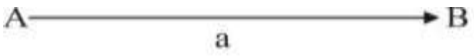
Types of Vectors:

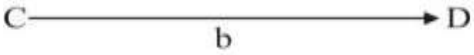
1. **Unit Vector:**

A vector whose magnitude is unity i.e., 1 and direction along the given vector is called a unit Vector. If a is a vector then a unit vector in the direction of a, denoted by a (read as a cap), is given as,

2. **Free Vector:**

A vector whose position is not fixed in space, thus, the line of action of a free vector can be shifted parallel to itself. Displacement is an example of a free vector as shown in figure 1:





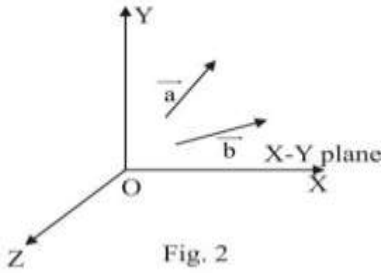


Fig. 2

3. Localized or Bounded Vectors:

A vector which cannot be shifted parallel to itself,

i.e., whose line of action is fixed is called a localized

or bounded vector.

Force and momentum are examples of localized vectors.

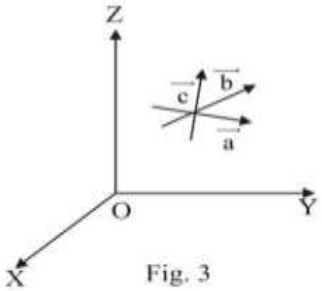


Fig. 3

4. Coplanar Vectors:

The vectors which lie in the same plane are called coplanar vectors,

as shown in Fig. 2.



5. Concurrent Vectors:

The vectors which pass through the common point are called

Concurrent vectors. In the figure no.3 vectors a, b and c are called concurrent as they pass through the same point.

6. Negative of a Vector:

The vector which has the same magnitude as the vector abut

Opposite in direction to a is called the negative to a.

7. Null or Zero Vector:

It is a vector whose magnitude is zero. We denote the null vector by O. The direction of a zero vector is arbitrary. The vectors other than zero vectors are proper vectors or non-zero vectors.

8. Equal Vectors:

Two vectors a and b are said to be equal if they have the same magnitude and direction.

9. Parallel and Collinear Vectors:

The vectors a and b are parallel if for any real number n, a = n b. If

(i) n > 0 then the vectors a and b have the same direction.

(ii) n < 0 then a and b have opposite directions.

Now, we can also define collinear vectors which lie along the same straight line or having their directions parallel to one another.

10. Like and Unlike Vectors:

The vectors having same direction are called like vectors and those having opposite directions are called unlike vectors.

11. Position Vectors (PV):

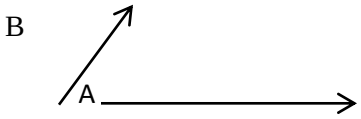
- ✓ If vector OA is used to specify the position of a point A relative to another point O. This OA is called the position vector of A

Graphical Method of Addition of Vectors in 2-D

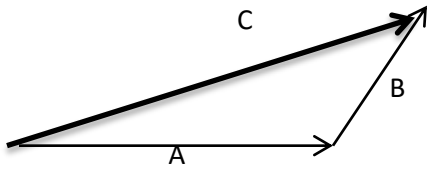
Representation of vectors

- In diagrams we represent vectors by arrows.
- The length of an arrow will be proportional to the magnitude of the vector and the direction of an arrow will be the direction of the vector

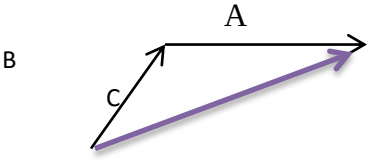
- **Vector sum of two vectors (Triangle Method)**
  - ✓ Let A and B be two given vectors



  - ✓ These vectors can be drawn with the initial point (tail) of B at the end point(head or tip) of A as shown below

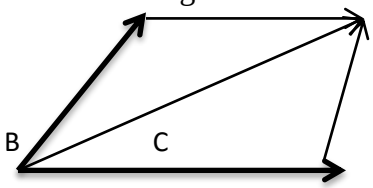


  - ✓ The vector sum C is given by the vector drawn from the tail of A to the head of B " C" is called the resultant(net) vector
  - ✓ C = A+B
  - ✓ The vectors can be drawn with the tail of A at the tip of B as shown below. "C" has the same magnitude and direction in the above diagram
  - ✓ The two vector sums are mathematically equal.
  - ✓ Therefore, vector addition is commutative
  - ✓ C = A + B = B + A



- **Parallelogram Method**
  - ✓ Draw both vectors, A and B, from a common point.

- ✓ The resultant "C" is given by the concurrent diagonal of the parallelogram of which the given vectors from the two adjacent sides as shown



- **Polygon Method**
- When more than two vectors are to be added, we may first find the resultant of any two; add this to the third, and so on.

2.3 **Algebraic Method of addition of vectors in 2D**

- **Adding two collinear vectors**

When two collinear vectors are in the same direction the resultant vector will be the sum of the individual vectors as shown below.



C = A + B

- The angle between A and B is 0^0
- The direction of the resultant vector(C) will be in the direction of both A and B
- **Adding two collinear vectors**

When two collinear vectors are in opposite direction the resultant vector will be the difference of the individual vectors as shown below.



- The resultant vector given by

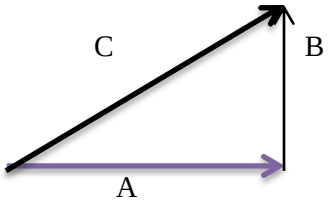
C = B – A or C = -A + B

- The direction of the resultant vector will be in the direction of the larger vector
- The angle between A and B is 180^0

- **Adding orthogonal vectors**

When two vectors are at right angle to each other the resultant vector can be calculated by using Pythagoras theorem

- The square of the hypotenuse C, is equal to the sum of squares of the other two sides, A and B

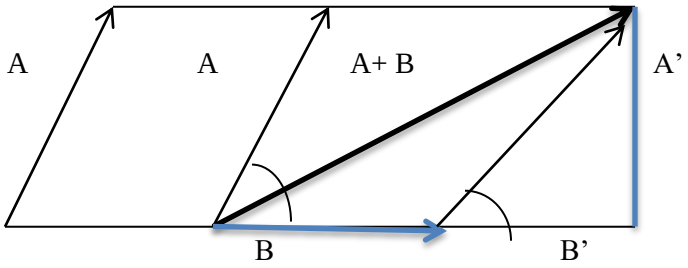


$C = \sqrt{A^2 + B^2}$ ------ Magnitude

$\theta = \tan^{-1}\frac{B}{A}$ --------- Direction

➢ Parallelogram law

Suppose you have two vectors A and B and are non- parallel, the resultant is found by using a parallelogram method as shown in the figure



$(A+B)^2 = A^2 + (B+B)^2 = A^2 \sin\theta^2 + (Acos\theta + B)^2$

$= A^2 \sin\theta^2 + B^2 + 2ABcos\theta + A^2cos^2\theta$

$= A^2 (sin^2\theta + cos^2\theta) + B^2 + 2ABcos\theta$

$= A^2 + B^2 + 2ABcos\theta$ ----------cosine law

The scalar (Dot) product of two vectors

➢ The scalar product of two vectors is defined as the product of the magnitude of the vectors and the cosine of the angle between the two vectors

❖ $\vec{A}.\vec{B} = |A||B| \cos\theta = A_xB_x + A_yB_y + A_zB_Z$

Properties of the dot product

- ✓ Dot product is commutative ,$\vec{A}+\vec{B} = \vec{B}+\vec{A}$
- ✓ Dot product is distributive, $\vec{A}.(\vec{B}+\vec{C}) = \vec{A}.\vec{B} + \vec{A}.\vec{C}$
- ✓ If m is a scalar, then (mA).B = m($\vec{A}.\vec{B}$) = $\vec{A}$.(m$\vec{B}$)

✓ **Cross Product(Vector Product)**

Definition:

If **a** = (a_1, a_2, a_3) and **b** = (b_1, b_2 , b_3), then the cross product of **a** and **b** is the vector,

ax **b** = ($a_2b_3 - a_3b_2$,$a_3b_1 - a_1b_3$,$a_1b_2 - a_2b_1$)

$(a_2b_3 - a_3b_2)\mathbf{i} + (a_3b_1 - a_1b_3)\mathbf{j} + (a_1b_2 - a_2b_1)\mathbf{k}$

Properties of the cross product:

If **a**, **b**, and **c** are vectors and *c* is a scalar, the

- ✓ **a** x **b** = –**b** x **a**
- ✓ (*c***a**) x **b** = *c*(**a** x **b**) = **a** x (*c***b**)
- ✓ **a** x (**b** + **c**) = **a** x **b** + **a** x **c**
- ✓ (**a** + **b**) x **c** = **a** x **c** + **b** x **c**
- ✓ **a** · (**b** x **c**) = (**a** x **b**) · **c**

- ✓ $\mathbf{a} \times (\mathbf{b} \times \mathbf{c}) = (\mathbf{a} \cdot \mathbf{c})\mathbf{b} - (\mathbf{a} \cdot \mathbf{b})\mathbf{c}$

Parallel Vectors

- ❖ Two nonzero vectors **a** and **b** are parallel if and only if **a** x **b** = **0**

Find **a** x **b**:

Given a = (1, 4,-1) and b = (2,-4,6),

$\mathbf{a} \times \mathbf{b} = (a_2b_3 - a_3b_2)\mathbf{i} + (a_3b_1 - a_1b_3)\mathbf{j} + (a_1b_2 - a_2b_1)\mathbf{k}$

A. $(4*6 - (-1)(-4))\mathbf{i} + ((-1)*2 - 1*6)\mathbf{j} + (1*(-4) - 4*2)\mathbf{k}$

B. $(24 - 4)\mathbf{i} + (-2 - 6)\mathbf{j} + (-4 - 8)\mathbf{k}$

C. $20\mathbf{i} - 8\mathbf{j} - 12\mathbf{k} = <20,-8,-12)$

Given $\mathbf{a} = \mathbf{j} + 6\mathbf{k}$ and $\mathbf{b} = \mathbf{i} + \mathbf{j}$,

$\mathbf{a} \times \mathbf{b} = ((1)(0) - 6(1))\mathbf{i} + (6*1 - 0*0)\mathbf{j} + (0*1 - 1*1)\mathbf{k}$

D. $-6\mathbf{i} + 6\mathbf{j} - \mathbf{k}$

E. $-6\mathbf{i} + 6\mathbf{j} - \mathbf{k} = (-5,6,-1)$

- ❖ The volume of the parallelepiped determined by the vectors **a**, **b**, and **c** is the magnitude of their scalar triple product:
- ❖ $V = |\mathbf{a} \cdot (\mathbf{b} \times \mathbf{c})|$
- ❖ If the triple scalar product is 0, then the vectors must lie in the same plane, meaning they are **coplanar.**

Chose the correct answer

1 Which of the following figure has four significant figures?
A. 0.0012m B. 0.1300m C. 0.0133m D. 6.543m

2 What will be the result if 4.1 cm $\pm$ 0.10cm + 9.82cm $\pm$ 0.20 cm?
A. 10.00 cm$\pm$ 0.2 cm C. 13.92 cm $\pm$ 0.1cm
B. 10.00 cm $\pm$ 0.4cm D. 13.9cm $\pm$ 0.3 cm

3 The area of a rectangular metal plate was found by measuring its length and its width. The length was found to be 5.37 cm $\pm$0.05cm and its width 2.4cm$\pm$0.1cm what is the area of the plate?
A. $12.9cm^2 \pm 0.7cm^2$ C. $13.55cm^2 \pm 0.66cm^2$
B. $12.89cm^2 \pm 0.7cm^2$ D. $13.55cm^2 \pm 0.888cm^2$

4 The error that arise because of the scale is not accurately drawn is known as
A. Parallax error B. Calibration error C. zero error D. all

5 The error that arise incorrect sighting the instrument is called
A. Calibration error B. parallax error C. random error D. all

6 The difference between the measured value and accepted value refers to

A. Error B. actual value C. True value D. All

7 One of the following is a special example of systematic error

A. Gross error B. Zero error C. Random error D. Environmental error

8 Repeated measurement having different values are

A. Random error B. systematic error C. gross error D. A and B

9 The accepted value of a certain length is 1.67 m and a student performs an experiment to measure this length and records the data as follows

Trial 1 measurement 1.58m
Trial 2 measurement 2.74m
Trial 3 measurement 1.33m

This experiment is

A. Accurate but not precise C. Precise but not accurate
B. Accurate and precise D. Neither accurate not precise

10 Which one of the following conditions cause to the environmental error?

A. Temperature B. Pressure C. Humidity D. All

11 Observational error causes by

A. Inaccurate estimation C. wrong scale reading
B. Incorrect conversion of unit D. all of the above

12 A student measures the density of unknown substance is 3.5g/cm^3. If the actual value of the unknown substance is 3.6 g/cm^3, what is the percentage error?

A. 2.8 % B. 4 % C. 5 % D. 1.8 %

13 The type of vector which lie in the same plane is called

A. Coplanar Vectors C. Free Vector
B. Concurrent Vectors D. Bounded Vectors

14 The vectors which pass through the common point are called

A. Concurrent Vectors C. Collinear Vectors:
B. Equal Vectors D. Position Vectors

15 A vector whose position is not fixed in space is called

A. Unit Vector B. Free Vector C. Equal Vectors D. Position Vectors

16 Two forces, 7N and 5N, exerts on a body at an angle of 60° with each other. What is the magnitude of the resultant force? ($\sin 60^0 = 0.8$, $\cos 60^0 = 0.5$)

A. 35N B. 17.5N C. $\sqrt{109}$N D. $\sqrt{105}$N

17 The horizontal component of a force "F" is 7 N that makes an angle of 37^0 with the positive x-axis. What is the magnitude of the force "F"? ($\sin 37^0 = 0.6$, $\cos 37^0 = 0.8$)

A. 8.75 N B. 12 N C. 5.6 N D. 4.2 N

18 Which of the following statements is true about scalar and vectors?

A. A vector quantity always has direction associated with it
B. Scalar quantity always has direction associated with it
C. vector can be added together, scalar quantities can not
D. scalar can be added together, vector quantities can not

19 The x- and the y- components of two vectors A and B are $A_x = 5$, $A_y = 7$, $B_x = -9$ and $B_y = -6$. The magnitude of the sum of these two vectors is:

A. 9 B. 5 C. 16 D. $\sqrt{17}$

20 What is the dot product of F = (10i +5j) and S = (7i+4j)

A. 26 J B.60J C. 90 J D. 40J

21 What is the torque due to a force $\overrightarrow{F} = (i\text{-}3j\text{+}\dot{k})$ N acting at a point $\vec{r} = (2i + 5j + \dot{k})$ m about the origin?

A. $8i\text{+}j - 11\dot{k}$ C. $-8i\text{+}j\text{-}11\dot{k}$

B. $-8i\text{+}j\text{+}11\dot{k}$ D. $8i\text{-}j\text{-}11\dot{k}$

22 For what values of "**a**" are the vectors $\vec{A} = \mathbf{a}i\text{-}2j\text{+}\dot{k}$ and $\vec{B} = 2\mathbf{a}i\text{+}\mathbf{a}j\text{-}4\dot{k}$ perpendicular to each other?

A. 2,-1 B. -3, 1 C. 0,1 D. 0,-2

23 The area of a triangle formed by ($i + j + \dot{k}$) unit and($2i - j\text{+}3\dot{k}$) unit is

A. $\frac{26}{2}$ Square units C. $\frac{\sqrt{26}}{2}$ Square units

B. $\frac{9}{2}$ Square units D. $\frac{\sqrt{9}}{2}$ Square units

24 Which of the following is the condition for two vectors to be **collinear**?

A. The vectors should have the magnitude 0 and 1
B. The vectors should have the same initial point
C. The vectors should be parallel to the same line
D. The vectors should have the same magnitude

25 If vector $\vec{A}$ and $\vec{B}$ are parallel, then

A. $\vec{A}\text{x}\vec{B} = 0$ C. $\vec{A} - \overrightarrow{B} = 0$

B. $\vec{A} \cdot \vec{B} = 0$ D. $\vec{A} + \vec{B} = 0$

26 If $\overrightarrow{|A|} = 3, \overrightarrow{|B|} = 4$ and $\vec{A} \cdot \vec{B} = 6$ then the value of $|\vec{A}x\vec{B}|$ will be

A. $8\sqrt{3}$ B. $4\sqrt{3}$ C. $6\sqrt{3}$ D. $\sqrt{3}$

27 Given $|\vec{A}x\vec{B}| = |\vec{A} \cdot \vec{B}|$.What is the angle between $\overrightarrow{A}$ and $\vec{B}$?

A. 90^0 B. 30^0 C. 45^0 D. 60^0

28 If a unit vector represented by xi +0.4j + 0.2k , then the value of x is

A. 0.8 B. 0.2 C. $\sqrt{0.8}$ D. $\sqrt{0.2}$

29 A boy runs 200m on a straight path making an angle of 53^0 East of North. How far east and how far north does he move from his starting point respectively? ($\sin 53^0 = 0.8$, $\cos 53^0 = 0.6$)

A. 200m, 160m B. 120m,160m C. 120m, 200m D. 12m,16m

30. The angle between $\overrightarrow{A}$ and $\overrightarrow{B}$ is θ. Then value of triple product, $\vec{A}.\vec{B}\text{X}\vec{A}$ is

A. $A^2B\sin\theta$ B. $A^2B\cos\theta$ C. A^2B D.zero

UNIT 2: KINEMATICS

- Kinematics is the branch of physics that deals with the analysis of the motion of objects without concern for the forces causing the motion. Scientists have developed equations that describe the movement of objects within certain parameters, such as objects moving with a constant velocity or a constant acceleration

Uniform motion: - the speed of a moving body may be uniform or variable. The speed is said to be Uniform when the body in motion covers equal distance in equal time interval

*For a body moving with a uniform (constant) speed

- ✓ Distance :- it is the total path length b/n two points
- ✓ Displacement : ($\vec{S}$):it is the shortest path length b/n two points
- ✓

$$\text{Speed (V)} = \frac{\text{distance travelled (S)}}{\text{Time taken (t)}} \qquad \boxed{V = \frac{S}{t}}$$

- ✓ SI unit of speed m/sec
- ✓ It is scalar physical quantity
- ✓ When more than one uniform motion with different speed exists we introduce the concept of average speed

$$\text{Average speed (Vav)} = \frac{total\ distance\ travelled}{total\ time\ taken}$$

$$\boxed{Vav = \frac{S_T}{\ }} \qquad S_T = S_1 + S_2 + S_3 + - - -$$
$$t_T = t_1 + t_2 + t_3 + - - -$$

$$\boxed{1m/sec = 3.6\ km/hr.}$$

Velocity ($\vec{V}$): is the displacement covered divided by the time interval during that displacement

- ✓ It is a vector physical quantity
- ✓ SI unit of velocity is m/sec
- ✓

$$\boxed{\vec{V} = \frac{S}{t}}$$

- ✓ When the velocity is variable average velocity is fined as the total displacement divided by the total time taken.

$$\vec{V}av = \frac{St}{tT}$$

Uniformly accelerated motion in 1D

Uniformly Accelerated Motion (UAM) is motion of an object where the acceleration is constant. In other words, the acceleration remains uniform; the acceleration is equal to a number and that number does not change as a function of time.

Examples of objects in UAM:

- A ball rolling down an incline.
- A person falling from a plane.
- A bicycle on which you have applied the brakes.
- A ball dropped from the top of a ladder.
- A toy baby bottle released from the bottom of a bathtub.

- Acceleration is the rate of change of velocity
- It is measured by m/sec^2
- $\vec{a} = \frac{\Delta V}{\Delta t} = \frac{Vf - Vi}{t}$ = average acceleration($\vec{a}_{av}$)

- When the velocity changes at a uniform rate because of constant acceleration, average velocity will be the average of the initial and final velocities
- Negative acceleration may or may not be deceleration, and deceleration may or may not be consider negative acceleration. If the velocity and acceleration have the same sign whether positive or negative it is speeding up. If the velocity and acceleration have different signs, then the object is slowing down

Instantaneous acceleration

The instantaneous acceleration is the acceleration at a particular instant of time and it is given by

$\vec{a}_{inst} = \lim_{\Delta t \to 0} \frac{\Delta \vec{V}}{\Delta t} = \frac{dV}{dt}$

The average acceleration between two points in time separated Δt , Δt approach to zero

- Instantaneous velocity it is the velocity of a body at instant of time
- $\vec{V}_{inst} = \lim_{\Delta t \to 0} \frac{\Delta \vec{x}}{\Delta t} = \frac{dx}{dt}$

Starting and stopping

- ✓ When a body accelerates from rest, its initial velocity is zero (Vi = 0)
- ✓ When a decelerating body comes to rest (stops),its final velocity becomes zero ($V_f = 0$)

Equations of a uniformly accelerated rectilinear Motion

1. $\vec{a} = \frac{Vf - Vi}{t}$
2. $V_f = Vi + at$
3. $Vav = \frac{Vf + Vi}{2}$
4. $S = Vav.t$
5. $S = \frac{(Vf + Vi).t}{2}$
6. $S = Vi.t + 1/2at^2$
7. $S = V_f.t - 1/2at^2$
8. $S = \frac{Vf^2 - Vi^2}{2a}$

*Distance travelled by a body in any particular second (n^{th} second) of its motion will be

9. $S_n = Vi + \frac{1}{2}\vec{a}(2t - 1)$

Relative velocity

Suppose two cars A and B are moving at velocity $\vec{V}_{AE}$ and $\vec{V}_{BE}$, respectively, relative to the Earth on a straight level road. If the cars move in the same direction, the velocity of B relative to A is given by

- $\vec{V}_{BA} = \vec{V}_{BE} - \vec{V}_{AE}$

If the cars move in the opposite direction, the velocity of B relative to A is given by

- $\vec{V}_{BA} = \vec{V}_{BE} + \vec{V}_{AE}$

- ✓ **Key ideas for relative velocity in two dimensions**: The relative velocity equation
- $\vec{V}_{BA} = \vec{V}_{BE} + \vec{V}_{AE}$ applies just as well in two or three dimensions as it does in one dimension. To solve the equation, we can apply the vector-addition methods, such as the component method,

Projectile Motion (compound motion)

Projectile motion is motion of a body where

- The path is determined by the action of gravity, and the only force acting on a body is gravitational force
- The path of a projectile is called its trajectory and it is parabolic in shape
- This motion is same times called compound motion for the simple reason that it Consists of both horizontal and vertical motion therefore, the motion is analyzed In the X – Y plane

Important points

1. There is no force acting on a projectile of mass 'm' in the horizontal direction

i.e. $\vec{F}_X = m\hat{a}_x = 0$

$\hat{a}_x = 0 \Rightarrow$ hence velocity is constant

Therefore, the initial velocity in the X – direction equals to final velocity in the x – direction

Horizontal motion is motion at constant velocity

- $V_{ox} = V_{fx}$, where V_{ox} = initial velocity in the X – direction
  V_{fx} = final velocity in the x – direction

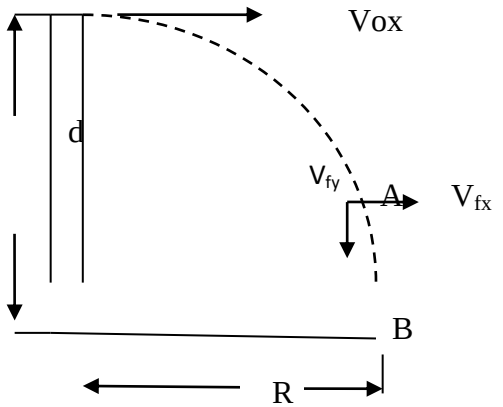
2. The force acting on the mass 'm' in the vertical direction is force of gravity

i.e. $F_y = m\hat{a}_y = m\vec{g}$

$\hat{a}_y = \vec{g}$

Vertical motion is free fall

Horizontal projection (2D) - A body of mass 'm' that is given an initial velocity V_{ox} in the horizontal



direction from a height 'h' above the ground

- If A is the position of the projectile after time't' the

$X = Vox.t$

$y = -\frac{1}{2}\vec{g}t^2$ --- where $\vec{V}_{oy} = 0$

$R = V_{ox}.\ t_T$ Range of the projectile

Range is the total horizontal distance

The total time taken to reach the ground can be determined using the equation

- $h = V_{oy}.\ t_{tol} - \frac{1}{2} g\ t^2_{tol}$ but V_{oy} is zero

$$t_T = \sqrt{\frac{2h}{g}}$$

The components of the velocity at point 'A' will be

- $\vec{V}_{ox} = V_{fx}$
- $\vec{V}_{fy} = \vec{g}.t$

The resultant velocity or instantaneous velocity

$$V = \sqrt{Vox^2 + Vfy^2}$$

2. Vertical projectile motion (1D)

When an object is falls to the ground under gravitational pull, experiment shows that the object has a constant or uniform acceleration and its value on or near to the surface of the Earth is $9.8 m/s^2$,

Signs of vectors

i. All vectors directed vertically upwards are positive

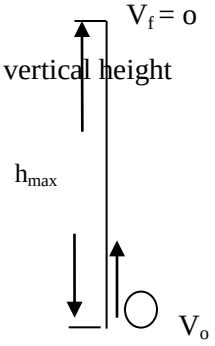
ii . All vectors directed vertically down words are negative

iii. The acceleration vector g is always directed down wards therefore it is always negative

Objects thrown straight up

$V_f = o$

2. The vertical height $h = vo.t - \frac{1}{2}gt^2$



1. Maximum height reaches by the object, $h_{max} = \frac{V02}{2g}$

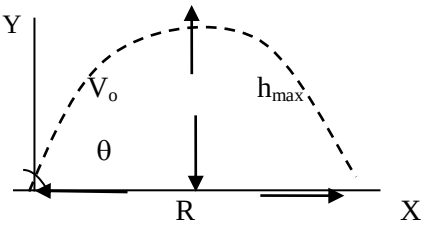
3. Final velocity at any time $V_f = V_O - gt$

4. Time taken to reaches maximum point, $t_{max} = \frac{Vo}{g}$

5. Total flight of time, $t_T = \frac{2Vo}{g}$

1. Inclined projection (2D) (oblique projection)

✓ When a mass "m" projected from the ground with an initial velocity of 'v_o',at an angle of 'θ',as shown in the fig below



i. Motion in the X – direction

- Initial velocity, $V_{ox} = V_o \cos\theta$
- Final velocity, $V_{fx} = V_o \cos\theta$
- Displacement, $X = Vo_x . t = V_o \cos\theta . t$
- Range, $R = V_o \cos\theta . t_T$

ii. Motion in the Y-direction

- Initial velocity, $V_{oy} = V_o \sin\theta$
- Final velocity, $V_{fy} = Vo \sin\theta - g t$
- Displacement, $y = V_o \sin\theta . t - ½ gt^2$

iii. Total time (flight of time) (t_T)

$$t_T = \frac{2Vo\sin\theta}{g}$$

iv. Maximum height (h_{max})

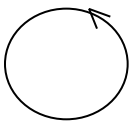
$$h_{max} = \frac{Vo^2.\sin^2\theta}{2g}$$

V. Range(R)

- $R = v_{ox}.t_T$
- $R = \frac{2Vo^2\sin\theta.\cos\theta}{g} = \frac{Vo^2.\sin 2\theta}{g}$

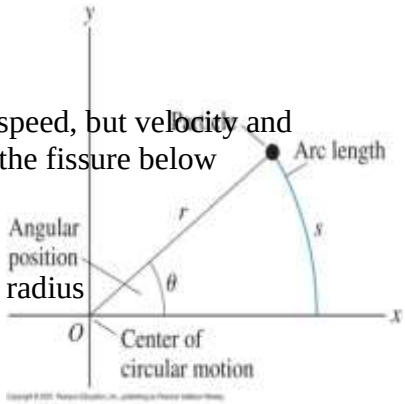
Uniform circular motion

-it is a type of motion about curved path with constant radius at steady speed, but velocity and acceleration is not constant because of the direction change as show in the fissure below



Where θ = angular displacement

S = tangential displacement and r = radius



Angular displacement (θ) can be measured by

$1rev = 360^0 = 2\pi rad$

i . Degree

ii . Radian

iii. Revolution

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

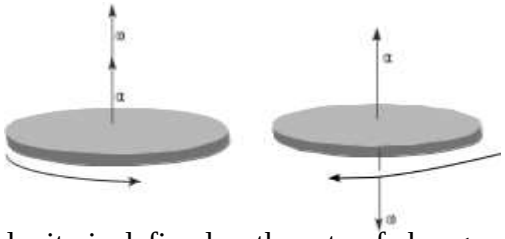
✓ The SI unit of angular displacement is rad

Angular velocity (ω)

✓ It is the rate of change of angular displacement
✓ It is denoted by **ω** (Greek letter omega)
✓ The unit of angular velocity is rad/sec
✓ It can also expressed as rev/min
✓ It is vector and its direction is determine by using RHR (Right Hand Rule)

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

RHR – Wrap your four right-hand fingers in the direction of rotation. Your extended thumb points



✓ Tangential (linear) velocity is defined as the rate of change of tangential displacement
✓ Linear velocity related with angular velocity by

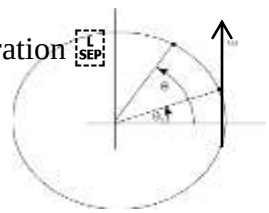
$V_t = \omega * r$

✓ It is vector and its direction is always a the tangent point
✓ SI unit m/sec

Acceleration in uniform circular motion

- when an object moves in a circular path ,such as a stone tied to one end of a string and whirled ,the speed of the object remains constant but the direction of its velocity changes continually
- If the magnitude of the tangential velocity is constant and its direction changes continuously due to the change in direction of the tangential velocity, there is a component of acceleration in the direction of the tension. This acceleration is called centripetal acceleration (a_c).Moreover, if the magnitude of the velocity changes, there is a component of acceleration tangent to the circle. This acceleration is called tangential acceleration (a_t)
  - Centripetal acceleration
  - Acceleration points towards centre (radial) acceleration

$$a_c = \frac{v2}{r} = \omega^2.r = \frac{4\pi r2}{T}$$



- Where T is the period = the time taken for one complete rotation
- Since V = $\frac{2\pi r}{T}$

Centripetal force

- Since the object is accelerating, there must be a force to keep it moving in a circle
- This centripetal force may be provided by friction, tension in a string, gravity etc. or combinations.
- Note that centripetal force is the *name* given to the resultant force: it is **not** a separate force in the free-body diagram.
- The centripetal acceleration has to be provided by some other force (tension, friction, normal force) in order for circular motion to occur.
- If the object is moving in a circle, there must be a **net force** pointing towards the centre of the circle.
-
- The magnitude of this net force is given by

$$F_c = ma_c = \frac{mv2}{r} = m\omega^2.r$$

Angular acceleration

- It's the rate of change of angular velocity
- $\alpha = \frac{\Delta\omega}{\Delta t} = \frac{\omega f - \omega i}{t}$ where ωf = initial angular velocity and ωi = initial angular velocity
- the unit of angular acceleration is rad /sec^2
- It is vector and its direction is determine by using RHR (Right Hand Rule)
- **RHR** – Wrap your four right-hand fingers in the direction of rotation. Your extended thumb points in the direction of α

.

Tangential acceleration

- It's the rate of change of tangential velocity
- It is the linear acceleration of a rotating body and is given by
- $a_t = \frac{\Delta v}{\Delta t} = \alpha.r$
- SI unit m/sec^2 and its direction always at the tangent point

Note

- ❖ All points on a body undergoing circular motion necessarily have the same angular displacement(θ),speed(ω) and acceleration(α).their linear(tangential) values depends on the radius .That is S = θ.r , V = ω.r and a_t = α.r
- ❖ For accelerated circular motion, the centripetal acceleration and tangential acceleration are perpendicular to one another, therefore the total acceleration must be found by vector addition

a = $\sqrt{ac^2 + at^2}$ = r$\sqrt{\omega^4 + \alpha^2}$

Constant angular acceleration formulas:

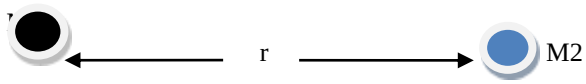
- $\omega_f = \omega_i + \alpha t$
- $\theta = \left(\frac{\omega f + \omega i}{2}\right).t$
- $\theta = \omega i.t + \frac{1}{2}\alpha t^2$
- $\theta = \omega_f.t - \frac{1}{2}\alpha t^2$
- $\omega f = \sqrt{\omega i^2 + 2\alpha\theta}$

Newton's Law of Universal gravitation

- ✓ Newton states that everybody attracts every other body irrespective of its shape and size. The mutual attraction of material bodies due to their masses is called gravitational attraction. It exists between
- ✓ Planets
- ✓ The sun and planets
- ✓ Between two masses on the surface of the Earth
- ✓ Molecules of any substance

Newton's law of gravitation states that

"Any two bodies in the universe attracts each other with a force which is directly proportional to the product of their masses and inversely proportional to the square of the distance between them"



$$\vec{F} = \frac{G.m1.m2}{r^2}$$

Where G is called universal gravitational constant

$G = 6.67 \times 10^{-11}\ N.m^2/kg^2$

Kepler's Law

- ✓ Johannes Kepler (1571-1630) had studies for many years, the records of observation on the planets and discovered three laws known by his name

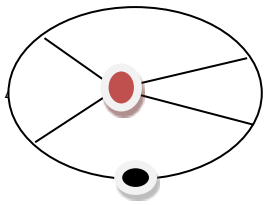
Law 1: the orbits of the planets are ellipses with the sun at one focus

Law 2: a line drawn from the planet to the sun sweeps out equal areas in equal times

Area 1 = Area 2

When, $\Delta t_1 = \Delta t_2$

$|V1| = |V2|$



Δt_2

Planet

Law 3: the square of the time of one revolution of a planet about the sun is directly proportional to the cube of its average distance from the sun.

That is $\frac{T^2}{R^3}$ = constant

Acceleration due to gravity

The gravitational force of attraction between a body of mass "m" and the Earth when the body is on or near the surface of the Earth is called the force of gravity (F_g)

- $\vec{F}_g = \frac{GMe.m}{r^2}$ where Me mass of the Earth, m mass of the body and r the radius of the Earth
- This force equals to the weight of the body
- mg = $\frac{GMe.m}{r^2}$
- g = $\frac{G.Me}{r^2}$ on the surface of the Earth
- At a given height "h" above the surface of the Earth
- g = $\frac{G.Me}{(r+h)^2}$

The period, position and function of a Geostationary Satellite

The earth now a day has a large number of satellites in orbit round it. Most were made by humans, but the biggest one of them all is natural the Moon.

Since the path of the Moon as it travel around the Earth is very nearly a circle and it is subjected to a centripetal force

- ✓ $\vec{F}_c = \frac{mv^2}{r}$
- ✓ were m is the mass of the Moon, v orbital speed and r is the distance from the Earth to the Moon
- ✓ From Newton law of universal gravitation
- ✓ F = $\frac{G.m1.m2}{r^2}$
- ✓ Hence F_c = F
- ✓ $\frac{mv^2}{r} = \frac{G.m1.m2}{r^2}$
- ✓ Then the orbital velocity become

$V_t = \sqrt{\frac{GM}{r}}$ …… Orbital velocity

Escape velocity of a satellite

- ✓ Escape velocity is the speed necessary for an object to completely escape the gravity of a large body such as a moon, planet or star. By using the conservation of energy and setting an object's kinetic energy equal to its negative gravitational potential energy, one can solve for velocity.
- ✓ *KE = PE*
  - ❖ $V_{ESC} = \sqrt{\frac{2GM}{R}}$



Worked examples

1 Starting from point A (x = 0) a ball rolls on a number line up to point B (x = 400cm) in 2.5 seconds and then turns back 100cm towards the starting point points in another 1 second what are the magnitudes of the speed and velocity

A. In moving from A to B

B. In moving from A to B and then to C

A B

X =0 X = 400cm

Sol^{n}. A) S = 400cm, $\vec{S}$ = 400cm towards B, t = 2.5sec

$V = \frac{S}{t} = \frac{400cm}{2.5sec} = 1.6m/sec$

Since the magnitude of distance and displacement is the same, the magnitude of the average velocity is also the same as the average speed

$Vav = \frac{400cm}{2.5\ sec} = 1.6\ m/sec$

B) In moving from A to B and then C

A C B

S_T = 400 cm + 100 cm = 500 cm

t = 2.5sec + 1sec = 3.5sec

$Vav = \frac{S}{t} = \frac{500cm}{3.5sec} = 1.43m/sec$

$\vec{S}_T$ = 400cm -100cm = 300cm

t_T = 2.5sec + 1sec = 3.5sec

$Vav = \frac{\vec{S}_T}{} = \frac{300cm}{} = 0.86m/sec$ towards A

t_T 3.5sec

2 A body starts its motion with an initial speed of 4m/sec and continues to move with an acceleration of 2m/sec^2 in 10 sec .**Find**

A. The velocity at the end of 6sec

A. The average velocity at the end of 6sec

B. The distance moved

Given
V_i = 4 m/sec
$\vec{a}$ = 2 m/s^2
t = 10 sec

sol^n
A) V_f = Vi + at
= 4 + 2 X 10
= 24m/s

B) Vav = $\frac{V_f + Vi}{2}$
= $\frac{24 + 4}{2}$
= 14 m/s

C) S = Vav x t
= 14 X 10
= 140m

3 A car initially at rest is accelerated uniformly at a speed of 20 m/sec in 5sec what is the distance covered by the car during the fifth second?

Given
V0 = 0
V_f = 20 m/sec
t = 5sec

so/n
$\vec{a}$ = $\frac{V_f - Vi}{t}$ = 4m/sec

S = Vi + 1/2a (2t – 1)

= 0 + ½ .4(2.5 – 1) = 18 m

4 The velocity of a particle that moves along a straight line varies as a function of time with a velocity equation as: V (t) = t^2-2t.Find the acceleration the particle at t= 2 sec

a (t) = $\lim_{\Delta t \to o} \frac{\Delta \vec{V}}{\Delta t} = \lim_{n \to \infty} \frac{\overrightarrow{V(t+\Delta t) - V(t)}}{\Delta t}$

Since, V (t) = t^2-2t

= $\lim_{\Delta t \to o} \frac{\overrightarrow{[t+\Delta t]2 - 2(t+\Delta t) - (t2 - 2t)}}{\Delta t}$

=2t-4 = 2*2- 2 = 2m/sec^2

5. The position of the particle moving along the x axis is described by x = 6t^2- 4t+20, where x is in meter and t in seconds. What is the acceleration of the particle?

Solution: $\vec{a} = \frac{dx2}{dt}$ = 12 m/sec^2

6. What is the instantaneous velocity of a particle at 2 seconds if it motion is described by the equation of
X= a + 4bt^2, where a =6 m/sec and b = 3m/se^2?

Solution: V = $\frac{dx}{dt}$ = 8bt = 8x3x2 = 48 m/sec

7. A frog can jump 0.9m with a takeoff angle 45^0
   A. What initial velocity does this required?
   B. How high could a frog jump

Solution: A. $R=\frac{V^2 \sin 2\theta}{g}$ $=V=\sqrt{\frac{Rg}{\sin 2x45}}$ $=\sqrt{0.9x10}$ = 3m/sec

B. h = $\frac{V^2 \sin \theta^2}{2g}$ $=\frac{(3)^2}{2x10}x1$ = 0.45m

8. A projectile is launches at an angle of 45^0 above the horizontal ground with a velocity of 10m/sec.Determain the maximum range

Solution: $R=\frac{V^2}{4g}$, since it is projected at a angle of 45^0

$R=\frac{10^2}{4x10}$ = 2.5m

9. What is the acceleration of a particle moving in a circular path of radius 0.5 m with an angular speed of 5 rad/sec?

Solution: $a = \omega^2.r = (5 \text{ rad/sec})^2 \text{ x } 0.5\text{m} = 12.5\text{m/sec}^2$

10. The period of Jupiter is 11.86 years. Determine its distance from the Sun.(take period of the Earth 1 year and mean distance $1.5x10^{11}$m)

Solution: $\frac{TJ^2}{RJ^3}=\frac{TE^2}{RE^3}$

- ✓ Where T_J period of the Jupiter
- ✓ T_E period of the Earth
- ✓ R_J mean distance of the Jupiter
- ✓ R_E mean distance of the Earth
- ✓ $R_J=\frac{(11.86\ yeay)^2}{(1year)^2}.(1.5x10^{11}\text{m})3$
- ✓ $R_J = 7.8x10^{11}$m

I. **Chose the correct answer**

1. A car covers a certain distance with uniform acceleration, starting from rest, and reaches a final velocity of 20m/sec. Its velocity after half the distance is:-

   A. 10m/sec B. $\sqrt{20}$m/sec C. 10 m/sec D. $\frac{10}{\sqrt{2}}$ m/sec

2. A ball is thrown vertically up ward with an initial velocity of 20m/sec. Its velocity in m/sec, when it strikes the ground will be:- ($\bar{g}$ = 10m/sec)

   A. 10 B. 20 C. 40 D. 30

3. The rate of change of distance moved with time in a specific direction is called

   A. Speed B. Velocity C. Acceleration D. Average speed

4. An object accelerated from rest for 't' seconds, the equation of the average speed for this time interval is:-

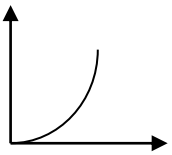
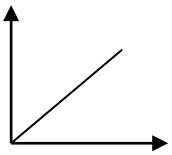
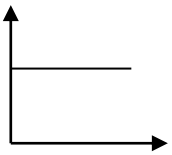
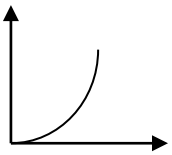
   A. ½ $\bar{a}$t B. ½ $\vec{a}t^2$ C. 2$\bar{a}$t D. $\frac{\vec{a}}{2t}$

5. On a distance time graph a horizontal straight line corresponds to motion at:

   A. zero velocity C. increasing velocity

B. constant velocity D. decreasing velocity

6. Which of the following graphs do not represent a uniformly accelerated motion

A.  B.  C.  D. 

7. If 4 *i* + j -3k and p *i* +qj -2k are collinear vectors, then what are the possible values of p and q?

A. 4, 1 B. 1, 4 C. $\frac{8}{3},\frac{2}{3}$ D. $\frac{2}{3},\frac{8}{3}$

8. If vector A and B are perpendicular to each other with values A = 2 *i* + λj + k and B = *i* − 2j + 3k, then what is the value of λ?

A. $\frac{2}{5}$ B. $\frac{-2}{5}$ C. $\frac{5}{2}$ D. $\frac{-5}{2}$

9. The type of vector which lie in the same plane is called

C. Coplanar Vectors C. Free Vector

D. Concurrent Vectors D. Bounded Vectors

10. The vectors which pass through the common point are called

C. Concurrent Vectors C. Zero vectors

D. Equal Vectors D. Position Vectors

11. Give three vectors A = *i* + 2j -3k B = 2 *i* - j + k and C = 5 *i* - λj +4k are coplanar vectors. What will be the value of λ?

A. $\frac{5}{7}$ B. $\frac{25}{7}$ C. $\frac{3}{7}$ D. $\frac{10}{7}$

12. If the value of the gravitational acceleration on the surface of the earth is g, then what will be its value at a distance of h = $6.38\text{x}10^6$m from the surface of the earth?

A. $\frac{g}{8}$ B. $\frac{g}{4}$ C. $\frac{g}{2}$ D.g

13. Two satellites are monitored as they orbiting the Earth; satellite Y is four times as far from the Earth's center as is satellite X. if the period of revolution of X is T, what is the period of revolution of Y?

B. 2 T B. 4 T C. 8 T D. 16 T

14. if a unit vector represented by 0.2 *i* + 0.3j +ck, then the value of c is

C. $\sqrt{0.78}$ B.$\sqrt{0.87}$ C.$\sqrt{0.04}$ D. $\sqrt{0.09}$

A. An object is launched at an angle of θ, how does the final velocity compare to the initial velocity if it lands at the same horizontal level?

A. Opposite C. Equal

B. Equal and Opposite D. Unable to determine

B. Which of the following is NOT an example of projectile motion?

A. a hot-air balloon drifting toward Earth C. a long jumper in action

B. a volleyball served over a net D. a baseball hit by a bat

C. An archer uses a bow to fire two similar arrows with the same string force. One arrow is fired at an angle of 60^0 with the horizontal, and the other is fired at an angle of 30^0 with the horizontal. Compared to the arrow fired at 60^0, the arrow fired at 30^0 has
   A. longer flight time and longer horizontal range
   B. shorter flight time and longer horizontal range
   C. shorter flight time and shorter horizontal range
   D. longer flight time and shorter horizontal range

18. The wheel of a cycle rotates with a constant angular acceleration of $2rad/sec^2$.if it attains an angular velocity of 100 rad/sec in 30 sec, what was its initial angular velocity?
   A. 160rad/sec B. 60rad/sec C. 40rad/sec D. zero

19. If a point on a spinning wheel changes its angular speed by a factor of 3 and its angular acceleration by a factor of 9. The magnitude of the total acceleration changes by a factor of ?
   A. 3 B. $\frac{1}{3}$ C. $\frac{1}{9}$ D .9

20. The escape velocity from the earth for a rock is 11.2 km/sec. the escape velocity of 2 kg body from the earth will be
   B. 112 km/sec B.1.12 km/sec C. 11.2 km/sec D. 0.112km/sec

21. Gravitational force of attraction “F" exists between two point masses, A and B, when they are separated by a fixed distance. After mass A is doubled , mass B is tripled and the distance between the masses decrease by half a, the new gravitational attraction between the two masses is
   A. $\frac{1}{24}$ F B. $\frac{6}{12}$ F C.$\frac{3}{2}$ F D.24 F

22. For planets orbiting the sun, the ratio of the orbital period the planet squared to the cubed of their mean distance of the orbit is
   A. Greatest for the massive planets C. The same for all planets
   B. Greatest for the least massive planets D. Constantly changing as a planet rotates

23. Car A traveling relative to the ground at 60Km/hr on straight level road is a head of car B traveling un the same direction at 80Km/hr. the velocity of car A relative to car B is
A. 20Km/hr B. 140Km/hr C. -20Km/hr D. -140km/hr

24. The displacement time graph of a moving object is a straight line that makes an angle of$30^0$with the time axis and passes through the origin. Which of the following is true about the motion of the object?

The speed of the objects is constant
   A) The slope of the line represents the acceleration of the object
   B) The slope of the line represents the speed of the object
   C) A and C

25. A girl standing on a bridge wants to find out how high the bridge is above the water surface. if she drops a stone and records the time to hit the water surface to be about 2 seconds, the height of the bridge above the water surface is approximately ($\vec{g}$ =10m/sec^2)
   A) 30m B) 25m C) 20m D) 10m

26. Two forces of magnitude 5 N and 4 N are acting on body at an angle of 120^0 to each other. What is the magnitude of the resultant force exerted on the body?
   ($Sin120^0$= 0.86, $Cos120^0$ = - 0.5)
   A. 9 N B. $\sqrt{7}$ N C. $\sqrt{21}$N D. 20 N

27. Two forces having magnitude of 15N and 10 N. the magnitude of the resultant force can never be

A. 5 N B. 25 N C. 12 N D. 25 N

28. the scalar product of A = 3 *i* +5j-k and B 2 *i* +j +4k is

A. 7 B. 6 C. 10 D. 40

29. Two forces F_1 = (2 *i* +j+3k) N and F_2 = (4 *i* +2j -3k) N acts on a particle to displace it from the point
(5 *i* +4j+6k) m to (12 *i* + 3j+ 10k) m. What is the net work done?

A. 21 J B. $\sqrt{21}$ J C. 39J D. $\sqrt{39}$ J

30. If θ is the angle between vector A and B, then $\frac{A\ x\ B}{A.B}$ is

A. $\sin\theta$ B. $\cos\theta$ C. $\tan\theta$ D. $\cot\theta$

UNIT 3: DYNAMICS

A force is commonly imagined as a push or a pull on some object, the known fundamental forces in nature are all field forces. These are in order of decreasing strength,

a. The strong nuclear force between subatomic particles
b. The electromagnetic forces between electric charges
c. The weak nuclear force, which arises in certain radioactive decay processes
d. The gravitational force between objects.

Newton's laws of motion

Newton's first law of motion (Law of Inertia)

Objects at rest or in uniform motion (at a constant velocity) in an inertial reference frame remain so unless acted upon by an unbalanced (net) force

Newton's second law of motion (Law of Dynamics)

The net force applied to an object is directly proportional to its acceleration in an inertial reference frame. The constant of proportionality is called the mass of the object. We write this algebraically as:

$$\sum F = ma = m\frac{\Delta v}{\Delta t} = \frac{\Delta \vec{P}}{\Delta t}$$

Newton's third law of motion (Law of Reaction)

If object A exerts a force F_{AB} on object B along a line connecting the two objects, then object B exerts an equal and opposite reaction force of F_{BA} on object A. We write this algebraically as:

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

Friction

An object moving on a surface encounters resistance as it interacts with its surroundings. This resistance is called friction. There are two types of frictional forces: static friction and kinetic friction.

Static friction

$$fs \leq f_s max = \mu_s N$$

Kinetic friction

$$f_k = \mu_k N$$

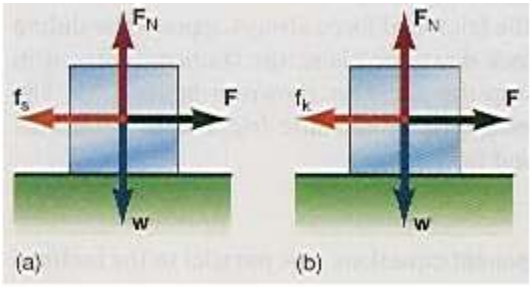
Worked Example 1

A 220-N wooden box is at rest on a wooden floor, as shown in figure shown below.



a. What horizontal force is necessary to start the box into motion? (μ_s=0.5)
b. If a force of 90N is continuously applied once the box is in motion, what will be its acceleration? (μ_k=0.3)

Solution:



a. The minimum force necessary to overcome static friction is found from equation

$$F = fs = \mu_s N = (0.50)\ (220) = 110N$$

b. Newton's second law applied to the box is

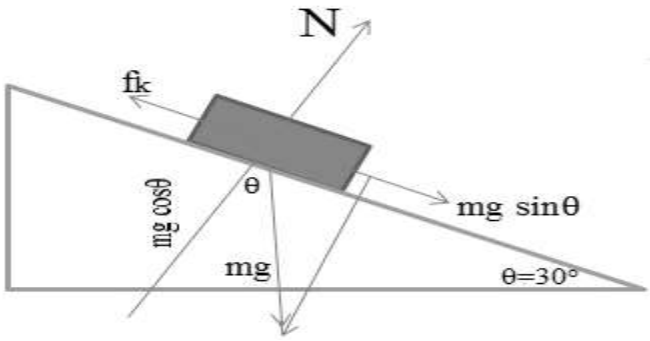
$$F - f_k = ma$$

$$f_k = \mu_k N = (0.30)(220\ N) = 66N$$

$$a = \frac{F - f_k}{m} = \frac{(90-66)N}{22kg} = 1.06 m/s^2$$

Worked Example 2

Find the acceleration of a block on an inclined plane (if $\mu_k = 0.3$ and $\theta = 30°$)



Solution:

Components Parallel to the Plane:

$$mg \sin \theta - fk = ma$$

$$N - mg\cos \theta = 0$$

$$mg \sin \theta - \mu_k mg \cos \theta = ma$$

Therefore; $mg \sin \theta - \mu_k mg \cos \theta = ma$

$$a = g \sin \theta - \mu k g \cos \theta$$

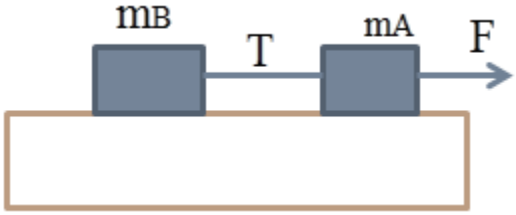
$$a = 9.80\ m/s^2) \sin 30° - (0.3)(9.80\ m/s^2)\cos 30°$$

$$a = 4.90\ m/s^2 - 2.55\ m/s^2$$

$$a = 2.35\ m/s^2$$

Worked Example 3:

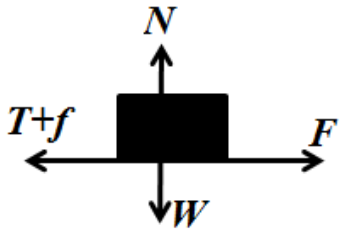
A block of mass m_A = 200 g is connected by a string of negligible mass to a second block of mass m_B = 400 g. The blocks are at rest on a rough table with a coefficient of kinetic friction of 0.3, as shown in figure below. A force of 2.50 N in the positive x-direction is applied to mass m_A. Find



a. The acceleration of each block
b. the tension in the connecting string
c. the position of mass A after 1.50 s
d. The velocity of mass A at 1.50 s.

Solution:

a. Applying Newton's second law to the first mass (m_A) gives



$F - T - f_{kA} = m_A a$

$f_{kA} = \mu_{kA}N = \mu_{kA}w_A = \mu_{kA}m_A g$ substitute this in the first equation we have

$$F - T - \mu_{kA}m_A g = m_A a \qquad (1)$$

We now apply Newton's second law to block B to obtain

$T - f_{kB} = m_B a$ where the force of kinetic friction on block B is

$f_{kB} = \mu_{kB}N = \mu_{kB}w_B = \mu_{kB}m_B g$

$$T - \mu_{kB}m_B g = m_B a \qquad (2)$$

Using equations (1) and (2) $a=1.23 m/s^2$

b.

$T - \mu_{kB}m_B g = m_B a$

$T = \mu_{kB}m_B g + m_B a$

$T = m_B[\mu_{kB}g + a]$

$T = (0.400\ kg)\ [(0.3)\ (9.80\ m/s^2) + 1.23\ m/s^2] = 1.67\ N$

c. The position of mass A after 1.50 s is found from the kinematic equation

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

Because the block starts from rest, $v_0 = 0$, and the block moves the distance

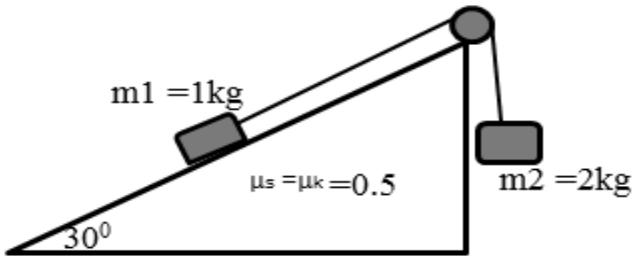
$x = \frac{1}{2}at^2 = \frac{1}{2}(1.23\ m/s^2)\ (1.50\ s)^2 = 1.38\ m$

d. The velocity of block A is found from the kinematic equation $v = v_0 + at$

$x = 0 + (1.23\ m/s^2)\ (1.50\ s) = 1.84\ m/s$

Worked Example 4:

Two blocks are on the inclined plane tilted at 30^0 to the horizontal. Find the acceleration of the large block. ($\mu_s = \mu_k = 0.5$, $g = 9.8 m/s^2$)



Solution:

First we have to determine the normal force on the inclined plane due to block 1.

$N = m_1 g \cos\theta = 8.49N$

$f = \mu N = 4.25$

$\sum F_x = 0$

$T - m_1 g \sin 30° - f = m_1 a$ (1)

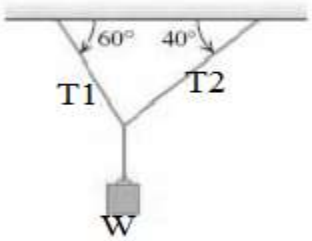
$\sum F_y = 0$

$m_2 g - T = m_2 a$ (2)

Solving (1) and (2) simultaneously gives $a = 3.5 m/s^2$

Worked Example 5:

Find the tension in each cord if the weight of the suspended object is 490 N.



Solution:

The sum of all horizontal forces is zero($\sum F_x = 0$)

$T_1 \cos 60° = T_2 \cos 40°$ (1)

The sum of all vertical forces is zero($\sum F_y = 0$)

$T1\sin 60° + T_2 \sin 40° = W$ (2)

Solving the above two equations we have

T_1=381N and T_2 =249N

Linear momentum (p)

The linear momentum p of an object of mass m moving with velocity v is the product of its mass and velocity.

P= mv SI unit: kilogram-meter per second (kgm/s)

$p_x = mv_x$ $p_y = mv_y$

Changing the momentum of an object requires the application of a force. This is, in fact, how Newton originally stated his second law of motion. Starting from the more common version of the second law, we have $\sum F = ma = m\frac{\Delta v}{\Delta t} = \frac{d\vec{P}}{dt}$ where the mass m and the forces are assumed constant.

$$F = \frac{\Delta P}{\Delta t}$$

Impulse is a vector quantity with the same direction as the constant force acting on the object. The impulse of the force acting on an object equals the change in momentum of that object.

$$I = F\Delta t = \Delta P$$

Worked Example 7:

A 0.15kg baseball, thrown with a speed of 40m/s, is hit straight back at the pitcher with a speed of 50 m/s.

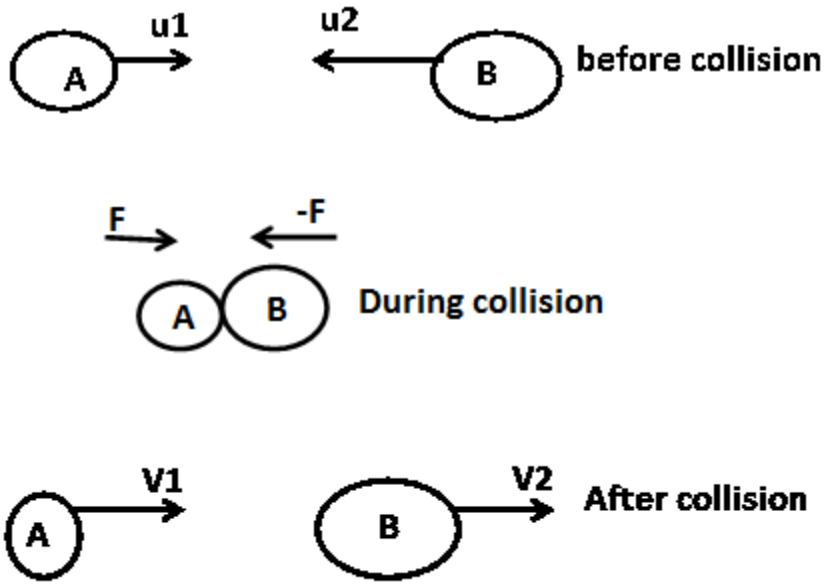
a. What is the impulse delivered by the bat to the baseball?
b. Find the magnitude of the average force exerted by the bat on the ball if the two are in contact for 2×10^{-3} s.

Solution:

a. I=m(v-u)=0.15kg(50m/s-40m/s)= 1.5 kg m/s
b. $F = \frac{\Delta P}{\Delta t} = \frac{1.5 kgm/s}{0.002s} = 750N$

Law of conservation of momentum

Consider an isolated system of two bodies "A" or "B" having masses m_1 and m_2 moving initially with velocities u_1 and u_2 respectively. They collide with each other and after the impact their velocities became v_1 and v_2.



Total linear momentum before collision is given by $P_{initial} = m_1u_1 + m_2u_2$

Total linear momentum after collision is given by $P_{after} = m_1v_1 + m_2v_2$

$m_1v_1 + m_2v_2 = m_1u_1\ m_2u_2$.This is the law of conservation of linear momentum

Elastic collision

An elastic collision is that in which the momentum of the system as well as kinetic energy of the system before and after collision is conserved.

$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$ momentum conserved

$\frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2 = \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2$ conservation of kinetic energy

Inelastic collision

An inelastic collision is that in which the momentum of the system before and after collision is conserved but the kinetic energy before and after collision is not conserved. An inelastic collision is sometimes called plastic collision.

$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$ momentum conserved

$\frac{1}{2}m_1u_1^2 + \frac{1}{2}m_2u_2^2 \neq \frac{1}{2}m_1v_1^2 + \frac{1}{2}m_2v_2^2$ kinetic energy is not conserved

Some parts of energy transferred into heat, sound, friction, etc.

$m_1\ u_1 + m_2\ u_2 = (m_1 + m_2)\ V$

$V = \frac{m1\,u1 + m2\,u2}{m1 + m2}$ is the common velocity of two objects after collision.

Worked Example 7:

A ball having mass of 2.5kg and velocity 2m/s eastward collides with another ball of mass 1kg and velocity 1m/s also eastward. After collision the 2kg ball has a velocity of 1m/s eastward, what is the velocity of 1kg ball?

Solution

$$m_1u_1 + m_2u_2 = m_1v_1 + m_2v_2$$

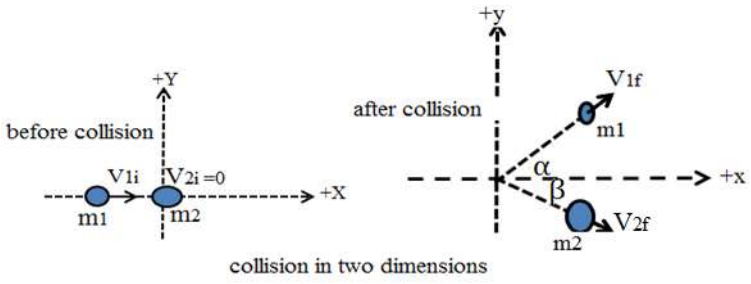
$$m_1u_1 + m_2u_2 - m_1v_1 = m_2v_2$$

$$v_2 = \frac{m1u1 + m2u2 - m1v1}{m2} = 3.5\text{m/s eastward}$$

Glancing collision (two dimensions)

Collision in two dimensions obeys the same rule as a collision in one dimension.

- Total momentum in each direction is always the same before and after the collision
- Total kinetic energy is the same before and after an elastic collision only.



The x- components of the total momentum of the system of the two balls is conserved.

$$P_ix = P_fx$$

$$P_{1i}x + P_{2i}x = P_{1f}x + P_{2f}x$$

$$m1V_{1i}x + m2V_{2i}x = m1V_{1f}x + m2V_{2f}x$$

But $V_{1f}x = V1\cos\alpha$ and $V_{2f}x = V2\cos\beta$

The y- components of the total momentum of the system of the two balls is conserved.

$$P_iy = P_fy$$

$$P_{1i}y + P_{2i}y = P_{1f}y + P_{2f}y$$

$$m1V_{1i}y+m2V_{2i}y=m1V_{1f}y+m2V_{2f}y$$

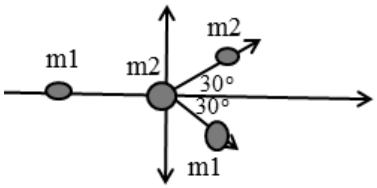
But $V_{1f}y=V1\sin\alpha$ and $V_{2f}y=-V2\sin\beta$

By considering the collision is elastic collision kinetic energy is conserved.

$$\frac{1}{2}m_1V_{1i}^2+\frac{1}{2}m_2V_{2i}^2=\frac{1}{2}m_1V_{1f}^2+\frac{1}{2}m_2V_{2f}^2$$

Worked Example 8:

Two objects slide over a frictionless horizontal surface. The first object, mass m_1 =5kg is propelled with speed 4.5m/s towards the second object mass m_2 =2.5 kg, which is initially at rest. After the collision both objects have velocities which are directed θ=30° on either side of the original line of motion of the first object as shown below. What are the final speeds of the two objects? Is the collision elastic or inelastic?



Solution:

Using conservation of momentum along x- axis

$$m1V_{1i}x+m2V_{2i}x=m1V_{1f}x+m2V_{2f}x$$

$$m1V_{1i}x=m1\,V_{1f}\cos 30°+m2V_{2f}\cos 30°$$

$$5(4.5)=(5\,V_{1f}+2.5V_{2f})\cos 30° \qquad (1)$$

Using conservation of momentum along x- axis

$$m1V_{1i}y+m2V_{2i}y=m1V_{1f}y+m2V_{2f}y$$

$$0=-m1V_{1f}\sin 30°+m2V_{2f}\sin 30°$$

$$m1V_{1f}\sin 30°=m2V_{2f}\sin 30°$$

$$5V_{1f}\sin 30°=2.5V_{2f}\sin 30° \qquad (2)$$

Solving (1) and (2) simultaneously

$$V_{1f}=2.6\text{m/s and } V_{2f}=5.2\text{m/s}$$

To state the type of collision check the initial and final values of kinetic energy.

$$KEi=\frac{1}{2}m_1V_{1i}^2+\frac{1}{2}m_2V_{2i}^2=\frac{1}{2}m_1V_{1i}^2=50.6J$$

$$KEf=\frac{1}{2}m_1V_{1f}^2+\frac{1}{2}m_2V_{2f}^2=50.6J\text{, the collision is an elastic collision.}$$

Center of mass

Consider a system of n particles of masses m_1, m_2, $m_3 \ldots m_n$ whose position vectors are r_1, r_2, r_3, r_n respectively; the center of mass of the system is defined as the point having the position vector $r(x_{cm}, y_{cm})$.

$$r_{cm} = \frac{1}{M}\sum_i^n m_i r_i$$

$$M = m_1 + m_2 + m_3 + \ldots + m_n$$

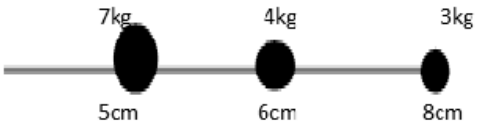
$$r_{cm} = \frac{m_1 r_1 + m_2 r_2 + m_3 r_3 + \cdots + m_n r_n}{m_1 + m_2 + m_3 + \cdots + m_n}$$

$$x_{cm} = \frac{m_1 x_1 + m_2 x_2 + m_3 x_3 + \cdots + m_n x_n}{m_1 + m_2 + m_3 + \cdots + m_n}$$

$$y_{cm} = \frac{m_1 y_1 + m_2 y_2 + m_3 y_3 + \cdots + m_n y_n}{m_1 + m_2 + m_3 + \cdots + m_n}$$

Worked Example 9

Find the center of mass of the system of masses 7kg, 4kg and 3kg along x- axis having distances 5cm, 6cm and 8cm respectively.



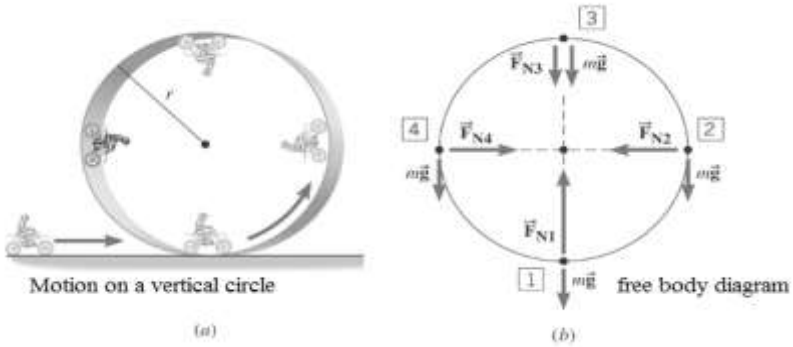
Solution

$$x_{cm} = \frac{m_1 x_1 + m_2 x_2 + m_3 x_3 + \cdots + m_n x_n}{m_1 + m_2 + m_3 + \cdots + m_n}$$

$$x_{cm} = \frac{7kg(5cm) + 4kg(6cm) + 3kg(8cm)}{7kg + 4kg + 3kg} = 4.4cm$$

Dynamics of uniform circular motion (vertical circle)

A vertical circle is any circle that is perpendicular to the ground. A common application of circular motion is an object moving in a vertical circle.



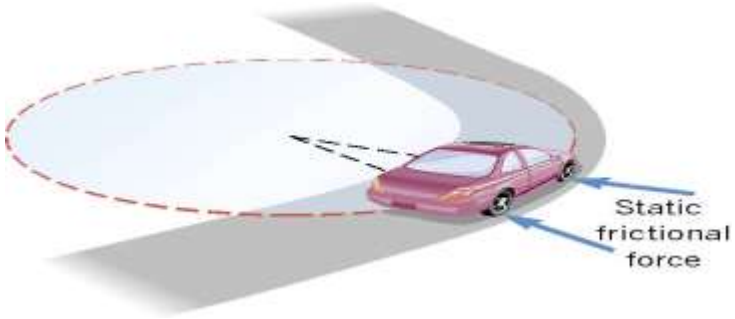
At each point the force normal and tension can be related as:

Depending on the location of the object on the vertical circle the force can be related as

$$T - mg\cos\theta = m\frac{v^2}{r}$$

Banked Curves

On an unbanked curve, the static frictional force provides the centripetal force.



On a frictionless banked curve, the centripetal force is the horizontal component of the normal force. The vertical component of the normal force balances the car's weight.

From the above free body diagram we have:

$$F_C = F_N\sin\theta = m\frac{v^2}{r} \qquad (1)$$

$$F_N\cos\theta = mg \qquad (2)$$

From the above two equations we can derive the angle θ

$$\tan\theta = \frac{v^2}{rg} \qquad (3)$$

Worked Example 10:

The turns at the Daytona International Speedway have a maximum radius of 316 m and are steeply banked at 31 degrees. Suppose these turns were frictionless. As what speed would the cars have to travel around them?

Solution:

$\tan\theta = \frac{V^2}{rg}$

$V=\sqrt{rg\tan\theta} =\sqrt{316m\ (10mm/s^2)\tan 31°}$ = 43m/s

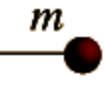
Rotational dynamics

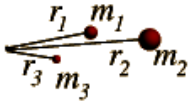
Moment of inertia (I)

Moment of inertia is the name given to rotational inertia, which is the rotational analog of mass for linear motion. Moment of inertia is an angular mass.

For a point mass m at a perpendicular distance r from the axis of rotation, the moment of inertia is the product of mass and square of perpendicular distance, its SI unit is kgm^2.

$I = mr^2$





$I = \sum_i m_i r_i^2 = m_1 r_1^2 + m_2 r_2^2 + m_3 r_3^2 + \ldots$

Sum of the point mass moments of inertia.

The following factors affect the moment of inertia of a body.

- Mass of the body
- Distribution of mass (shape of the body)
- The position of the axis of rotation

Rotational kinetic energy (KE_{rot})

The kinetic energy of a rotating object is analogous to linear kinetic energy and can be expressed in terms of the moment of inertia and angular velocity.

$$KE_{rot} = \frac{1}{2} I\omega^2$$

If an object exhibit both translational and rotational motion the total kinetic energy is the sum of translational and rotational kinetic energies.

$$KE_{tot} = \frac{1}{2} mv^2 + \frac{1}{2} I\omega^2$$

Worked Example 11

A circular disk of mass M and radius R is rolling on a horizontal plane and its total kinetic energy is 150J. If its rotational inertia is $\frac{1}{2}MR^2$, find the translational and rotational kinetic energy of the disk.

Solution

$KE_{tot} = \frac{1}{2}Mv^2 + \frac{1}{2}I\omega^2$ but $v=R\omega$

$KE_{tot} = 150J = \frac{1}{2}Mv^2 + \frac{1}{2}(\frac{1}{2}MR^2)\,\omega^2$

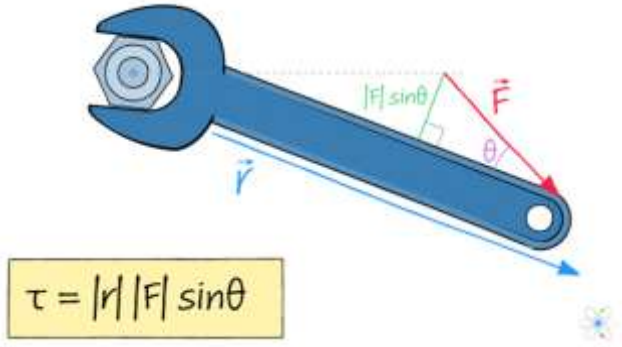
$KE_{tot} = \frac{1}{2}Mv^2 + \frac{1}{2}(\frac{1}{2}Mv^2) = \frac{3}{4}MV^2 = 150J$

$\frac{1}{2}Mv^2 = \frac{2}{3}(150J) = 100J$ it is translational kinetic energy.

The remaining rotational kinetic energy becomes 150J – 100J =50J.

Torque (τ)

Torque is the turning effect of force which causes an object to turn. It is also called the moment of force because it is the tendency of a force to rotate an object about an axis, fulcrum or pivot.



$\tau = r \times F = rF\sin\theta$

$\tau = I\alpha$

Work done by torque (W)

Work done by torque is the dot product of torque and angular displacement.

$W = \tau . \theta$ It is the replacement from W=F.S

Worked Example 12

A spanner that is used to tighten a nut is 300mm long. The force exerted on the end of a spanner is 100 N.

a. What is the torque exerted on the nut?
b. What is the work done when the nut turns through 30°?

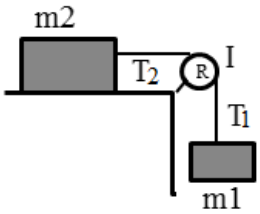
Solution:

τ =rF= 0.3m (100N) =30Nm

W= τ. θ =30Nm ($\frac{\pi}{6}$)= 15.7J

Worked Example 13:

Two blocks of masses m1 and m2 are attached with a massless string on a frictionless surface as shown in the figure below. If the pulley has moment of inertia I and radius R. determine the acceleration of the block and tensions?



Solution:

The equations are

T2 = m2a (1)

m1g –T1= m1a (2)

(T1-T2)R =Iα = I ($\frac{a}{R}$) (3)

Adding (1) and (2) gives:

T2 – T1 + m1g = (m1+m2) a (4)

Adding (3) and (4) gives:

m1g = I ($\frac{a}{R^2}$) + (m1+m2) a

m1g = ($\frac{I}{R^2}$ + (m1+m2)) a

a= $\frac{m_1 g}{\frac{I}{R^2}+m1+m2}$ (5)

By inserting (5) into (1) and (2) we can determine the tension T1 and T2:

T2= m2a = $\frac{m_2 m_1 g}{\frac{I}{R^2}+m1+m2}$

$T1=m1g - m1a = m1g - \frac{m_1{}^2 g}{\frac{I}{R^2}+m1+m2}$

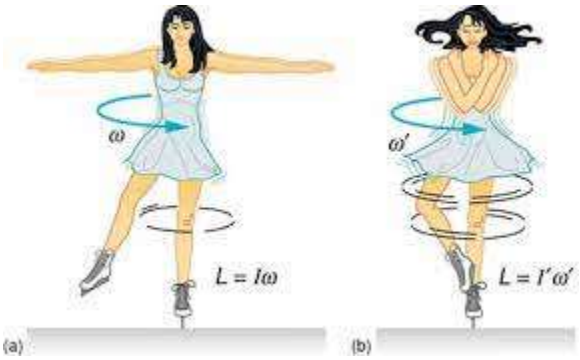
Angular momentum (L)

The angular momentum of a particle of mass m with respect to a chosen origin is given by

$L = mvr \sin\theta$ or $L = r \times p$

Conservation of angular momentum

States that "If the net external torque acting on a system is zero, the angular momentum of the system remains constant, no matter what changes take place within the system."



$I_i\omega_i = I_f\omega_f$

If there is net torque acting on an object its angular momentum becomes changed. The change in angular momentum is called an angular impulse (J).

$$\tau = I\alpha = I\frac{\Delta\omega}{\Delta t}$$

$$\tau\Delta t = I\Delta\omega = \Delta L$$

$J = \tau\Delta t = \Delta L$ the equation used to solve angular impulse.

Worked Example 14:

A skater is spinning with an angular velocity of 5rad/s. the skater has her arms close to her body. Her moment of inertia is $1.2kgm^2$. She puts her arms out and her angular velocity decreases to 3 rad/s, what is her moment of inertia now?

Solution

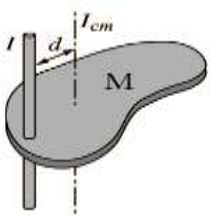
Based on the conservation of angular momentum the initial and final angular momentum of the skater is constant (equal).

$I_1\omega_0 = I_2\omega$

$I_2 = \frac{I_1\omega_0}{\omega} = \frac{1.2kgm^2(5rad/s)}{3rad/s} = 2kgm^2$

Parallel axis theorem

The moment of inertia of any object of mass M about an axis through its center of mass is the minimum moment of inertia for an axis in that direction in space.



The moment of inertia about any axis parallel to that axis through the center of mass is given by:

$$I = Icm + Md^2$$

Worked Example 15:

A rod of mass M= 3kg and length L=1.2m pivots about an axis perpendicular to its length, which passes through one of its ends. What is the moment of inertia of the rod?

Solution:

The moment of inertia of rod at the center of mass is $\frac{1}{12}ML^2$. Now we are asked to find its moment of inertia at either end points (d=L/2). Using parallel axis theorem

$I = Icm + Md^2$

$I = \frac{1}{12}ML^2 + M\left[\frac{L}{2}\right]^2 = \frac{1}{3}ML^2$

By substituting the values $I = 1.44kgm^2$

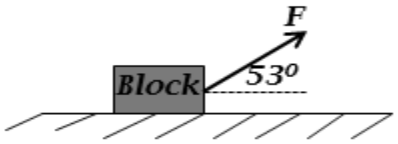
Review questions

1. A car (mass m1) is driving at a velocity V, when it smashes into unmoving car (mass m2), locking bumpers. Both cars move together at the same velocity. The common velocity will be given by:
   A. $\frac{m_1 V}{m_2}$ C. $\frac{m_1 V}{m_1 + m_2}$
   B. $\frac{m_2 V}{m_1}$ D. $\frac{(m_1 + m_2)V}{m_1}$
2. A woman driving a 2000kg car along a level road at 30m/s takes her foot off the gas to see how far her car will roll before it slows to a stop. She discovers that it takes 150m. What is the average force of friction acting on the car?
   A. 9000N B. 6000N C. 3000N D. 400N

3. A 2kg object experiences two concurrent forces of 100N at 30° above the positive x-axis 80N at 60° above the negative x-axis. What is the magnitude of the acceleration of the object?
   A. $68m/s^2$ B. $64m/s^2$ C. $48m/s^2$ D. $46m/s^2$

4. Two particles with masses 2m and 3m are moving towards each other along x-axis with the same initial speeds V. Particle 2m is travelling to the right. They undergo an electric glancing collision such that particle 2m is moving in the negative y- direction after the collision. What are the x-component of the final velocity of the particle3m and the kinetic energy of particle 2m respectively?
   A. 0.33V and $0.7mV^2$ C. 0.67V and $0.7mV^2$
   B. 0.33V and $1.4mV^2$ D. 0.67V and $1.4mV^2$

5. A force F of magnitude 20N is applied to a block of mass 2kg that lies on rough horizontal surface as shown in the figure below. The coefficient of kinetic friction between the block and the surface is 0.4. What is the magnitude of the acceleration of the block?
   A. $10m/s^2$ C. $5.2m/s^2$
   B. $4.2m/s^2$ D. $2.8m/s^2$



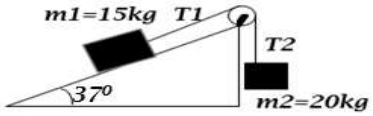
6. A hard ball moving on horizontal frictionless surface with a speed of 5m/s in the positive x direction strikes a stationary hard ball of the same mass. After the collision, the first ball moves with a speed of 4m/s along a direction that makes an angle of 37^0 with its initial direction of motion. What is the struck ball's speed and the smallest angle between its direction of motion and the positive x axis after the collision?
   A. 3m/s and 53° C. 4m/s and 53°
   B. 3m/s and 37° D. 4m/s and 37°

7. A net external non zero force acts on a particle that is moving along a straight line. Which one of the following statements is correct?
   A. The, velocity but not the kinetic energy, of the particle is changing.
   B. Both the velocity and the kinetic energy of the particle are changing.
   C. The kinetic energy, but not the velocity, of the particle changing.
   D. The momentum is conserved.

8. Which of the following objects has the largest moment of inertia assuming they all have the same mass and radius?
   A. A solid disk. B. A solid sphere C. A circular loop D. A solid cylinder

9. A hoop of mass M and radius R is at rest at the top of an incline plane of height h. The hoop rolls down the plane without slipping. When the hoop reaches bottom, its angular momentum about its center of mass is:
   A. Mgh B. $MR\sqrt{2gh}$ C. $MR\sqrt{\frac{gh}{2}}$ D. $MR\sqrt{gh}$

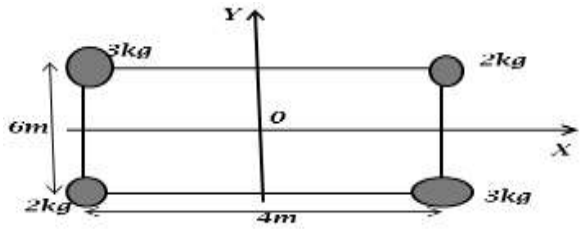
10. As shown in the figure below two blocks are connected by a string of negligible mass passing over a pulley of radius r = 0.2m and moment of inertia I. The block on the frictionless incline is moving with a constant acceleration a = 2m/s^2 up along the incline. What is the moment of inertia of the pulley?



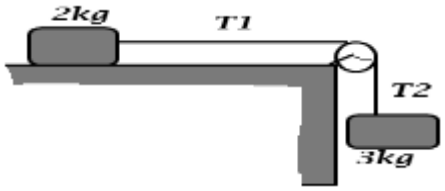
A. 0.8kgm^2 B. 1.25kgm^2 C. 4kgm^2 D. 40kgm^2

11. The particles shown in the figure below are connected by rectangular rigid rods of negligible mass. The origin of the xy plane is at the center of the rectangle. The system rotates in the xy plane about the z-axis with an angular speed of 6rad/s. What is the rotational kinetic energy of the system?

A. 2574J
B. 2340J
C. 1287J
D. 1170



12. Two blocks are connected by a string of negligible mass passing over a pulley of radius r =0.2m and moment of inertia I as shown in the figure below. The block on the horizontal frictionless surface is moving with a constant acceleration a=2m/s^2. If the pulley axis is frictionless, the string is inextensible and doesn't slip on the pulley, what should be the moment of inertia of the pulley?



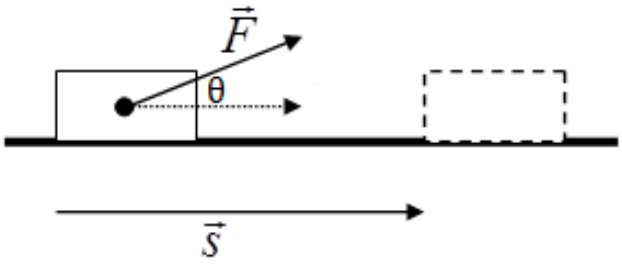
A. 0.4kgm^2 C. 0.8kgm^2
B. 4kgm^2 D. 8kgm^2

13. If the impulse of rotating disc is non-zero, what can you conclude?
    A. The change in linear momentum is zero
    B. The torque acting on object is zero
    C. Impulse of the disc equals its moment of inertia
    D. The change in angular momentum is non-zero
14. The rotational analogue of mass is:
    A. Moment of inertia C. Angular momentum
    B. Torque D. Angular acceleration.

UNIT 4: WORK, ENERGY AND POWER

Introduction

Consider the block given below which displaced from initial position to final position by the force applied on it. In this case work is done on the block because it becomes displaced by the effect of horizontal component of the force.



Work=force. Displacement

W=F.S =FScosθ θ is the angle measured between force and displacement

The SI unit of work is joule (J) $1J=1Nm=kgm^2/s^2$

1 J is the work done by a force of one Newton through one meter along the line of the force.

Key features of work done

- Positive work is done by the force if the force is in the same direction as motion. The object gains energy.
- No work is done by the force if it is perpendicular to the direction of motion
- No work is done by any force if the object is motionless
- Negative work is done by the force if the force acts in the opposite direction of motion. In the case of negative work on an object energy is lost by the object.

Worked Example 1

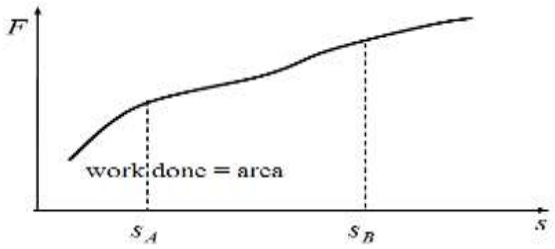
A 25N force is applied to a box and a box moves horizontally in the direction of applied force about 8m. Find the work done on the box.

Solution

Since the object is displaced in the direction of force or force and displacement are parallel to each other work is done. W= Fs =25N (10m) =250Nm

Work done by a variable force

Work done by a force is represented and calculated as the area under the curve of F versus displacement S, where F is that component of the force, which is parallel to S.



Energy

Energy is a property of objects, the measure of the ability of the object to perform work or Energy is the capacity to do work. It has the same unit as work.

- ✓ Kinetic energy(K_E)
- ✓ Potential energy(PE)

Kinetic energy

Kinetic energy is energy possessed due to motion. Any moving object has kinetic energy which is dependent on mass (m) and velocity ($\vec{v}$) of the moving object.

$$KE = \frac{1}{2}mv^2$$

Example; sound energy, electrical energy, heat energy, wind energy, etc.

Worked Example 2

What is the speed of 400kg car running with kinetic energy of 3.2×10^3J?

Solution:

$KE= \frac{1}{2}mv^2$

$V=\sqrt{\frac{2KE}{m}}=4m/s$

Worked Example 3

With what factor does the kinetic energy change if the velocity doubled and the mass tripled?

Solution

$KE_1 = \frac{1}{2}m_1{v_1}^2$

$KE_2 = \frac{1}{2}m_2v_2^2 = \frac{1}{2}\,3m_{1(}2v_1)^2 = 12KE_1$, when the given quantities are inserted here

$KE_2 = 12KE_1$

Work-energy theorem

States that the work done by the net force is equal to the change in kinetic energy, the net work done on an object is equal to the change in the object's kinetic energy:

$$W_{\text{net}} = KE_f - KE_i = \Delta KE$$

$$W = \Delta KE = \frac{1}{2}m\,(v^2 - u^2)$$

Worked Example 4

What work is done when a 4kg object increases its velocity from 6m/s to 8m/s?

Solution;

Using work- energy theorem

$W = \Delta KE = \frac{1}{2}m\,(v^2 - u^2)$

$W = \frac{1}{2}\,4kg(64m^2/s^2 - 36m^2/s^2)$

W=56J

Potential energy

Potential energy is stored energy an object has because of its position or state (configuration).

- Gravitational potential energy(GPE)
- Elastic potential energy(EPE)
- Electric potential energy
- Nuclear energy
- Chemical energy

Gravitational potential energy

Gravitational potential energy comes from earth's gravity. The object has a potential energy as a result of its position in the gravitational field of the Earth.

$$GPE = mgh$$

Worked Example 5

What is the potential energy of 2kg rock sitting at the top of 10m high cliff? ($g=10m/s^2$)

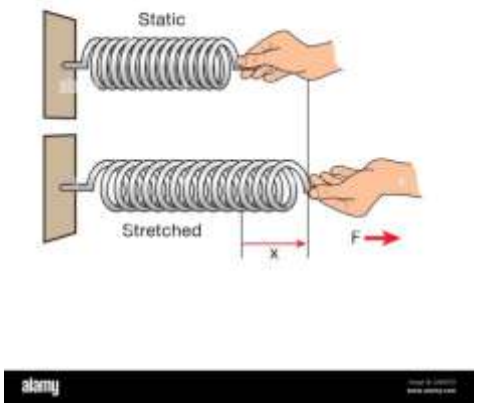
Solution:

GPE = mgh = 200J

Note: the potential energy is equal to the amount of work done to get an object in to its position or configuration.

Elastic potential energy

Elastic potential energy is potential energy stored as a result of deformation of an elastic objects such as stretching or compressed/deformation of elastic materials. Example spring, rubber band and slingshots.



$$W = EPE = \frac{1}{2}F\Delta x \quad \text{but from Hook's law } F=K\Delta x \text{ then}$$

$$EPE = \frac{1}{2}K\,\Delta x^2$$

Worked Example 6

A compressed spring has potential energy of 20J. If the spring constant of the spring is 200N/m, find the displacement of the spring?

Solution

$$EPE = \frac{1}{2}K\,\Delta x^2$$

$$\Delta x = \sqrt{\frac{2EPE}{K}} = 0.4\text{m}$$

Mechanical energy (ME)

Mechanical energy is the overall sum of kinetic and potential energy.

$$ME = KE + PE$$

Worked Example 7

A person of mass 50kg is sitting on a building of height 20m. Calculate the total mechanical energy?

Solution:

$ME = KE + PE$

$ME = \frac{1}{2}mv^2 + mgh$

$ME = 114.4J$

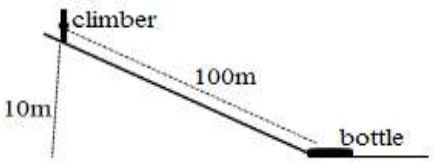
Conservation of mechanical energy

States that "the total amount of mechanical energy in a closed system in the absence of dissipative force (friction, air resistance) remains constant"

Or "energy is neither created nor destroyed but it merely changed from one form to another forms of energy".

Worked Example 8

A mountain climber (60kg) who is climbing a mountain in the Ras Dashen (north Gondar) during winter, by mistake he drops his water bottle (0.5kg) which then slides 100m down the sides of the steep icy slope to a point which is 10m lower than the climber's position. Neglect friction.



a. If the bottle starts from rest, how fast is it travelling by the time it reaches the bottom of the slope?

b. What is the total change in climber's potential energy as he climbs down the mountain to fetch his fallen water bottle?

Solution:

a. Based on the conservation of mechanical energy for the bottle its kinetic energy at the top of the mountain and potential energy at the bottom of the slope are zero.

mgh= $\frac{1}{2}mV^2$ then v=$\sqrt{2gh}$ =$\sqrt{200m^2/s^2}$ =14.2m/s

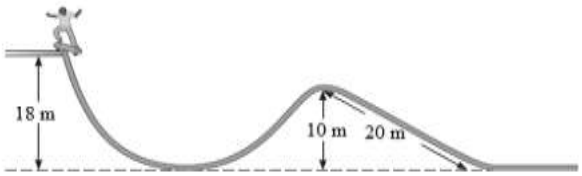
Note: the distance that the bottle travelled (100m) does not play any role in calculating the energies. It is only the height difference that is important in calculating potential energy.

b. ΔGPE =mgΔh =60kg×10m/s^2×10m=6000J

Worked Example 9

A 66kg man rides his skateboard at a local skate park. He starts from rest at the top of the track as shown in the fig below and begins descent down the track, always maintaining contact with the surface. The mass of the skateboard and friction becomes ignored.

a. What is Shawn's speed when he reaches the bottom of the initial dip, 18m below the starting point?
b. He then ascends the other side of the dip to the top of a hill, 8m above the ground. What is his speed when he reaches this point?



Solution:

a. From the conservation of mechanical energy: potential energy at the top of 18m transforms into kinetic energy at the bottom of the dip.

$mgh_1=\frac{1}{2}mv_1^2$

$V_1=\sqrt{2gh_1}$ =$\sqrt{360}$ =$6\sqrt{10}$ m/s

b. From the conservation of energy: potential energy at the top of the 18m transforms into kinetic energy and potential energy at the top of a hill.

$mgh_1=\frac{1}{2}mv_2^2+mgh_2$

$mg(h_2-h_1)=\frac{1}{2}mv_2^2$ but $h_2-h_1=8m$

$V_2=\sqrt{2g(h_1-h_2)}$ =$\sqrt{160m^2/s^2}$ =$4\sqrt{10}$ m/s

Conservative and dissipative forces

Forces in nature are divided into two groups (conservative and dissipative forces).

Conservative forces

A force is conservative if: the work done by the force on an object moving from one point to another depends only on the initial and final positions of the object, and is independent of the particular path taken.

Work done by conservative force =zero

Example: gravitational force, elastic force and electrostatic force

Dissipative forces

Non conservative force or dissipative force results wastage of energy. For non-conservative force the work done is path dependent.

Example: friction, air resistance, tension on cord, push or pull by a person and motor or rocket propulsion.

$$W_{nc}=\Delta E_k+\Delta E_p$$

Work done by dissipative force =the change in mechanical energy

Power (P)

Power is the rate at which work is done upon the object or energy transferred. Like all rate quantities power is time based quantity..

$$\text{Power} = \frac{\text{work done}}{\text{time}} \qquad P = \frac{W}{t}$$

$$P = \frac{F.S}{t} = F.V$$

Worked Example 11

A 60 kg man is runs up to 12m high in 60 seconds. Calculate his power.

Solution:

W= mgh = 60kg×10N/kg×12m =7200J

$$P = \frac{W}{t} = \frac{7200J}{60s} = 120W$$

Review questions

1. 1kg mass is attached to a spring of stiffness constant 100N/m. what is the maximum displacement of the mass from its equilibrium position if its speed is 3m/s at the equilibrium point?
   A. 0.1m B. 0.3m C. 3m D. 10m
2. The speed of a mass is increased by two fold. By what factor does the kinetic energy change?
   A. 2 B. 8 C. 4 D. 16
3. A block of mass 0.25kg is placed on top of a light vertical spring of force constant 5000N/m and pushed downward so that the spring is compressed by 0.1m. After the block is released from rest, it travels upward and then leaves the spring. To what maximum height above the point of release does it raise?
   A. 10.2m B. 9.2m C. 8.0m D. 9.0m

4. If two particles have equal momenta then which one of the following statement is TRUE about their kinetic energy?
   A. Their kinetic energies are always equal
   B. Their kinetic energies are never equal
   C. Their kinetic energies are equal when their masses are the same
   D. Their kinetic energies are equal when the speed of one of the particle is half the speed of the other particle and their masses are the same
5. A block of mass 1.6kg is attached to a horizontal spring that has a force constant of 200N/m. the spring is compressed 2cm and is then released from rest. At what speed will the block pass through the equilibrium position of a constant friction force of 10N retards its motion from the moment it is released?
   A. 70m/s B. 50m/s C. 70cm/s D. 50cm/s
6. A car of mass 1500kg is travelling at a uniform velocity of 30m/s due to east. The driver applies the breaks to slow down the car to a velocity of 10m/s due east. What is the work done in slowing down the car?
   A. 15kJ C. 600kJ
   B. 300kJ D. 750kJ
7. Which one of the following statement is true about a spring-mass system oscillating on a horizontal frictionless surface?
   A. The kinetic and potential energies are equal at all times.
   B. The kinetic and potential energies are both constant.
   C. The maximum potential energy is achieved when the mass passes through its equilibrium position.
   D. The maximum potential energy and the maximum kinetic energy are equal.

8. A block of mass 10kg is pulled up a rough inclined plane with a force of 100N parallel to the incline plane. The incline plane is makes an angle of 37^0 with the horizontal. At the instant when the force is applied the block has a speed of 1.5m/s. If the coefficient of kinetic friction is 0.4, and the block is pulled up 5m, what is the change in kinetic energy of the block?
   A. 20J B. 30J C. 40J D. 45.5J
9. The area under a force versus distance graph represents:
   A. Acceleration
   B. The change in energy
   C. The change in momentum
   D. Work done
10. Which statement is correct about conservative and dissipative forces?
   A. The work done by conservative forces is path dependent.
   B. The work done, along a closed path, by non-conservative force is nonzero.
   C. Gravitational force is an example of non-conservative force.
   D. Friction is an example of conservative force.

UNIT 5: SIMPLE MACHINES

- Simple machines are a devices designed to make it easier to do mechanical work

Machines are used to

- Transform energy → generator
- Transfer energy → chain – wheel in bicycle
- Multiple force → system of pulleys
- Multiple speed → bicycle
- Change the direction of a force as affixed pulley
- The force applied to a machine is called the effort (E)
- The force exerted by the machine on an inject is called the load (L)
- Mechanical advantage (MA) sometimes is called actual mechanical advantage (AMA) is the ratio of load to effort

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

- velocity ratio which is called ideal mechanical advantage (IMA) it is the ratio of distance moved by the effort to distance moved by the load

$$VR = \frac{SE}{SL}$$

- Work in put (Wi) it is the product of effort and distance moved by the effort

$$Wi = E \times S E$$

- Work out put (Wo) it is the work done by the machine ,or the product of load and distance moved by the load

$$W_O = LXSL$$

- Wastage energy (We) :it is the energy loss

$$We = Wi - Wo$$

- Efficiency (η) it is the ratio between the work output and work input

$$\eta = \frac{wO}{wI} X100\% \qquad \eta = \frac{MA}{VR} \text{x}100\% \qquad \eta = \frac{Po}{Pi} \text{x}100\%$$

Ideal Machine

- Wi = Wo
- $\eta \geq 1$ or $\eta \geq 100\%$
- MA = VR
- We = 0

Real Machines

1. Wi > Wo
2. $\eta < 1$ or $\eta < 100\%$
3. MA ≠ VR
4. We ≠ 0

Different types of simple machines

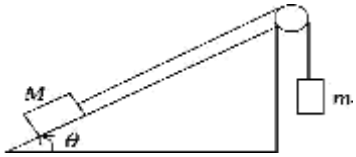
- There are six different types of simple machine

- Inclined plane
- Wedge
- Screw
- 4. lever
- 5. Wheel and axle
- 6. Pulley

1. ***Inclined plane*** *:- it used to increase the height or elevation of an object (i.e. a load) without lifting it*

Since VR = $\frac{dE}{dl}$, but dE = $\frac{h}{\sin\theta}$ and dL = h so VR becomes

$$VR=\frac{1}{\sin\theta}$$



L = mg

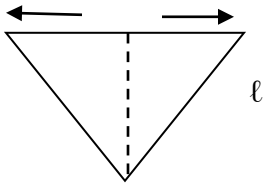
$$MA=\frac{1}{\sin\theta+\mu\cos\theta}$$

2. ***Wedge***
   - The wedge is a double inclined plane (a triangular),
   - Two sides of which are at small angle

t = thickness

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

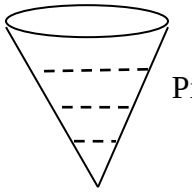
Used to 1. Fix wheels on shafts
2. for cutting and weaving
3. for transmitting motion



ℓ = length

3. **The screw**
   - A screw is an inclined plane wound upon a cylinder
   - Distance between threads is called the pitch (p) of the screw
   - For one revolution
   - SE =2πr
   - SL = p

$$VR=\frac{2\pi r}{p}$$



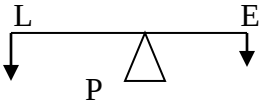
Pitch

4. **Lever** A lever is a rigid bar which is free to turn about a pivot point 'p' also called fulcrum

Type of lever

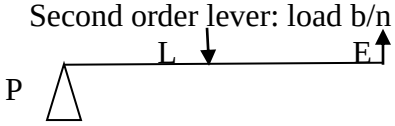
- First order lever ; pivot point 'p' between load and effort

(Force multiplier)



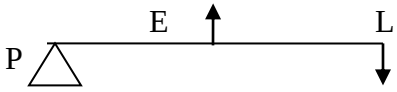
Example: see-saw, crowbar, pliers, scissors pincers, lever balance Hammer removers, opening a tin

- Second order lever: load b/n pivot point and Effort



Example: Wheel barrow, a rowing oar, Nut cracker, paper cutter

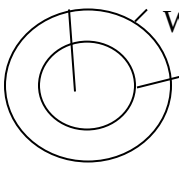
- Third order lever : Effort between turning point 'pivot 'and load



Example: Catapult, spade, tongs, tweezers,

5. ***Wheel and Axle****:* is a wheel or crank rigidly attached to an axle

-In one revolution, E moves a distance equal to the circumference of the wheel during this time L travels a distance of equal to the circumference of the axle

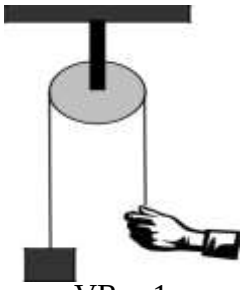


$VR = \frac{R}{r}$

Where R= radius of the wheel
r = radius of the axle

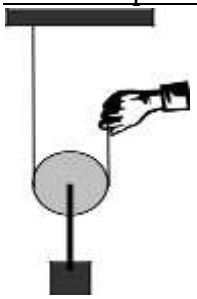
6. **Pulley** : A pulley is a wheel that turns readily on axle which in turn is mounted in frame one or more pulleys enclosed in a frame is usually called block and a series of pulleys with the attached with rope or chain is known as a block and tackle

I fixed pulley



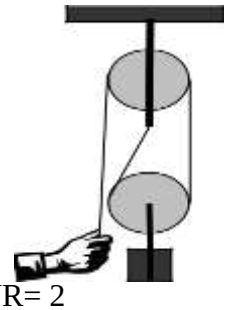
VR = 1

II Movable pulley



VR =2

III Compound pulley



VR= 2

VR = number of strands /ropes/ that support the movable pulley

Gears

- A set of wheels teeth on their edges that revolve together to transmit energy from the driving gear to the driven gear, Gears multiply rotational speed.

$$VR = \frac{Number\ of\ rottion\ of\ the\ driving\ gear}{Number\ of\ rottion\ of\ the\ driven\ gear}$$

$$VR = \frac{Number\ of\ teeth\ on\ the\ driven\ gear}{umber\ of\ teeth\ on\ the\ driving\ gear}$$

II. Solved Problems

1. A machine is used to lift a 400 N load by an effort of 100 N.What is the mechanical advantage of the machine?

   Soln: $MA = \frac{Load}{Effort} = \frac{400N}{100N} = 4$

   Based on the following information answer Q No 2-6

   A system of pulleys has a velocity ratio of 6 and a mechanical advantage of 5 the system is used to raise a load of 3000 N through 10m.

2. What is the work done on the load?

   Soln: $W_o = L*S_L = 3000N * 10m = 30000\ J$

3. What effort is required to raise the load?

   Soln: $E = \frac{L}{MA} = \frac{3000N}{5} = 600\ N$

4. What distance is moved by the effort?

   Soln: $S_i = So * VR = 10m * 6 = 60m$

5. Determine the work done by the effort

   Soln: Wi = E* SE = 600N* 60 m = 36000 J

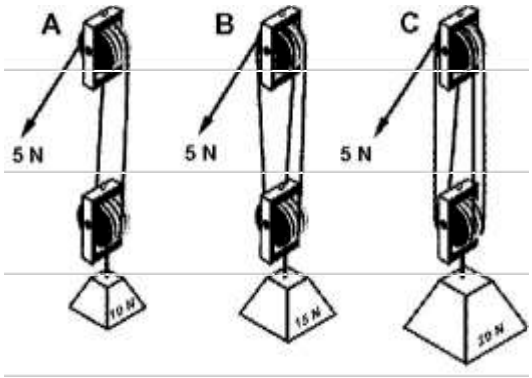
6. Find the efficiency of the machine
   Soln: $\eta = \frac{AMA}{IMA} * 100\% = \frac{5}{6} * 100\% = 83.3\%$
7. A frictionless inclined plane is used to raise a 100N load through a height of 4m.If the angle the plane makes with the horizontal is 30^0.
   Determine the velocity ratio and mechanical advantage of the inclined plane
   Soln: VR = $\frac{1}{sin\,30} = \frac{1}{0.5} = 2$ and
   MA = $\frac{L}{E}$ = VR, since it is frictionless
8. In problem 7, if the coefficient of friction between the load and the surface of the plane is 0.2, determine the efficiency of the plane
   Soln: VR = $\frac{1}{sin\,30} = 2$
   MA = $\frac{1}{sin\,30+\mu\,cos\,30} = \frac{1}{0.5+0.2*0.86} = \frac{1}{0.672} = 1.488$
   $\eta = \frac{MA}{VR} = \frac{1.488}{2} * 100\% = 74.4\%$
9. The handle of a screw is 1m long. If the screw has 8 threads to 10 cm, find the ideal mechanical advantage of the screw
   Soln: since there are 8 threads, we have a length of 10 pitches
   Therefore
   IMA = $\frac{2\pi l}{p} = \frac{2*\pi*1m}{0.01} = 628$
10. The gear on the pedal wheel of a bicycle has 24 teeth and the gear on the back wheel ha 8 teeth. What is the velocity ratio of the system?
    Soln: number of teeth on the driving gear (pedal wheel) = 24
    Number of teeth on the driven gear (back wheel) = 8
    VR = $\frac{8}{24} = \frac{1}{3}$

III. Chose the correct answer

1. The efficiency of an inclined plane used as a system to raise loads is 50%. If the inclined plane has a length of 4m and a height of 1m, what is the mechanical advantage?
   A. 3 B. 2 C. 5 D. 4
2. Which one of the following equations correctly defines the efficiency of simple machine
   A. $\eta = \frac{AMA}{IMA}$ B. $\eta = \frac{IMA}{AMA}$ C. $\eta = \frac{IMA}{V.R}$ D. $\eta = \frac{VR}{MA}$
3. A machine has an ideal mechanical advantage of 5 and actual mechanical advantage of 2. What is the efficiency?
   A. 250% B. 80% C. 50% D. 40%
4. If the mechanical advantage of a simple machine is greater than one, the machine is
   A. Speed multiplier B. Distance multiplier C. Force multiplier D. energy multiplier
5. Which of the following set of simple machines are examples of 3rd order lever?
   A. Tweezers spade and tong C. bottle opener, spade and tong
   B. Spanner, nut cracker and crow bar D. crow bar, fishing net and tong.
6. A wheel and axle has a radius of 50cm and 5cm, respectively. What is the velocity ratio?
   A. 10 B. 0.1 C.5 D. 50
7. An effort of 80N lifts a load of 100N using a machine of velocity ratio = 2, The efficiency of the machine is:

A. 0.72 B. 0.8 C. 0.625 D. 0.5

8. A screw jack has a pitch of 1cm and the effort is applied at the end of handle 28cm long. The velocity ratio is approximately.
   A. 7 B. 176 C. 88 D. 44
9. The velocity ratio of a fixed pulley is:
   A. 2 B. 3 C. 1 D. 4
10. A driving gear wheel having 25 teeth engages with a second gear 100 teeth what is velocity ration of the gear?
   A. 4 B. 2 C. 8 D. 10
11. When the effort is applied to the rope that connects the larger fixed pulley of the differential. Then the velocity ratio is given by
   A. $\frac{2r}{R+r}$ B. $\frac{2r}{R-r}$ C. $\frac{2R}{R+r}$ D. $\frac{2R}{R-r}$
12. Which of the following devices is always speed multiplier?
   A. 1st order lever B. 2nd order lever C. 3rd order lever D. All
13. Which one of the following is an example of 2nd order lever?
   A. Tongs B. paper cutter C. crow bar D. fishing rod
14. All of the following are considered to be simple machines EXCEPT:
   A. Scissors. B a bicycle. C. jackknife. D. wheelbarrow
15. A lever rotates around a fixed point called a:
   A. Ball bearing. B. Gear C. Pulley D. Fulcrum.
16. Mechanical advantage can be defined as the ratio of:
   A. Work input to work output. C. Work output to work input.
   B. Output force to input force. D. input force to output force
17. The simple machine that operates as a ramp that curves around a shaft is a:
   A. Rope and pulley system. B. Screw. C. Lever D. Gear
18. The force directed along the ropes of a rope and pulley system is called:
   A. Thread. C. Lead.
   B. Mechanical advantage. D, Tension.
19. The gear ratio is equal to:
   A. Output teeth divided by input teeth.
   B. Output turns divided by input turns.
   C. Input speed divided by output speed.
   D. Input direction divided by output direction.
20. Gears may be combined in a system to:
   A. Transfer motion. C. Change rotating speeds.
   B. Multiply forces. D.All of the above
21. Which of the following rope and pulley systems has the largest mechanical advantage?



10N 15N 50N

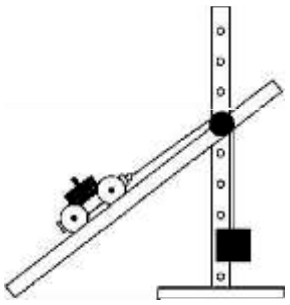
A. System A has the largest mechanical advantage.
B. System B has the largest mechanical advantage.
C. System C has the largest mechanical advantage.
D. All three systems have the same mechanical advantage

22. A rope and pulley system has an input force of 2.5N and an output force of 10N. What is the mechanical advantage of the system?
A. 0.25 B.4 C.7.5 D. 25

23. A rope and pulley system is used to lift a box that weighs 90N. How much force do you need to pull on the rope if the machine has a mechanical advantage of 5?
A.21N B. *9 N* *C. 18 N* *D. 10 N*

24. Making a ramp steeper:
A. Increases its mechanical advantage.
B. Decreases its mechanical advantage.
C. Increases its efficiency.
D. Decreases its efficiency.

25. All of the following simple machines are represented in the diagram below EXCEPT*:*

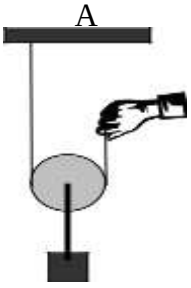


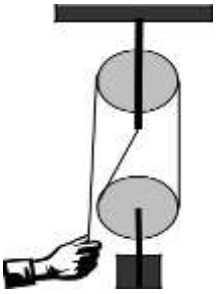
A. Wedge B. ramp C. wheel and axle D. rope and pulley

26. In the human body, what does the elbow joint act as?
A. Fulcrum B. Gear C. Ramp D. Screw

27. When you stand on your toes, what does your foot act as?
A. Gear B. Lever C. Screw D. Ramp

28. If we ignore friction, which of the following pulley systems will require less effort (force) to lift the load? A B

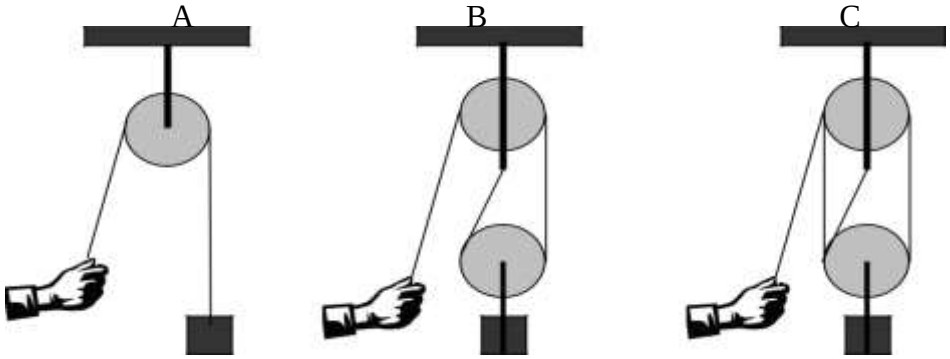




A. Pulley System A
B. Pulley System B

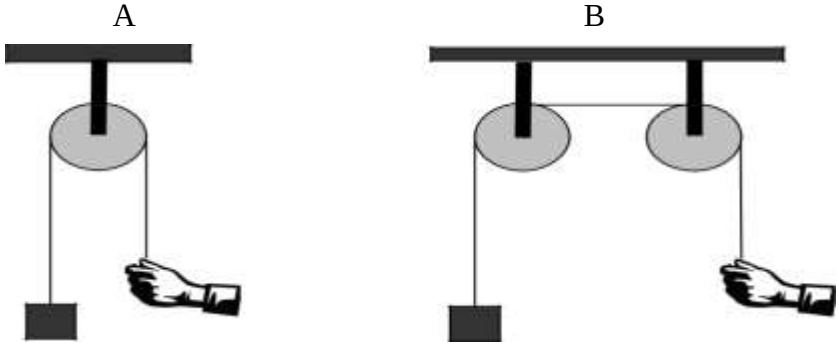
C. Both A and B will require the same effort (force)
D. Not enough information to decide

29. Arsema is using pulley system A, Surafel is using B, and Hana is using C. What can you tell about the work needed to lift the same load to the same height by each of them, if we ignore friction?



A. Arsema (using pulley system A) is doing more work
B. Surafel (using pulley system C) is doing more work
C. Hana (using pulley system C) is doing more work
D. The work done in all three situations is the same

30. If we ignore friction, which one of the following pulley systems will give more mechanical advantage?



A. Pulley System A
B. Pulley System B
C. Pulley System A and Pulley System B will give you the same mechanical advantage
D. Not enough information

UNIT 6: FLUID STATICS AND DYNAMICS

- Fluid Mechanics is the science that deals with behavior of fluids at rest (fluid statics) or in motion (fluid dynamics) and the interaction of fluids with solids or other fluids at the boundaries.
- A substance in liquid / gas phase is referred as 'fluid'. Distinction between a solid & a fluid is made on the basis of substance's ability to resist an applied shear (tangential) stress that tends to change its shape. A solid can resist an applied shear by deforming its shape whereas a fluid deforms continuously under the influence of shear stress, no matter how small is its shape

Air pressure

- Pressure is defined as the amount of acting per unit area

$P = \frac{F}{A}$

* $P_{max} = \frac{F}{A\ min}$ * $P_{min} = \frac{F}{A\ max}$

- Pressures is measures in Pascal (Pa)

  $1pa = 1N/1m^2$

- E.g. A boy weighs 600N and the soles of his feet have an area of $500cm^2$ determine the pressure he exerts on the ground when he stands

  A. On both feet B. on one foot

  ✓ When the boy stands on his both feet

  $P = F/A = \frac{600N}{0.05m2} = 12000pa$

  ✓ when the boy stands on one foot

  $P = \frac{600N}{0.025m2} = 24000Pa$

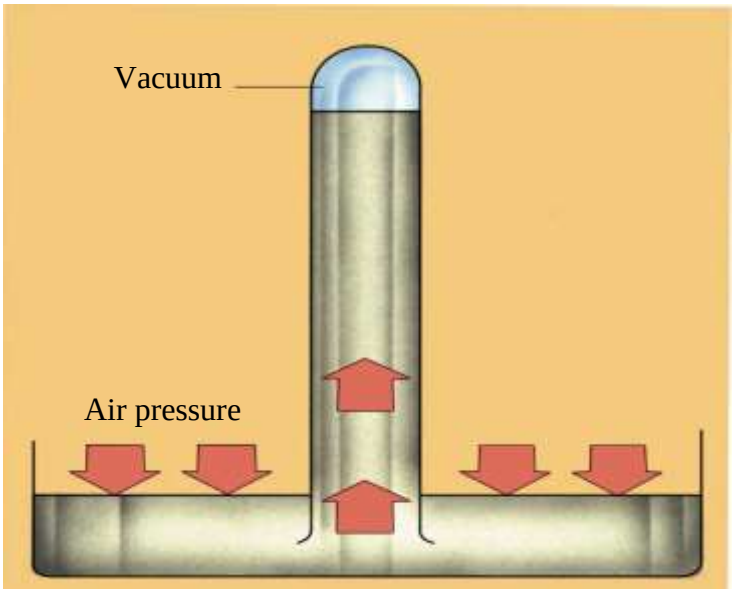
Atmospheric pressure

- Atmosphere is a layer that surrounds the earth
- Air has amass and weight then it exerts pressure on you
- There is a kind of equilibrium between the pressure in our bodies and the surrounding atmosphere
- 1atm = 101kpa of sea level (ground level) (1atm = one atmospheric pressure)
- Atmospheric pressure affects by altitude
- As an altitude increase atmospheric pressure decrease and as an altitude decrease atmospheric pressure increase

Measuring atmospheric pressure

- There are several instruments used to measure atmospheric pressure the most common is a barometer
- A mercury barometer is long and in convenient heavy and contains a liquid that is hazardous and easily spilt therefore, an aneroid barometer is commonly used (aneroid means without liquid

1atom=760mmhg=101kpa



Barometer

Aneroid Barometer

- ✓ Aneroid barometers have lower accuracy than mercury barometers, but thanks to their compact and portable configuration, aneroid barometers are easier to handle and use, and suitable for self-recording.
- ✓ An aneroid barometer measures the distortion of an evacuated, sealed elastic capsule inside with change in atmospheric pressure.

Problems

1. *Calculate the pressure in pa if the reading from a barometer is 820mm*

   Soln: $p = \rho gh = 13570\ kg/m3 * 10m/sec2 * 0.82m = 109.048.52 \approx 109\ kpa$

2. *Determine the pressure if it is water in a dish and the reading of the meter is76cm*

   Soln: $p = \rho gh = 1000kg/m3 * 10m/sec2 * 0.76m = 7600\ Pa$

Fluid density

- ➢ Density is defined as mass per unit volume

$$\rho = \frac{m}{V}$$

- ➢ The SI unit of density is kg/m^3

$1000kg/m^3 = 1grm/cm^3$

Relative density

- It is the ratio between

The density of two substances

$$\text{Relative density} = \frac{density\ of\ substance}{Density\ of\ water}$$

1.What is the relative density of mercury?

Soln: Relative density = $\frac{\text{density of mercury}}{\text{density of water}} = \frac{13570\text{Kg/m3}}{1000\text{kg/m3}} = 13.57$

2. The relative density of unknown substance is 0.5 if the mass of the unknown is 10gram calculate the volume of the substance

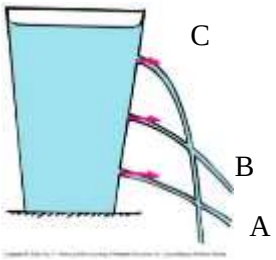
Soln: Relative = $\frac{density\ of\ substance}{Density\ of\ water} = 0.5$

Density of the unknown substance = 0.5 *1000kg/m^3 = 500kg/m^3

Volume of substance = $\frac{m}{\rho} = \frac{0.01kg}{500kg/m3} = 0.2\text{x}10^{-4}m^3$

Pressure in fluids

- The pressure of fluids depends on the depth of the fluid (liquid)
- At any given depth the pressure is equal in all direction



→ The pressure at point or depth 'A' is maximum

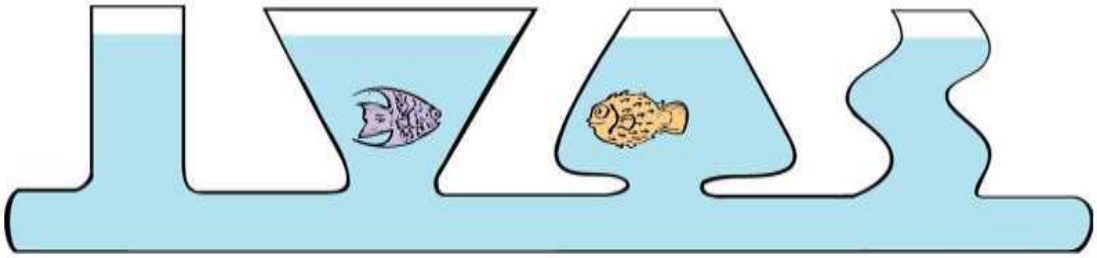
→ The pressure at point or depth 'C' is zero

→ The pressure of fluids given by

$P=\rho\vec{g}h$

ρ= density of liquid, $\vec{g}$ = gravity and h = depth

Fluid pressure does not depend on the surface area and the shape of the container as shown in the diagram below



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❖ ***Note***: When there is an atmospheric pressure above the liquid surface the total pressure P_T at a depth "h" below the surface given by

$$P_T = P_{atm} + \rho\ \vec{g}\ h$$

✓ Absolute pressure: it is the actual pressure at a given point it is the true pressure of a system

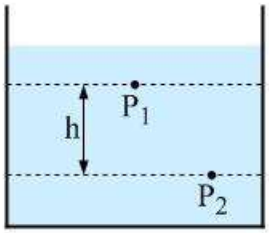
✓ Grouse pressure: pressure gauges often give readings gauge pressure rather than absolute it is the pressure difference between a system and atmospheric pressure

$P_g = P_s - P_{atm}$

P_g = gauge pressure

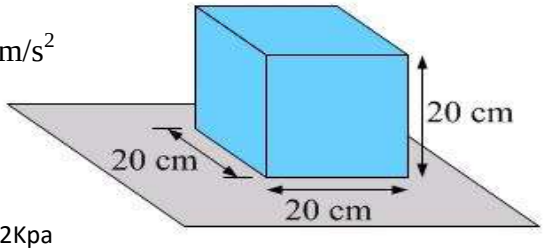
P_s = system pressure

- ✓ The pressure difference between two points is proportional to the vertical distance between them. Pressure increases with depth in a static fluid.



Problem

1. A plastic box is in the shape of a cube measuring 20 cm on each side. The box is completely filled with water and remains at rest on a flat surface. The box is open to the atmosphere at the top.



Assume atmospheric pressure is 1.0×10^5 Pa and use $\vec{g}$ = 10 m/s^2

A. What is the gauge pressure at the bottom of the box?
Soln: $P_g = P_s - P_{atm} = \rho\vec{g}h$ = 1000kg/m^3* 10m/sec^2 *0.2m = 2000Pa

B. What is the absolute pressure at the bottom of the box?
Soln: $P_T = \rho\vec{g}h + P_{atm}$= 1000kg/m3 * 10m/sec2 *0.2m +1x10^{5}Pa = 102Kpa

C. What is the force associated with this absolute pressure?
Soln: F = P_T*A = 102000Pa* 0.04m^2 = 4080 N

D. What is the force associated with the absolute pressure acting on the inside surface of one side of the box?
Soln: F = P_g*A = 2000Pa * 0.04m^2 = 80 N

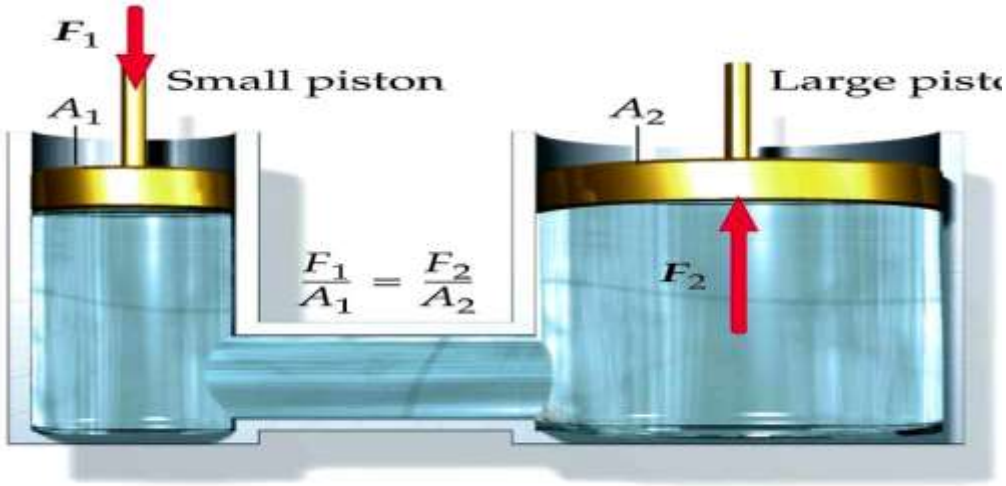
2. Calculate the pressure of sea water at a depth of 30m ($\vec{g}$ = 10m/sec^2, ρ = 1020kg/m$^{3)}$
Soln: USE P = ρ$\vec{g}$h = 1020 kg/m^3* 10m/sec^2* 30m = 3060kPa

3. Determine the pressure acting on a diver 20m below the surface
(USE $\vec{g}$= 10m/sec^2, ρ = 1000kg/m^3)
Soln: $P_T = P_{atm} + \rho\,\vec{g}\,h$ = 100000Pa + 1000kg/m^3*10m/sec^2*20m =300KPa

4. Calculate the pressure caused by sea water when diving to a depth of 100m and the total pressure acting on the diver?
Soln: pressure due to sea water = ρ$\vec{g}$h = 1020Kg/m^3*10m/sec^2*100m = 1020KPa
Total pressure = P_{atm} + ρ$\vec{g}$h = 100000Pa + 1020000Pa = 1120KPa

Pascal's principle

It states that "the pressure applied to an enclosed fluid is transmitted to every part of the fluid, as well as to the walls of the container without reducing in value" ($P_1 = P_2$)



1. Two pistons are connected together to make hydraulic lift. The smaller piston has an area of $0.05m^2$ and larger piston has an area of $2m^2$ calculate
   A. The pressure in the fluid and force at the larger piston if the force on the smaller piston is50N

      Soln: $P_1 = \frac{F1}{A1} = \frac{50N}{0.05m2} = 1000$ Pa

      Then the force on the larger piston = $P_1 * A_2$, since pressure if the same

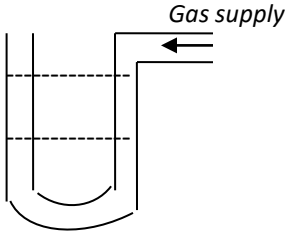
      $F2 = 1000\ Pa * 2m^2 = 2000$ N
   B. The pressure in the fluid and the force from the smaller piston requires to lift a car of mass 1200kg

      Soln: $P_2 = \frac{mg}{A2} = \frac{1200Kg*10m/sec2}{2m2} = 6000$ Pa

      Since the pressure is the same $F_1 = P_1 * A_1 = 600\ pa * 0.05m^2 = 30$ N

Measuring pressure:

- barometer and aneroid barometer are the most deuces that used to measure atmospheric pressure however most modern techniques use electronic pressure sensory
- Bourdon gauge: it is practical instrument for measuring the pressure of gas
- Manometer: is a simple instrument often used to measure the pressure of gas supply



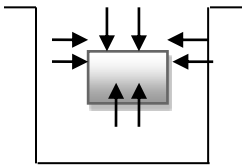
Pressure of gas = $P_{atm} + P_{gas}$

1. A water filled manometer was connected to a gas supply and the level of the water is 10cm calculate the pressure of the gas

Soln: Pressure of gas = Patm + P_{gas}
= 101kpa + 1000kg/m^3* 10m/sec2 * 0.1m
= 101kpa + 1kpa
= 102kpa

Forces in fluids

- There is a force from the water that pushes you up, acting against gravity this force is culled a buoyant force (up thrust)
- **Buoyant force = upward force acting on an object in liquid**, due to pressure on lower part of object being higher than pressure on upper part
-



- There is difference in force acting on the top and bottom of the Object the force on the bottom is greater and so there is net force
- The magnitude of the buoyant force (F_b) depends on
  1. Density of fluid
  2. The volume of the object

$\vec{F}_b = \rho \vec{g} v$ where $\vec{F}_b$ = buoyant force (up thrust)
ρ = density of the fluid
$\vec{g}$ = gravity

Apparent weight;

- When an object is immersed in a fluid, the buoyant force pushes up words, acting against the objects weight and so the weight appears to drop this weight is known as apparent weight
- The apparent weight may be calculated using the equation below

Apparent weight = weight in air – buoyant force

$W_A = W - F_b$

2. the weight of an object in air is 11N and its apparent weight is 9N.what is the buoyant force

Soln: $\vec{F}_b = W - W_A$ = 11N – 9N = 3N

3. the weight of an object measured in air is 15N, when it is immersed in a fluid if appears a weight of 11N calculate the buoyant force

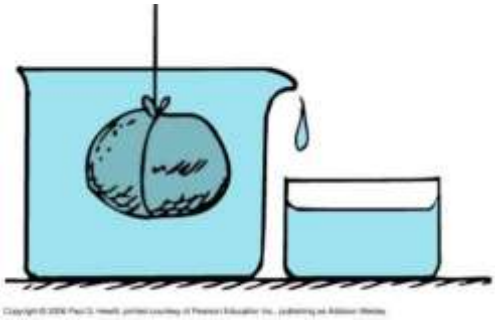
Soln: $\vec{F}_b = W - W_A$ = 15N – 11N = 4 N

Archimedes' Principle

Displacement: towards Archimedes principle

First we need the concept of "volume of water displaced"

- ✓ A completely submerged object always displaces a volume of liquid equal to its own volume
- ✓ If have container full of water, and then add a rock:
- ✓ Volume of water dripped out = volume of rock.(V_{df} = Vo for fully submerged)

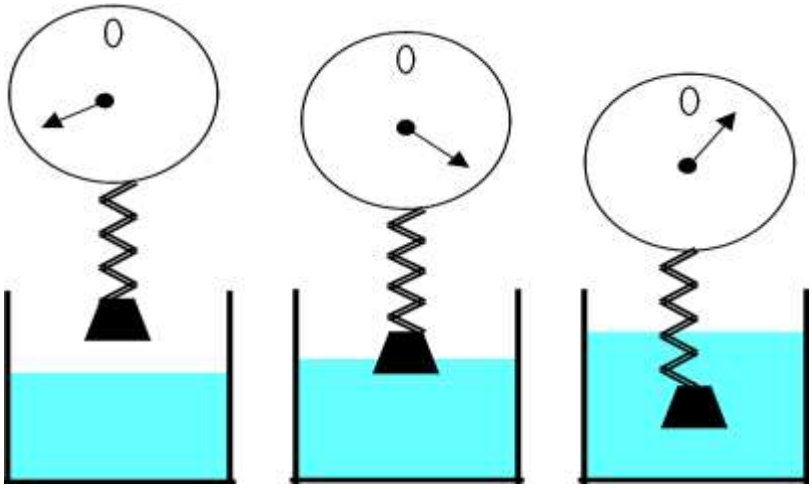




Archimedes' Principle

- **When an object is completely or partially immersed in a fluid, the fluid exerts an upward force on the object equal to the weight of the fluid displaced by the object.**

- When a solid object is wholly or partly immersed in a fluid, the fluid molecules are continually striking the submerged surface of the object. The forces due to these impacts can be combined into a single force the **buoyant force**. The immersed object will be "lighter" i.e. It will be buoyed up by an amount equal to the weight of the fluid it displaces



Floating: partially submerged

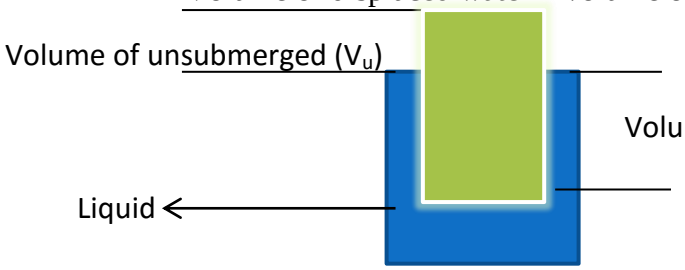
- Weight of object < weight of fluid that can be displaced by object
- Weight of liquid displaced by partially submerged object = weight of object
- The object will be **floats**

Floating: fully submerged

- Weight of object = weight of fluid displaced by object
- Volume of displaced water = volume of object

Sinks

- ❖ Weight of object > weight of fluid displaced by object
- ❖ Volume of displaced water = volume of object



Total volume = $V_s + V_u$

$$\frac{\rho o}{\rho l} = \frac{Vdf}{V0}$$

Where;

- ✓ ρ_l = density of liquid
- ✓ ρ_o = density of body
- ✓ V_{df}= volume of displaced liquid
- ✓ V_o= volume body

1. A plastic cube having aside of 10cm floats on fresh water if the volume of the cube that is un submerged in water is 60% of its total volume find
   A. The volume of the object
      Soln: $V_o = 10cm*10cm*10cm = 1000Cm^3$
   B. The volume of the un-submerged part
      Soln: $V_{un} = 1000cm^3*0.6$(60% of the total volume) $= 600cm^3$
   C. The volume of the sub merged part
      Soln: $Vs = Vo - Vu = 1000cm^3 - 600cm^3 = 400\ cm^3$
   D. The height of un submerged part
      Soln: $h_u = 10cm*0.6$(60% of the height of the cube) $= 6$ cm
   E. The height of submerged part
      Soln: $h_s = h_o - h_u = 10cm - 6\ cm = 4$ cm
   F. Fraction of un submerged part
      Soln: *Fraction of the body unsubmerged* $y = \frac{Vun}{Vb} = \frac{600cm3}{1000cm3} = \frac{3}{5}$
   G. Fraction of submerged part
      Soln: $X = 1 - y = 1 - \frac{3}{5} = \frac{2}{5}$

Elastic behaviour

Rigid Body

F. is one in which the relative position of its constituent particles does not change under the influence of impressed forces or in other words an ideal rigid body does not change in shape or size under the influence of applied force of any magnitude. When a body is subjected to external forces, it may get deformed. Such a force is called restoring force. As a result of deforming forces applied to body reactionary forces come into play internally due to relative displacement of its molecules, tending to balance the load and restore the body to its original condition. The body undergoes a change in its shape or size or both. These reactionary forces tend to restore the body to its original conditions. When the deforming forces are removed, the body tends to recover its original form.

G. The property of a material body by virtue of which the bodies are restored to their original shape or size or both after the removal of external deforming force is called elasticity. Extent to which the original form of a body is restored, when the deforming forces are removed varies from material to material.

- **Stress**

H. When a body is deformed by external force, internal reactionary forces are developed between the molecules of the body to oppose the action of the deforming force, which tend to restore the body to its original condition.

I.

J. The internal restoring force developed / unit area of the body when subjected to external deforming force is called stress.

K. Being a disturbed force, it is measured in the same manner as fluid pressure (i.e.,) in terms of load on deforming force applied / unit area of the body, being equal in magnitude but opposite in direction to it, until a permanent change has been brought about in the body.

L.

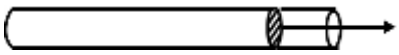
M. These forces are self-adjusting forces. As deforming force increases restoring force also increases. When deforming force is equal to restoring force, body attains equilibrium. Due to this, at equilibrium, stress can be measured by the deforming force applied on a unit area of the body.

N.

O. Stress $= \frac{Restoring\ force}{Area} = \frac{Deforming\ force}{Area} = \frac{F}{A}$

P. The stress developed in a body depends upon how the external forces are applied over it. Depending on this three types of stress, are as follows.

1. **Longitudinal stress (or) Tensile stress**
   - ✓ If the deforming force acting on a body is along its longitudinal axis and produces a change in its length, then the deforming force / unit area acting normal to the surface is called longitudinal or normal or tensile stress.
   - ✓ If the applied force is a thrust or produces a compression, then the stress is called normal compressive stress

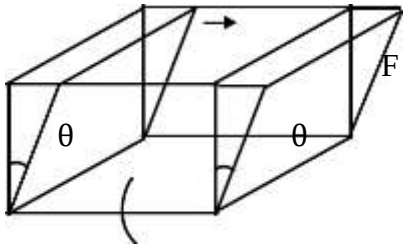


- ✓ **Tensile stress** $= \frac{F}{A}$

2. **Volume or Bulk stress**
   - ✓ If the equal deforming forces can be applied uniformly on each 6 faces of a cube in outward direction, then the cube suffers an increase in its volume under equilibrium, the applied force/unit area is called volume or bulk stress.

Stress

- ✓ If the deforming forces are applied tangentially over the top surface of a cube and bottom surface being kept fixed then, the top face gets displaced towards the direction of applied force



- ✓ The tangential force/unit area or the stress which tends to make one part of theory slide across the other part is termed as shearing stress or tangential stress.

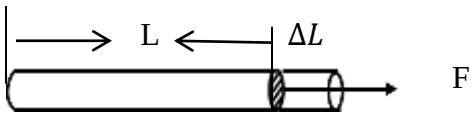
❖ **Strain**

- ✓ A body under deforming forces undergoes a change in length, volume or shape. Then the body is said to be under strain.
- ✓ The strain produced in the body is measured in terms of the fractional change produced in the dimensions of a body.
- ✓ Under a system of forces in equilibrium strain is also measured as the ratio of change in dimension of the body to its original dimension. As strain is just a ratio, it is a dimensionless quantity, having no units

Types of strain

1. Longitudinal strain or Tensile strain

- ✓ If the deforming force is of the nature of pull or a tension and acting along the longitudinal axis of a wire of length L, and produces a change in length ΔL without any change in shape then this fractional change ΔL/L, is called longitudinal str*ain.*

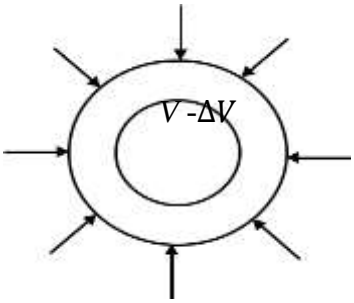


- *Longitudinal strain* $= \frac{Change\ in\ length}{original\ length} = \frac{\Delta L}{L}$

2. ***Volume strain***

- ✓ *When the forces or pressure are applied uniformly and normally inwards (or out-wards) over the whole surface of a body of volume V, then its volume gets decreased (or increased) by an amount ΔV without any change in shape. The ratio of this change in volume to its original volume is called volume strain.*

- *Volume strain* $= \frac{Change\ in\ volum}{Original\ Volume} = \frac{\Delta V}{V}$



3. ***Shearing strain or Shear***

- ✓ When the deforming forces are applied tangentially over the top surface of the body, it suffers a change in shape without any change in volume or length and is said to be sheared.
- ✓ Shear is numerically equal to the ratio of the displacement of any layer in the direction of applied tangential force to its distance from the fixed surface.
- ✓ Strain produced by stretching or compressing force, both volume & shape of the body may alter, while the strain produced by shearing forces only the shape of the body is altered though the volume remains constant.

- **Elastic limit**

- ✓ The maximum stress which produces maximum amount of recoverable deformation is called Elastic limit. If the stress applied exceeds the elastic limit, then the substance does not return to its original state when the stress is removed. The substance is then said to have acquired permanent set.

- **Hooke's Law**

- ✓ If a substance is subjected to a stress below the elastic limit, it recovers completely when the stress is removed or within elastic limit, the stress is directly proportional to strain produced.
- ✓
- ✓ The linear relationship between the stresses and deformations produced below elastic limit is called Hooke's law. (i.e.,)

  $\frac{stress}{strain}$ = constant = E
- ✓ E → Modulus of elasticity (coefficient of elasticity)
- ✓ The value of modulus of elasticity depends upon the type of stress and strain produced.

Young's modulus

- ❖ If the strain is longitudinal then the modulus of elasticity is called "Young's Modulus" (Y).
- ❖ Y = $\frac{Longitudinal\ stress}{Longitudinal\ strain} = \frac{F.L}{A.\Delta L}$

❖ Within elastic limit, the ratio of longitudinal stress to the corresponding longitudinal strain is called Young's modulus of elasticity.

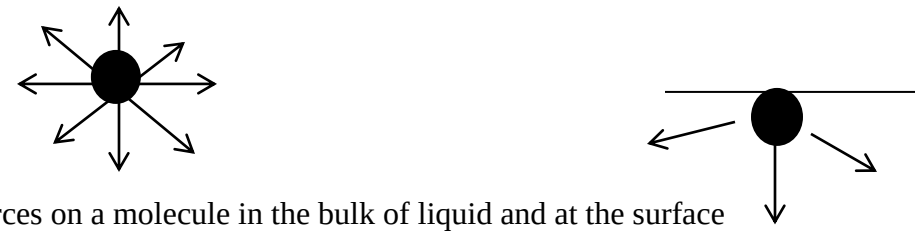
Bulk modulus

❖ When a uniform pressure (normal force) is applied normally over the whole surface of a body of an isotropic material, it suffers a change in its volume though its shape remains unchanged within elastic limit. The ratio of the volume stress to the volume strain is called bulk modulus of elasticity of the material

$$K = \frac{\text{Volume stess}}{\text{Volume strain}} = \frac{P,V}{\Delta V} \quad , \quad (p = \frac{F}{A})$$

SURFACE TENSION AND SURFACE ENERGY

- surface tension is a property of a liquid's surface that causes it to act like a stretched elastic skin; its caused by the force of attraction between the particles of the liquid and the other substance with which it comes into contact or a cohesive effect at the surface of the liquid due to the forces between the liquids, atoms or molecules
- $f = \frac{Force}{length} = \frac{F}{l}$
- Surface tension can be reduced by
  I. Adding detergent
  II. Warming the liquid
- **surface energy** it is a measure of the disruption of intermolecular bonds caused by a surface
- The molecules in the bulk of the liquid are surrounded by other molecules and so all the pulls cancel, but you can see that the ones at the surface seem to be tugged inwards. This disruption measured by surface energy.



The forces on a molecule in the bulk of liquid and at the surface

Pressure difference across a surface film

❖ When we observe that the surface of a liquid will tend to take on a curved shape. And this tells there is a pressure difference across a film, the Young-Laplace equation is given by

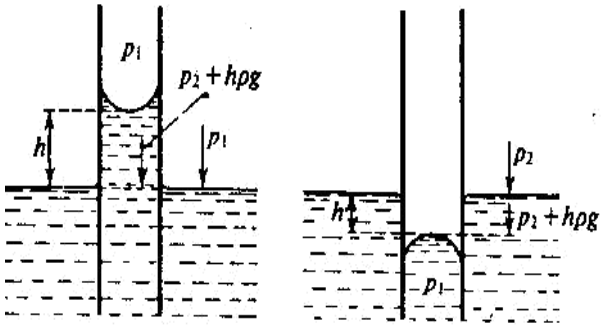


Pressure difference = surface tension*($\frac{1}{R1}$x$\frac{1}{R2}$)

$$\Delta P = f * (\frac{1}{R1} \text{x} \frac{1}{R2})$$

- ✓ Where R_1 and R_2 are the radii of curvature of each of the axes that are parallel to the surface

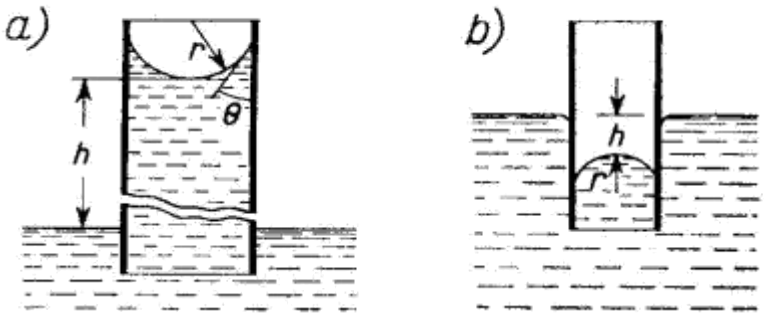
$\Delta P = P_1 - P_2 = \rho\, g\, h$



- ✓ On the concave side of the meniscus the pressure is p_1. The mechanical equilibrium is attained when the pressure values are the same in the capillary and over the flat surface.
- ✓ In the case of wetting liquid, the pressure in the capillary is lower than outside it, ($p_2 < p_1$). Therefore the meniscus is shifted to a height h when the pressure difference $\Delta p = p_2 - p_1$ is balanced by the hydrostatic pressure caused by the liquid raised in the capillary

Capillarity action; - is the movement of a liquid along the surface of a solid caused by the attraction of molecules of the liquid to molecules of a solid.

- ❖ **Meniscus**;- is a curve in the surface of a liquid caused by the relative attraction of the liquid molecules to the solid surface of the container
  - ✓ A consequence of the surface tension appearance at the liquid/gas interface is moving up of the liquid into a thin tube that is capillary, which is usually made of glass
  - ✓ This phenomenon was applied for determination of the liquid surface tension.
  - ✓ For this purpose, a thin circular capillary is dipped into the tested liquid.
  - ✓ If the interaction forces of the liquid with the capillary walls (adhesion) are stronger than those between the liquid molecules (cohesion), the liquid wets the walls and rises in the capillary to a defined level and the meniscus is hemispherical **concave**.
  - ✓ In the opposite situation the forces cause decrease of the liquid level in the capillary below that in the chamber and the meniscus is semispherical **convex.** Both cases are illustrated as follow



For capillary rise

$$h = \frac{2f\cos\theta}{\rho g r}$$

- *Hence the surface tension (f) = F/L , and F =fL*
- *$F\cos\theta = mg$, but $m = \rho V = \rho\pi r^2 h$*
- *$L = 2\pi r$ the by sustitutng*
- *$f2\pi r\cos\theta = \rho\pi r^2 hg$*
- $h = \frac{2f\cos\theta}{\rho g r}$

Fluid Dynamics

In order to describe the motion of a fluid we consider the properties of the fluid such as velocity & pressure at a fixed point in space.

Characteristics of an ideal fluid;-

- ✓ **Steady:** the velocity & pressure at each point are constant in time.
- ✓ **Non – viscous:** there is no dissipation of energy due to internal friction between adjacent layers in the liquid.
- ✓ **Non- Rotational:** a tinny paddle placed in the liquid will not rotate.
- ✓ **Incompressible:** its density is constant.

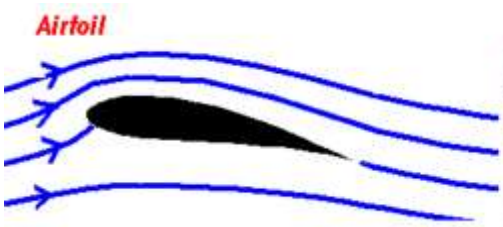
Terminologies in fluid dynamics

- The path followed by an element of a moving fluid is called a line of flow
- Stream lines: These are imaginary lines drawn with in the volume of flowing liquid ,tangent drawn to which at any point gives the direction of velocity of the particle, cross that point

Types of flow

❖ ***streamline(laminar)***

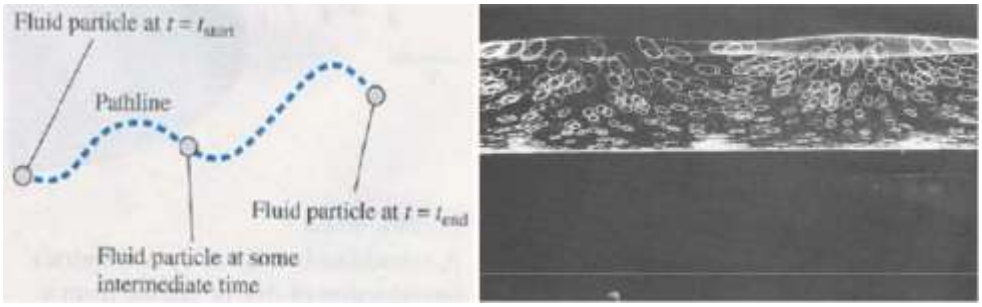
Is a line that is everywhere tangent to the velocity vector at a given instant.





❖ ***Turbulent flow***

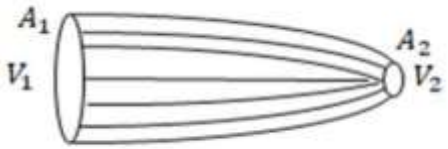
- ✓ A type of fluid flow where there is disruption to the layers of fluid
- ✓ the speed of the fluid at any point is continuously *changing both in magnitude and direction*



Motion of water induce by surface waves

Equation of continuity

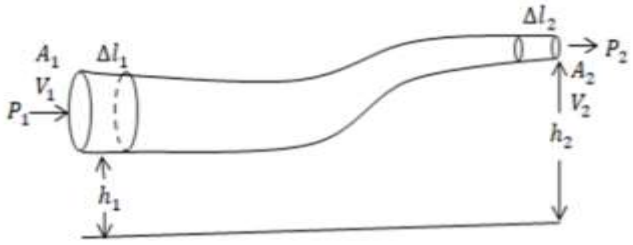
- ✓ In general, the velocity of a particle will not be constant along a streamline. The density & cross-sectional area of a tube of flow will also change. The mass of fluid contained in a small cylinder of non – uniform cross-section of length & area A, is later this mass pass through the second point in the cylinder as shown in the diagram below



- ❖ V_1 be the speed at the cross sectional area A_1 and V_2 be the speed at the cross sectional area A_2.the mass entering the area A1 during the time interval Δt is given by $\rho V_1 A_1 \Delta t$,similarly the mass that flows out cross A2 in the same time interval is $\rho V_2 A_2 \Delta t$
- ❖ **That is $\rho V_1 A_1 \Delta t = \rho V_2 A_2 \Delta t$ ……. (Equation of continuity)**
- ❖ **$V_1 A_1 = V_2 A_2$ …….. since density is constant**

Bernoulli's Equation

- ❖ Bernoulli's equation is a fundamental relation in fluid mechanics and is a general expression that relates the pressures difference between two points in a flow tube to both velocity changes and elevation changes



- ❖ Using work energy theorem :
- ❖ $\mathbf{P_1 + \frac{1}{2}\rho V_1^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho V_2^2 + \rho g h_2}$ ……. Bernoulli's equation

- The pressure P + ρgh is called static pressure and
- $\frac{1}{2}\rho V_1^2$ is called the dynamic pressure
- static pressure + dynamic pressure = total pressure
- According to Bernoulli's principles **total** pressure is constant along a stream line

Viscosity

- The property of a fluid to oppose the tendency to flow is known as **viscosity**
- Newton's law states that in a steady flow viscous force F opposing the flow is proportional to the velocity gradient& surface area in contact
- $F = \eta A \frac{\Delta V}{\Delta y}$
- η = ***Coefficient of viscosity***
- *η depends on the nature of the liquid & temperature*

Stokes' law and terminal velocity

- *A* drag force is a force retarding force that arises due to viscosity in a fluid when a body tries to move. Stokes' showed that the drag force F_d of a fluid medium on a spherical body is proportional to;-

A. Radius of the spherical body (r).
B. The coefficient of viscosity (η).
C. The velocity of the sphere (v).
   - **$F = 6\pi\eta rv$**
   - **coefficient of viscosity is Pascal* second which is called poise**
   - The drag force is proportional to the speed of the object. At some point the viscous force equal to the weight of the drop. The drop then falls down with constant velocity which is called terminal velocity. At this terminal velocity, the weight of the sphere equals to the viscous retarding force plus the buoyant force.
   - The terminal velocity is the constant velocity when a body sinks in a fluid
   - The terminal velocity of a sphere of radius r and density ρ falling in fluid of density σ and coefficient of viscosity **η is given by**
   - $\mathbf{V_T = \frac{2}{9} r^2(\frac{\rho-\sigma)g}{\eta}}$

Problems

1. Water flows a long a horizontal pipe of cross-sectional area 30cm^2. The speed of the water is 4m/sec, but this rises to 9m/sec in a contraction of pipe. What is the area of the narrow part of the tube?

   Soln: Using *Equation of continuity* $V_1A_1 = V_2A_2$, then $A_2 = \frac{V1A1}{V2} = = \frac{4m/\sec 30cm2}{9m/sec} = 13.33\text{cm}^2$

2. A mercury barometer reads 747mm on the roof of a building and 760mm on the ground. If the density of the air has a constant value of 1.3Kg/m^3, what is the height of the building?

   Soln: P_1 = 747mm-Hg at the top of the building

P_2 = 760mm-Hg at the base of the building

Density of air = 1.3kg/m^3 and density of mercury = 13600kg/m^3

$\rho_{Hg} * g * H_{Hg} = \rho_{air} * g * H_{building}$

$H_{building} = \frac{\rho_{Hg}}{\rho_{air}} H_{Hg} = \frac{13600*(760-747)x10-3}{1.3}$ = 136m

3. A 1m long rubber is stretched to a new length of 1.1m. What is the tensile strain?

Soln: *tensile strain* = $\frac{\Delta L}{L} = \frac{0.1m}{1m} = 0.1$

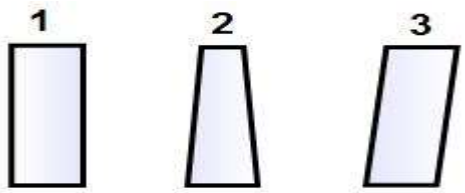
4. A column of water 40cm high support a 25cm column of an unknown fluid.

What is the density of the unknown fluid?

Soln: $\boldsymbol{\rho 1 g h_1 = \rho 2 g h_2}$ $\boldsymbol{= \rho 2} = \frac{\rho 1 * h1}{h2} = \frac{1000*40}{25}$ = 1600kg/m^3

I. **Chose the correct answer**

1. Two substances mercury with a density 13600 kg/m^3 and alcohol with a density 6000 kg/m^3 are selected for an experiment. If the experiment requires equal masses of each liquid, what is the ratio of alcohol volume to the mercury volume?
   A.30/15 B. 30/68 C. 1/13 D. 1/10
2. A perpendicular force is applied to a certain area and produces a pressure P. If the same force is applied to a twice bigger area, the new pressure on the surface is:
   A. 2P B. 4P C. P D.P/2
3. Three containers are used in a chemistry lab. All containers have the same bottom area and the same height. A chemistry student fills each of the containers with the same liquid to the maximum volume. Which of the following is true about the pressure on the bottom in each container?
   F. P1>P2>P3
   G. P1<P2<P3
   H. P1<P2>P3
   I. P1= P2=P3



4. What is the difference between the pressure on the bottom of a pool and the pressure on the water surface?
   A. ρgh B. ρg/h C. ρ/gh D. gh/ ρ
5. A boy swims a lake and initially dives 0.5 m beneath the surface. When he dives 1 m beneath the surface, how does the absolute pressure change?
   A. It doubles C.It quadruples
   B. It cut to a half D. It slightly increases
6. A hydraulic lift is used to lift a car. The small piston has a radius of 5 cm and the large piston has a radius of 50 cm. If a driver applies a force of 88 N to the small piston, what is the weight of the car the large piston can support?
   A. 880 N B.88 N C. 8800 N D. 8.8 N E. 88000 N
7. What happens to a solid object with a density that is less than the density of water when it is placed in water?
   A. The object dissolves in the water.
   B. The object displaces a quantity of water greater than its volume.
   C. The object settles to the bottom of the water.

D. The object floats on top of the water.

8. Why doesn't an ice cube float in air?
   A. Water is less dense than air. C.Air is denser than ice.
   B. An ice cube is denser than air. D. Air has more pressure.
9. What scientific rule states that the buoyant force on an object is equal to the weight of the fluid displaced by the object?
   A. Archimedes' principle C. Pascal's principle
   B. Bernoulli's principle D. Newton's third law of motion
10. A ship stays afloat as long as the buoyant force is
    A. Less than the ship's weight. C. Greater than the ship's weight.
    B. Less than the ship's speed. D. Greater than the ship's speed.
11. The mass per unit volume of a substance is its
    A. Density. B. Buoyancy. C. Weight. D. Fluid pressure.
12. Stress is
    A. External force B. Internal resistive force C.Axial force D. Radial force
13. Tensile Strain is
    A. Increase in length / original length C. Change in volume / original volume
    B. Decrease in length / original length D. All of the above
14. Young's Modulus of elasticity is
    A. Tensile stress / Tensile strain C.Tensile stress / Shear strain
    B. Shear stress / Shear strain D.Shear stress
15. The stress at which extension of a material takes place more quickly as compared to increase in load, is called
    A. No elastic zone B. Plastic point C. Yield point D.Breaking point
16. When a section is subjected to two equal and opposite forces tangentially to the section, the stress produced is known as
    A. Tensile stress B. Lateral stress C. Shear stress D.No stress
17. When a bar is subjected to a change of temperature and its longitudinal deformation is prevented, the stress induced in the bar is
    A. Tensile B. Compressive C.Shear D. Temperature
18. Which law is also called as the elasticity law?
    A. Bernoulli's law B. Stress law C. Hooke's law D. Poisson's law
19. A steel bar of 5 mm is heated from 25°C to 45°C and it is free to expand. The bar will induce
    A. No stress B. Shear stress C.Tensile stress D.Compressive stress
20. Strain energy is the
    A. Energy stored in a body when strained within elastic limits
    B. Energy stored in a body when strained up to the breaking of a specimen
    C. Maximum strain energy which can be stored in a body
    D. Minimum strain energy which can be stored in a body
21. The volumetric strain is the ratio of the
    A. Original thickness to the change in thickness
    B. Change in thickness to the original thickness
    C. Original volume to the change in volume
    D. Change in volume to the original volume
22. A block of wood floats in water with two-thirds of its volume submerged. What is the density of the wood? ($\rho_{water} = 1gm/cm^3$)

A. 67gm/cm^3 B. 6.7gm/cm^3 C. 0.67gm/cm^3 D. 0.7 x 10^{3}kg/m^3

23. A block of wood (Density= 800kg/m^3) having a volume of 0.4m^3 floats on water (Density =1000kg/m^3). What mass should be placed on the block in order for its top surface to be the same level with the surface of the water?
    A. 80kg B.40kg C. 8kg D. 32kg
24. A certain wire of length L, cross-sectional area of 1x10^{-4}m^2 and young's modulus 8x10^{8}N/m^2 has a 200kg load hung on it.By what percent will the length increase? (g = 10m/sec^2)
    A. 25% B. 2.5% C. 40% D. *4%*
25. In steel, the young's modulus and the strain at the breaking point are 2x10^{11} N/m^2 and 0.2 respectively. The stress at the breaking point for the steel is
    A. 0.4x10^{11}N/m^2 B. 1x10^{10}N/m^2 C. 4x10^{-10}N/m^2 D. 1x10^{-12}N/m^2
26. A body is put one by one in three liquids P, Q and R having different densities. Consider the following statements and arrange the liquids in ascending order of densities
    I. In liquid P, the body is floats 1/3 of their volume inside the liquid
    II. in liquid R, the bod is completely submerged
    III. in liquid Q, the body floats with 1/4 their volume inside the liquid
    A. R< Q <P B. R< p <Q C. Q< p < R D. P< R <Q
27. What is the specific gravity of a marble stone, which weighs 400N in air and 200N in water? (Density of water = 1000Kg/m^3)
    A. 8 B. 6 C. 4 D. 2
28. According to Archimedes' principle if a solid object floats, the volume of displaced water is equal to the volume of:
    A. the portion of the object that is submerged
    B. the portion of the object that is above the water
    C. half of the object
    D. the whole object
29. A certain object floats in three fluids, F_1, F_2 and F_3 of densities 0.9ρ, ρ and 1.1ρ respectively. The volume of the displaced fluid by the object is
    A. greatest for F_2 B. least for F_2 C. least for F_3 D. least for F_1
30. A plastic cube having a side of length 10cm floats on fresh water. If the volume of the cube that is submerged in water is 40 percent of its total volume, what is the density of the cube? (ρ_{water} = 1000kg/m^3)
    A. 400kg/m^3 B. 1000kg/m^3 C. 600kg/m^3 D. 500kg/m^3

II. <u>solve the following problems</u>

1. When a wire is stretched to double in length, what is the longitudinal strain produced in it?
2. The length of a wire is increased by 4mm on the application of a certain load. In a wire of the same material but of twice the length and half the radius, Determine the length if the same force exerted on it.
3. During a surgery a patient receives a blood transfusion through needle of radius 1mm and length of 40cm. The density of blood is 1.05g/cm^3. The bottle supplying the blood 0.5m above the patient's arm.What is the rate of flow through the needle
4. Water flows through a pipe between two points having a cross-sectional area of 32cm^2 & 8cm^2 respectively, the speed at the 1st point is 16m/what is the speed at the 2nd point?
5. A rod, 1.20m long and of diameter 2cm is subjected to an axial pull of 200N. Find The stress
6. A rod 3 m long is heated from 10°C to 100°C. Find the expansion of rod.

Take Young's modulus = $1.0 \times 10^{11} N/m^2$ and coefficient of thermal expansion = $1.2 \times 10^{-5}/^0c$

7. A 200gm of water is mixed with 160gm of liquid of relative density 1.2. What is the relative density of the mixture?
8. The volume of a cube is $10cm^3$.What is the buoyant force on it when it is completely submerged in water?
9. Water flows into a horizontal pipe having a diameter of 6cm with a velocity of 4m/sec, at a certain point this pipe is connected to a pipe of diameter 4cm. Calculate the velocity of the liquid
10. A piece of ice floats with 10/11 of its volume submerged under fresh water. If the piece of ice is put into sea water of density $1020kg/m^3$. What is the fraction of unsubmerged part of the ice?

UNIT 7: TEMPERATURE AND HEAT



What is heat?

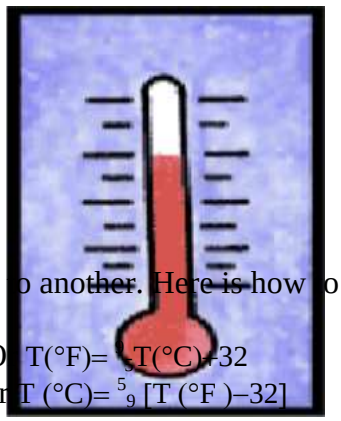
- Heat (denoted Q) is a flow of energy between two objects as a result of temperature difference between them
- Heat flows from higher temperature body to a lower temperature body
- This flow reduce the higher temperature body and increase the temperature of the lower body until the two bodies will have the same temperature
- If two objects are at the **same temperature no heat energy is transferred** between them when they are brought into contact

Temperature

- Temperature is a measure of the average kinetic energy of atoms and molecules.
- Temperature is a characteristic of an object related to the average kinetic energy of atoms and molecules in the object
- Hotness" and "coldness of a body , **SI unit of temperature is the Kelvin**

Temperature Scales

- *Temperature is the level of heat in a gas, liquid, or solid.*
- *Three scales are commonly used for measuring temperature.*
- *The Celsius and Fahrenheit scales are the most common.*
- *The Kelvin scale is primarily used in scientific experiments.*



Converting Temperatures

- ✓ It is sometimes necessary to convert temperature from one scale to another. Here is how to do this.
- ✓ To convert from ºC to ºF, use the formula: ºF = ºC x 1.8 + 32. Or $T(°F) = \frac{9}{5} T(°C) + 32$
- ✓ To convert from ºF to ºC, use the formula: ºC = (ºF-32) ÷ 1.8.Or $T(°C) = \frac{5}{9} [T(°F) - 32]$
- ✓ To convert from K to ºC, use the formula: ºC = K – 273.15
- ✓ To convert from ºC to K, use the formula: K = ºC + 273.15.
- ✓ To convert from ºF to K, use the formula: K = 5/9 (ºF – 32) + 273.15.
- ✓ To convert from K to ºF, use the formula: ºF = 1.8(K – 273.15) + 3

Thermal equilibrium

- ✓ If two objects are in thermal contact, the hotter object cools and the cooler object warms until no further changes take place the objects are in **thermal equilibrium**.

Typical question

Consider a hot cup of coffee sitting on a table as the system. Using this system as an illustration, give a scientific interpretation of the terms:

- ✓ **temperature**,
- ✓ **heat and**
- ✓ **thermal equilibrium**



The first law of thermodynamics

Thermodynamics is the study of the effects of work, heat, and energy on a system
Thermodynamics is only concerned with macroscopic (large-scale) changes and observations
The First Law of thermodynamics is:

- The **increase** of the *internal energy* of a system is equal to the sum of the *heat* added **to** the system plus the *work* done **on** the system.

In symbols:

$$\Delta U = \Delta Q + \Delta W.$$

Where ΔU= internal energy
ΔQ = heat added or removed
ΔW = work done on the system or by the system

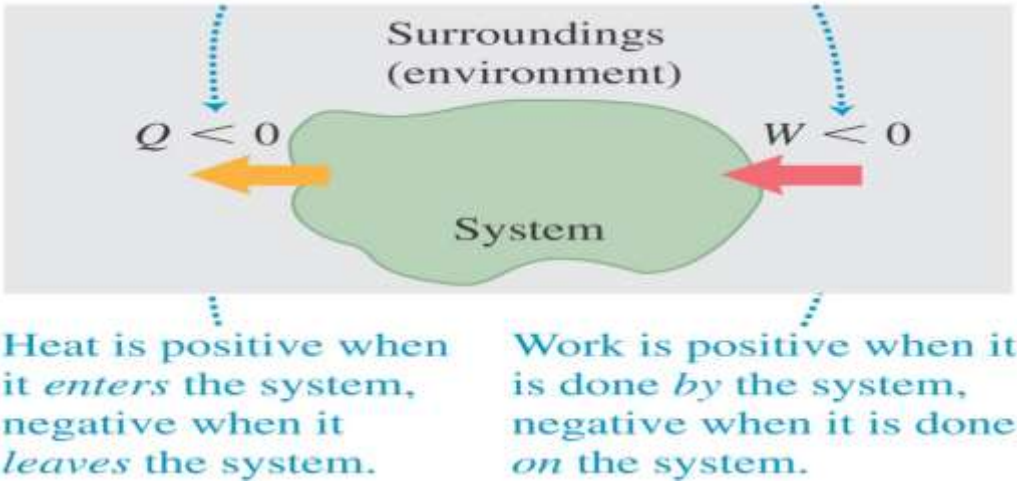
- ✓ The internal energy of a system is made up of many components, any or all of which may be increased when you add heat **to** the system or do work **on** it.
- ✓ If the system is a gas, for example, the internal energy includes the translational, vibrational and rotational kinetic energies of the molecules. It also includes potential energy terms arising from the forces between the molecules, and it may also include excitation energy if the atoms are excited to energy levels above the ground state.
- ✓ It may be difficult to calculate the total internal energy, depending on which forms of energy you take into account. And of course the *potential* energy terms are always dependent on what state you define to have zero potential energy. Thus it is really impossible to define the total internal energy of a system uniquely. What the first law tells us is the *increase* in internal energy of a system when heat is added **to** it and work is done **on** it.

$$U = \Sigma KE + \Sigma PE$$

In general internal energy *U*

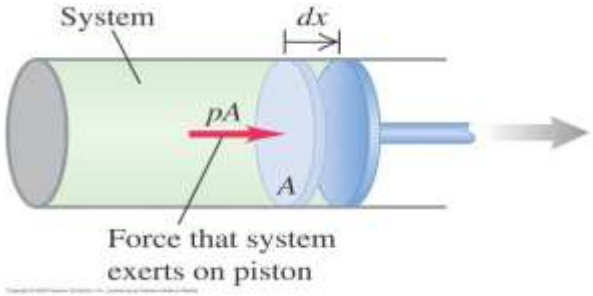
- ✓ We define the *internal energy* of a system to be the sum of
- ✓ the kinetic energy of all its particles
- ✓ the potential energy of interactions between particles

Sign convention



Work (W)

- Let's look at work done during volume changes.
- Pressure exerts a force on the piston, which moves from x_1 to x_2:
- W = F.dx but F = P.A
- W= P.A.dx since
- volume = A.dx therefore
- W = PΔV
- ***W* > 0** energy removed from system (work is done by the system against its surroundings) (expansion)
- ***W* < 0** energy added to system (work is done on the system) (compression)



Examples

1. 5000J of heat is added to the system and the gas performs 7500J.what is the internal energy of the system?
   Solution

$$\Delta U = \Delta Q - \Delta W.$$
$$= 5000J - 7500J$$
$$= -2500J$$

The Second Law of Thermodynamics

- It state that Heat generally cannot flow spontaneously from the region of lower temperature body to a region of higher temperature body or heat can flow from a region of higher temperature body to a region of lower body
- There is a net energy flow from hotter to colder object
- Energy will flow from colder to hotter Object if work is done on the system (E.g. fridge)

THE EFFECTS OF HEAT ON MATTER

When heat is added to a body, various things can result:

A. Expansion
B. increase in temperature
C. change of state
D. chemical change

Expansion of solid, liquid and gas

- ✓ When heat is added to a solid, the particles gain energy and vibrate more vigorously about their fixed positions, forcing each other further apart. As a result expansion takes place.
- ✓ Similarly, the particles in a liquid or gas gain energy and are forced further apart. The degree of **expansion** depends on the substance.

For a given rise in temperature a liquid will expand more than a solid. Gases expand enormously on heating, causing a possible explosion if the gas is in a confined space.

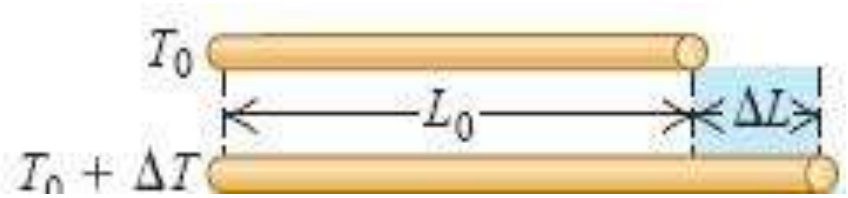
- ✓ In a fire, the thermal expansion of steel beams, concrete and glass can cause considerable damage, especially if expansion takes place at different rates, setting up stresses in the material or structure.
- ✓ Liquids in drums and pans may overflow when heated. This is due to the fact that liquids expand at a greater rate than solids.

Expansion of solid

I. Linear expansion

How does a change in temperature affect the dimensions of a system?

- ❖ Most materials expand when their temperatures increase.



- ❖ the increase in length is found to be proportional to the **temperature increase**, and to the **length** of the object:
- ❖ $\Delta L = \alpha L_o \Delta T$ Where
  - ✓ ΔL change in length
  - ✓ Lo the original length
  - ✓ ΔT change in temperature
  - ✓ α is the coefficient of linear expansion.

  Units: K^{-1}, $°C^{-1}$

II. Area thermal expansion*:*

- ✓ Consider square, side length *L*, area $A = L^2$ New area:
- ✓ $A_o + \Delta A = (L_o + \Delta L)^2 = L_o^2 + 2L_o \Delta L + \Delta L^2$
- ✓ $A_o + \Delta A \approx L^2 + 2L_o \Delta L$ Thus
- ✓ $\Delta A = 2L \Delta L = 2L(L\alpha\Delta T) \Delta A = L^2(2\alpha)\Delta T = A(2\alpha)\Delta T$
- ✓ $A = A_o(1 + \beta\Delta T)$
- ✓ Thus, the coefficient of area expansion is approximately 2α
- ✓ $\Delta A = A_o 2\alpha\Delta T$ but $\beta = 2\alpha$

  Where ΔA = change in area, Ao = original area and β = coefficient of area expansion

III. Volume expansion

- ✓ Volume expansion is the change in volume due to temperature.
- ✓ Volume expansion formula is given by
- ✓ $\Delta V = V_o \gamma \Delta T$ *or*
- ✓ $V = V_O (1 + \gamma \Delta T)$

Where V_O = original volume
V = expanded volume
γ = coefficient of volume expansion
ΔV = change in volume after expansion
ΔT = temperature difference

Thermal Expansion of liquids

- ✓ Unlike solids, liquids have no definite shape. They always take the shape of their container. Therefore it is only possible to consider volume expansion. Because of a liquid and its container will expand when they are heated it is not easy to find the true coefficient of volume expansion of liquids.
- ✓ If the expansion of the vessel is neglected then the coefficient obtained is called the apparent coefficient of volume expansion (γ_{app}) and it is given by

$$\gamma_{app} = \frac{\Delta V}{Vo\Delta T} \qquad \text{and } V = Vo\,(1+\gamma_{app}\,\Delta T)$$

If we want to find the true coefficient of volume expansion, we have to add the coefficient of expansion of the container to the apparent coefficient of the liquid and it is given by

$$\gamma_{True} = \gamma_{app} + \gamma$$

Where γ_c =expansion coefficient of the container

Expansion of gases

- ➢ There are no volume expansion coefficients for gases because of the following factors
  A. Pressure
  B. Temperature
  C. Amount of gas present (number of moles)

- ➢ The relationship between the volume of gas and its temperature can be shown using the ideal gas equation

$$PV = nRT$$

Where P= pressure in pa
V= volume of gas in m^3
T= absolute temperature in K
N= number of moles of gas in mole
R= universal gas constant (8.314J/mole/k)

Note: if the pressure and amount of gas are constant
$V \approx T$ (volume is directly proportional to temperature)

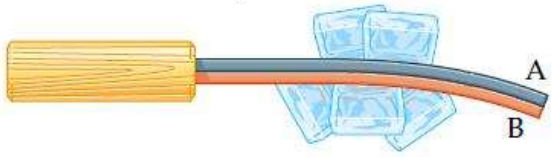
The bimetallic strip

- ✓ A bimetallic strip is made out of two metals for example iron and brass bonded together.
- ✓ The coefficient of linear expansion (α) of iron ($1.1X10^{-5}k^{-1}$) is less than that of brass ($1.9X10^{-5}k^{-1}$)

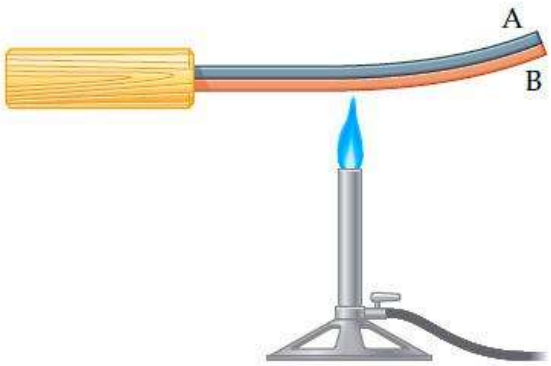
When the strip is heated, the brass expands more than the iron and the strip bends.



(a) A bimetallic strip



(b) Chilling the strip



(c) Heating the strip

Measuring heat energy

- ➢ **Quantity of heat (Q)** -
  Substances differ from one another in the quantity of heat needed to a given rise of temperature in a given mass.
- ➢ Quantity of heat is directly proportional to the change in temperature

  i.e. $Q \approx \Delta T$
- ➢ Quantity of heat is also directly proportional to the mass of the substance

  i.e. $Q \approx m$

Then $\boxed{Q = mc\Delta T}$ where c =specific heat capacity of the substance

The unit of c = J/Kg.K

- ➢ The quantity of heat (Q) needed to change the temperature of an object depends on:

1. temperature change (ΔT)
2. mass (m)
3. specific heat of substance

- ❖ The specific heat capacity (c) of a substance is the heat energy required to raise the temperature of a unit mass (say 1kg) of the substance through one degree

Specific Heat

Depends on the nature of the substance

•Large for insulator

•Small for metals

•Concerns the storage of thermal energy

❖ Heat capacity (C) is the amount of heat needed to raise the body temperature by one degree the SI unit of C is J/k

$$C = \frac{Q}{\Delta T} \quad \text{or } C = mc$$

Where c= specific heat capacity

C= heat capacity, Q= Quantity of heat

ΔT =Change in temperature, m =mass

The low of heat exchange

✓ It is obvious that when two substances at different temperatures are mixed, the hotter loses some heat and colder one gains it when we record the temperature of the mixture after their **THERMAL EQULUBRIUM**, we can see that the temperature of the mixture is less than that of the hot substance and greater than the cold substance.

✓ The law of heat exchange can be states as follows

"The amount of heat lost by hot substance is equal to the quantity of heat gained by cold substance provided that there is no heat transfer to the surrounding system"

Heat loss = heat gained

$$m_1 C_1 \Delta T_1 = m_2 C_2 \Delta T_2$$

$$m_1 c_1 (T_1 - T_3) = m_2 c_2 (T_3 - T_2)$$

Where: m_1, c_1, T_1 are the mass, specific heat capacity and temperature of hot body.

m_2, c_2, T2 are the mass, specific heat capacity and temperature of cold body,

* T_3 is the Temperature of the mixture

Latent heat

✓ It is the heat required to change the state of substance (from one state to the other) sometimes it is called "hidden" heat because when this energy is absorbed or liberated, there is no temperature change.

✓ If the phase changes from liquid to solid or solid to liquid state, it is known as the latent heat of fusion (L_f) Then

$Q = m L_f$ And $Q = m L_v$

Where Q is heat quantity

m is the mass

L_f is lateen heat of fusion

Lv is lateen heat of vaporization

Transfer of heat energy

- ✓ There are various ways by which heat energy may be transferred.
- ✓ Conduction, convention and radiation are the main way in which heat energy transferred

1. Conduction

- In solid the particles vibrate but do not change their equilibrium position
- As the temperature raises the speed and the amplitude of the vibration becomes larger.
- So conduction is the process by which heat is transferred through a material by collision of adjacent atoms or molecules
- The rate of flow of heat(heat current) is defined as

$$H = \frac{\Delta Q}{\Delta t}$$

- The rate of heat flow is proportional to:
  - ✓ The temperature gradient (ΔT)
  - ✓ The cross- sectional area(A)

$$\frac{\Delta Q}{\Delta t} = kA\frac{(T2-T1)}{X}$$

K = thermal conductivity of the material

2. Convention

- The other way of transferring heat energy is by convention.
- This way of heat transfer does not occur in solids, but only in liquids and gases
- It cannot occur in vacuum

3. Radiation

- It is the form of heat transferred method by electromagnetic wave
- If an object is at temperature T and its surrounding are at temperature T_0, the net energy gained or lost each second by the object as a result of radiation is

$$P = \sigma Ae\ (T^4 - T_o^4)$$

  - ✓ σ = is constant equal to $5.67x10^{-8}W/m^2k^4$
  - ✓ e = is constant called the emissivity and
  - ✓ T temperature of the object and T_0 temperature of the surrounding

1. Concrete slabs of length 25 m are laid end to end to form a road surface. What is the width of the gap that must be left between adjacent slabs at a temperature of -15^0C to ensure they do not buckle at a temperature of $+45^0C$.Coefficient of thermal expansion for concrete $\alpha = 12x10^{-6}\ ^0C^{-1}$

Solution:

- ✓ Slabs should barely touch at the higher temperature.
- ✓ Each slab must expand at either end by an amount equal to half the gap. The total expansion of each slab should be equal to the gap.

$\Delta L = (L)(\alpha)(\Delta T)$, $\Delta L = 25m*12x10^{-6}(^0C^{-1})*60^0C = 18\ x10^{-3}m$

2. A rod of length 5m is heated to 40^0c .If the length increase to 7m after some time. Find the expansion coefficient. Room temperature is 30^0c

Given: initial length = 5 m, expanded length = 7m, change in length =7m -5m = 2m

Temperature difference = 40^0c -30^0c = 10^0c = 283K

Solution: $\alpha = \Delta L/Lo\Delta T$

$= 2m/5mx283K$

$=1.4x10^{-4}/K$

3. A sheet of glass has an area of 6000 cm^2 at 10^0 C. If the temperature rises to 200^0 C. what will be its new area?

Solution:

$\Delta A = A_o 2\alpha\Delta T$

Change in area $= 6000^2$cm x 2 x 0.000008 x 190

$= 18.2\ cm^2$

New area = 6018.2 cm^2 ($A = Ao + \Delta A$)

4. *A steel storage tank has a volume of 20^3m at 20^oC. As a result of a fire the tank is raised to 300^oC. What is the new volume of the tank?*

Solution: $\Delta V = V_o\gamma\Delta T$

Change in volume = 20 m^3 x 3 x 0.000012 x 280

$= 0.20\ m^3$

New volume = 20.20 m^3 ($V = V_O + \Delta V$)

5. If the steel storage tank in the example 3 above were filled with oil, what would be the increase in the volume of the oil in that fire?(expansion coefficient of oil = 0.0009/^{0}c)

Solution: Change in volume of oil = 20 m^3 x 0.0009 x 280

$=5.04\ m^3$

6. 650g of water at 33 ^{0}C are poured into an aluminum pot of mass 250g at 15 ^{0}C. If no heat is lost to the surroundings, find the final temperature of the system. c_{Al} = 900 J/Kg.k

Solution: No heat is lost to the surroundings Conservation of energy

Heat lost by the water = Heat gained by pot

$Q_w = Q_{Al}$

$0.65Kg*4200J/Kg.k* (33^0c - T_3) = 0.25Kg*900J/Kg.k* (T_3_15^0c)$

$T_3 = 31.6^0c$

7. How much heat is needed to boil away 2kg of water at 10°C contained in an aluminum pot of mass 200g?

C_{water} = 4200J/Kg.k, $C_{aluminium}$ = 910J/Kg.k

Heat of vaporization of water = 2260KJ/Kg

I. Heating of the pot:

$Q = mc\Delta T$

$= 0.2kg*910J/Kg.k *90K$

$=16380J$ or 16.380KJ

II. Heating of the water

$Q = mc\Delta T$

$= 2kg*4200J/Kg.k*90k$

$= 756000J$ or 756KJ

III. Vaporization of the water

$Q = mLv$

$= 2Kg * 2260000J/Kg$

$= 4520000J$ or $4520KJ$

IV. Total heat required

$Q = 16.38KJ + 756KJ + 4520KJ$

$= 5292.38KJ$

8. Find the amount of heat transferred in half hour by conduction through an asbestos wall 5m high, 4m long and 0.3m thick if one side of the wall is held at 30^0c and the other side is at 10^0c (k = 0.25J/s.m.^{0}c)

Solution: $Q = kA\Delta t \frac{(T2-T1)}{X} = \frac{0.25 \text{ x5x4x.0.5x3600x20}}{0.3} = 600kJ$

9. Compute the temperature at which a tungsten filament that has an emissivity of 0.25and surface area of $2.5x10^{-5}m^2$ will radiate energy at the rate of 25W in room where the temperature is 22^0c

Solution: $T^4 = \frac{P}{\sigma Ae} - T_o^4 = \frac{25}{5.67x10^{-8}x2.5x10^{-5}\ x2.5x10^{-1}} K^4 - 295^4K^4 = 1700K$

Choose the correct answer from the alternatives

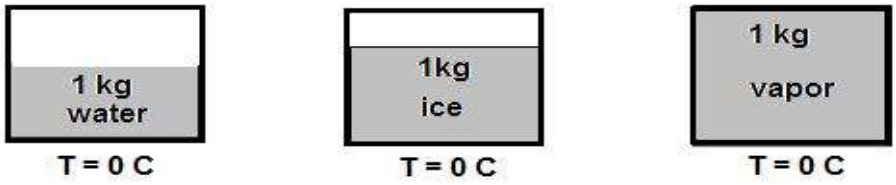
1. What is the name of the following statement: "When two systems are in thermal equilibrium with a third system, then they are in thermal equilibrium with each other"?
   A. First Law of Thermodynamics
   B. Second Law of Thermodynamics
   C. Zeroth Law of Thermodynamics
   D. Mechanical equivalent of heat
2. A bimetal plate consists of two materials of different coefficients of thermal expansion. The coefficient of thermal expansion of the top part of the plate is less than the bottom part. If the temperature of the entire plate increases, what happens to the plate?
   A. Expends
   B. Contracts
   C. Stays the same
   D. Bends down



3. A sample of ideal gas has an internal energy U and is then compressed to one-half of its original volume while the temperature stays the same. What is the new internal energy of the ideal gas in terms of U?

   A. U B. 1/2U C.1/4U D. 2U E. 4U

4. Two identical objects, one light colored and the other dark colored are at the same cool temperature. Then, you place them outside, on a warm day, in direct sunlight. Which object will warm up faster?
   A. The dark one
   B. The light one
   C. Both warm up at the same rate.
   D. As strange as it seems, neither object will ever warm up because energy conservation prevents the addition of energy.



5. Three containers filled with 1 kg of each: water, ice, and water vapor at the same temperature T = 0 C̊. Which of the following is true about the internal energy of the substances?
   A. U water > U ice > U vapor
   B. U water < U ice > U vapor
   C. U water = U ice = U vapor
   D. U water < U ice < U vapor
6. The difference in length between copper and steel wire at any temperature is 10cm.What must be the relation between their lengths at any temperature?(take $\alpha_{steel} = 1.2x10^{-5}/k$ and $\alpha_{copper} = 1.8x10^{-5}/k$)
   A. 30cm B.60cm C.300cm. D.600cm
7. While studying for this quiz you realize that you still have 100 g coffee at 40°C left in a paper cup. When you pour 20 g of boiling water into the cup, the temperature of the resulting coffee-like mixture will be now
   A. 50°C. B.67^0C C.80^0C D. 60°C.
8. The temperature of 100 g of water is to be raised from 10°C to 90°C. The energy needed to do this is about
   A. $1x10^3$ cal. B.$6x10^3$cal C.$5.4x10^4$cal D.$8\ x10^3$ cal
9. Heat flows into a gas in a piston and the gas performs some work on its surroundings. The amount of work done is less than the heat added. In this situation,
   A. The internal energy of the gas decreased.
   B. The internal energy of the gas increased
   C. The internal energy of the gas did not change.
   D. The gas experienced a phase change.

10. A material of length L_1 at temperature θ_1 K is subjected to a temperature rise of θ K. The coefficient of linear expansion of the material is α K^{-1}. The material expands by:
    A. $L_2(1 + \alpha\theta)$ C.$L_1\alpha(\theta - \theta_1)$
    B. $L_1[1 + \alpha(\theta - \theta_1)]$ D. $L_1\alpha\theta$
11. Some iron has a coefficient of linear expansion of $12 \times 10^{-6}\ K^{-1}$. A 100 mm length of iron piping is heated through 20 K. The pipe extends by:
    A. 0.24 mm B.0.024 mm C. 2.4 mm D.0.0024 mm

12. If the coefficient of linear expansion is A, the coefficient of surface expansion is B and the coefficient of cubic expansion is C, which of the following is false?
    A. C = 2B B.B= 2A C. C= 3A D.C= 3/2B

13. A thin copper wire of length **L** increases in length by 1% when heated from temperature T1 to $\mathbf{T}_2$ what is the percentage change in area when a thin copper plate having dimension 2**L** x **L** is heats from $\mathbf{T}_1$ to $\mathbf{T}_2$
    A. 1% B. 3% C. 2% D.4%
14. A steel wire 3m long at 20^0c is found to increase in length by 1.5cm when heated to 520^0c the coefficient of linear expansion of the steel is
    A. $10^{-4}/^0$c B. $10^{-5}/^0$c C. $10^{-6}/^0$c D. $10^{-7}/^0$c
15. The change in temperature of an object is 30^0c the equivalent change in the Fahrenheit scale is
    A. 30^0F B. 54^0F C. 62^0F D. 86^0F
16. If a gas has a volume of one liter at STP what will be its volume at twice the temperature and twice the pressure of the STP values?
    A. 1 liter B.2 liters C. 4 liters D. ¼ liters
17. When 0.2kg of water at 85^0c is mixed with 0.5kg of liquid at 75^0c the final temperature is 45^0c the specific heat capacity of the liquid is
    A. 240J/kg.k B.1240J/kg.k C. 2240J/kg.k D. 480J/kg.k
18. How much ice (heat of fusion = 80 cal/g) at 0^0c must be added in order to lower the temperature of one liter of water from 70^0c to 20^0c?
    A. 750gm A. 700gm C. 625gm D. 500gm
19. A 42kg mass of ice initially moving with a velocity of 8m/sec slides on a horizontal surface and comes to rest after traveling a certain distance, assuming the temperature to remain at0^0c though out , the mass of the ice melted because of work done against friction is:-
    (Heat of fusion=80cal/gm)
    A. 16.8kg B. 320kg C.49m D. 4kg
20. Body A has 3 times the mass and 2 times the specific heat of body B if they are supplied with equal amount of heat, how do their temperature compare?
    A. Change of temperature in A is 5 times greater
    B. Change of temperature in B is 6 times greater
    C. Change of temperature in A and B are equal
    D. Change of temperature in B is 2 times greater
21. The amount of heat that raises the temperature of 1 kg of a certain metal by 10^0c rises the temperature of 1kg of water by 2^0c what is the specific heat of the metal?
    A. 210J/kg^{0}c B. 840J/kg^{0}c C.4200J/kg^{0}c D.8400J/kg^{0}c
22. A brass cube measures 10cm by at 0^0c at what temperature would its volume be 1036cm^3?
    (Coefficient of liner expansion of brass is 1.6 X 10^{-6}/k)
    A. 7500^0c B. 2250^0c C. 1125^0c D. 375^0c
23. How much energy is needed to change 2kg of ice at 0^0c to 2kg of water at 50^0c?
    (C_{ice} =2100J/kg k,C_{water}= 4200 J/kg k L_f of water =3.336 X 10^5J/kg)
    A. 3.02 X 10^6J B. 2.68 X 10^6J C. 4.2 X 10^5J D.1.09 X 10^6J
24. An aluminum rod is 56cm long at 20^0c at what temperature will it be 1mm longer?
    (Coefficient of linear expansion of aluminum is 2.4 X $10^{-5}/^0$c)
    A. 74.4^0c B. 94.4^0c C. 54.4^0c D. 148.8^0C
25. A fixed mass of gas has pressure P and volume V at 3000K at what temperatures will its pressure and volume becomes 5P and V/3?
    A. 300k B. 200k C. 400k D. 500k

26. When 800J of heat energy is supplied to 0.5kg of a substance, its temperature rises from 15^0c to 55^0c the specific heat of the substance is (in J/kg^{0}c *)*

A. 400 B. 200 C.100 D. 300

27. If a rectangular solid box of aluminum is heated, which of the following is not true?

A. Its mass remains constant C. its density increase

B. Its volume increase D. none of the above

28. 100gm of water at 90^0c,200gm of water at 75^0c and 500gmof water at 40^0c are mixed , if the heat lost to the environment is neglected, the final temperature of the mixture is:-

A. 55^0c B. 60^0c C. 50^0C D. 45^0c

29. A metal rod is 1m long at 200c and 1.005m at 450c what is the length of the rod at 950c?

A. 1.15m B. 0.015m C. 0.15m D. 1.015m

30. The heat required to raise the temperature of an object from 20^0c to 70^0c is 150kcal how much heat is required to change the temperature of the same object from 50^0c to 80^0c?

A. 60kcal B. 90kcal C. 120kcal D. 75kcal

Solve the following problems

1. An iron can is filled with 100 cm^3 of mercury at 291K. What volume will flaw out of the can if the temperature is raised to 331K? Take the coefficient of linear expansion of the iron $1.2x10^{-5}$/k and the volume coefficient of expansion of mercury is $1.8x10^{-4}$/k

   6kg of cold water at 10^oc is added to 6kg of hot water of 100^oc. What is the value of the temperature after the water is mixed?
2. A square metal plate has an area of 0.09m^2 at a temperature of 30^oc. If the temperature is raised to 60^oc.Determain the area increase (The coefficient of linear expansion for metal is 1.1 x $10^{-5}/^o$c*)*
3. Determine the quantity of heat needed to change 1kg of ice at -20^0c to steam at 100^0c. Show it in the temperature versus quantity of heat graph.

   Specific heat capacity of ice = 2100 J/kg.^{0}c

   Specific heat capacity of water = 4200 J/kg.^{o}c

   Latent heat of fusion (L_f) =$3.35x10^5$ J/kg

   Latent heat of fusion vaporization (L_v) =2. J/kg$256x10^6$ J
4. 6kg of ice at -10^oc added to 6kg of water at 10^oc. what will be the temperature of the resulting mixture is(C_{ice} = 2100J/kg^{o}c, C_{water} = 4200J/kg^{o}c)
5. The heat capacity of object B is twice that of object A.Initially A is at 300K and B 450K.They are placed in thermal contact and the combination is isolated.What is the final temperature of both objects?(Assume both have the same mass)
6. What is the ratio of the coefficient of linear expansion to coefficient of volume expansion?
7. What mass of cold water at 10^0c must be added to 20kg hot water at 80^0c someone who wants to have bath at 50^0c?
8. A scientist is trying to decide what to wear in a certain environment. The air in the environment is 25^0c.If his body temperature is 37^0c,how much heat is lost from the body in 30minuts?(e =0.9 and A = 1.8m^2)

9. A glass vessel with an insulating cover and with a surface area of 100 cm^2 and 1.5mm thick is filled with ice at 0^0c and placed in a second vessel maintained at a temperature of 100^0c.Find the mass of the ice that melts per minute when the flow of heat becomes steady(specific latent of ice is $3.36x10^5$J/kg and K for glass = 1Wk/m)
10. A body which has a surface area $5cm^2$ and a temperature of 727^0c radiates 300J of energy each minute. What is its emissivity?

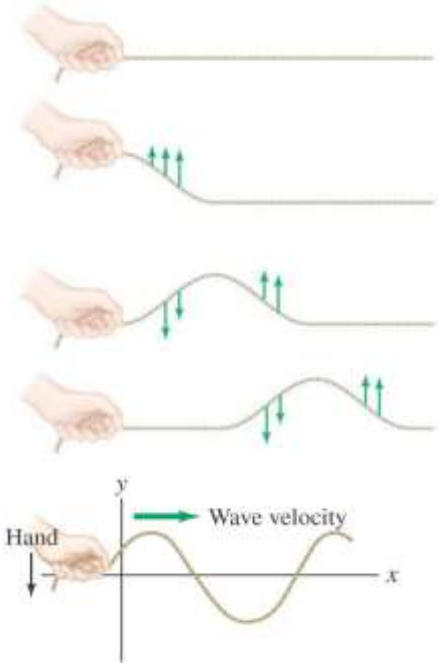
Unit 8: WAVE MOTION AND SOUND, ELECTROMAGNETIC WAVE & GEOMETRICAL OPTICS

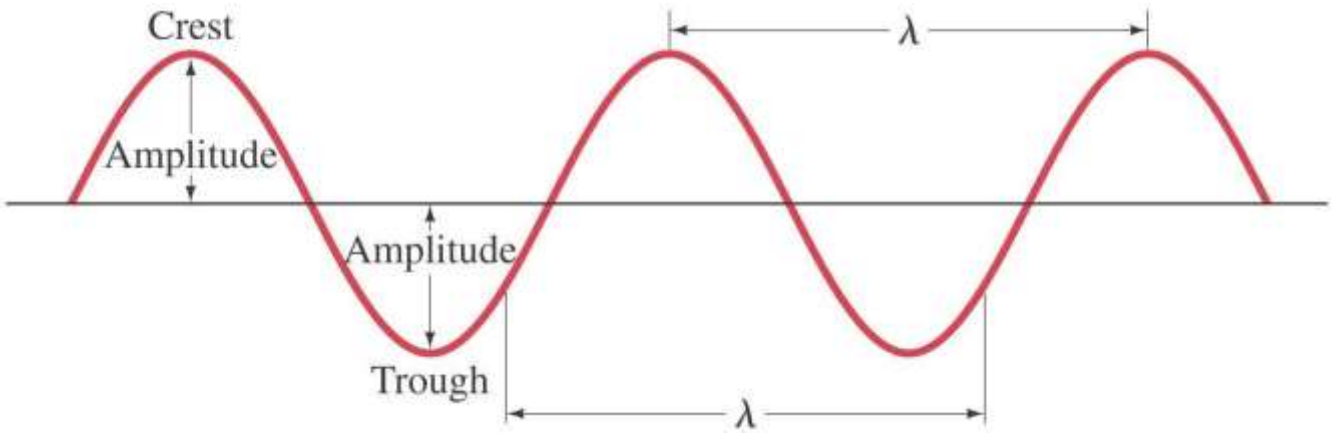


- ✓ **Definition of waves**: Waves are a series of vibrations that travel through a medium
- ✓ All waves transfer energy from one place to another, but waves does not transfer <u>matter</u>.

Key Words

- ❖ Equilibrium position: it is the central point about which vibration occur
- ❖ Vibrations: it is an oscillation about a central equilibrium point
- ❖ Wave pulse: a wave with <u>no</u> repeated vibrations.
- ❖ Continuous wave: a wave with repeated vibration
- ❖ Wave movement: the direction in which the wave is travelling
- ❖ Crests (peak): the maximum point of a transverse wave
- ❖ Troughs (valley) : the minimum points of transverse wave
- ❖ Amplitude (A):the maximum displacement from the equilibrium position
- ❖ Wave length(λ): the distance b/n two consecutive crest or trough
- ❖ Frequency(f):the number of complete oscillation per unit second
- ❖ Period(T): the time taken for a complete oscillation
- ❖ Wave speed (V): the distance that a wave travels in one second
- ❖ Hertz(HZ): the unit of frequency

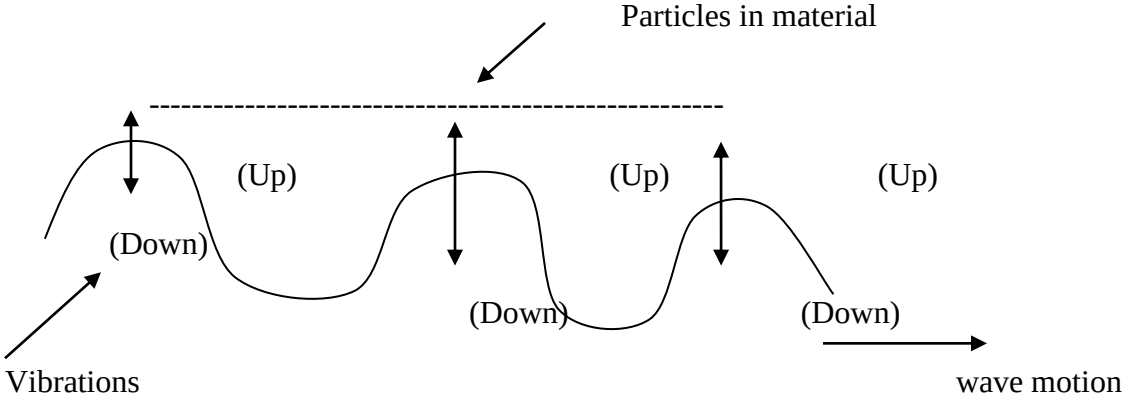




- Wave speed = $\frac{wave\ length}{period}$ | $V = \frac{\lambda}{T}$ | $V = \lambda f$
-

Longitudinal and transverse waves

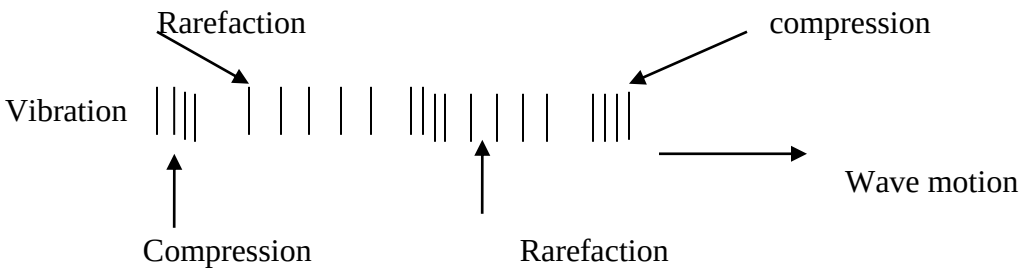
1. **Transverse waves**: are waves where the vibrations are perpendicular to the direction of wave motion



Examples of transverse waves

- All electromagnetic wave
  - ✓ Light *X-rays* *Micro waves* *S-wave in earth quakes*
  - ✓ Radio waves *waves on strings* *Waves on the surface of deep water*
  - ✓ TV-wave *Radar wave and heat wave etc. .....*

2. **Longitudinal waves**: are wave where the vibration are parallel to the direction of wave motion

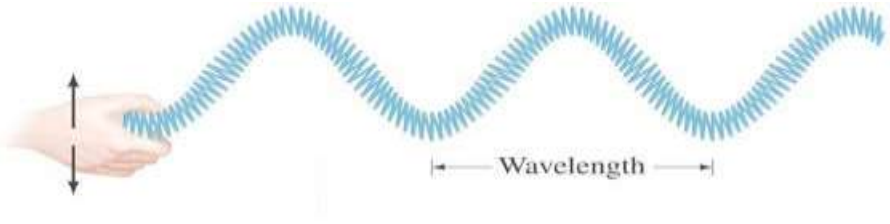


Note: **compression**: is a region of a wave where the particles are pushed together

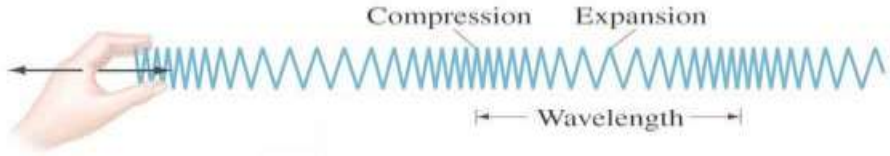
: **Rarefaction**: is a region of a wave where the particles are spread out

Examples of longitudinal waves

- ✓ Sound wave *spring wave (for word and back ward)*
- ✓ Pressure wave *P - wave*



Transverse waves



Longitudinal waves

MECHANICAL AND ELECTROMAGNETIC WAVE

- **Mechanical waves**: are waves that propagate through a medium of solid, liquid and gas but not in vacuum

  Example:
  - sound waves water wave Seismic waves
- **Electromagnetic waves**: are waves that propagate through a medium of solid, liquid, gas and vacuum
- **Electromagnetic wave are** a combination of electric filed and magnetic fields
- **They produced** when electric filed and magnetic field are perpendicular to each other

  Examples of electromagnetic waves
  - ✓ Light wave *x-ray* *Radio wave* *micro wave*

Water wave

- If you throw a stone in to a pond you can see ripples as crests and troughs travelling out from the splash
- Water waves arise due to the surface tension on the water, As some of the water molecules are pushed down they pull their neighboring particles down and a trough is created, and travels away from the source
- As water waves enter shallower water their speed reduce, so the waves bunch up, the wave length gets shorter but the amplitude increase
- An easy way to remember this, use ssss , water waves, shallower (Medium), shorter(λ), steeper(A) and slower(V)

Seismic waves

- ✓ Are waves produced by earth quakes

- ✓ They travel out from the focus in all directions throughout the earth
- ✓ These waves usually cause the damage buildings when they reach the surface
- ✓ There are three types of seismic waves

1. L- waves: It is complex types of rolling wave which travel along the surface of the earth and cause the most damage to building
2. P- wave (primary or pressure) are an example of longitudinal waves and travel very fast ≈7000m/sec
3. S- wave (secondary or shear) are an example of transverse waves and travel ≈ 4000m/sec Travel through the solid parts of the earth's in terror

- ❖ Triangulation: using measurements from three position to work out an exact point
- ❖ Tsunamis : huge water waves on the open see often causes by earth quakes
- ❖ The speed of water wave is given by the equation

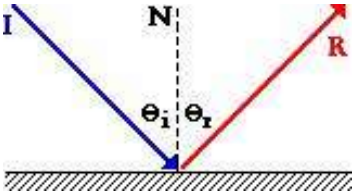
$V = \sqrt{gD}$ V= speed
g = gravity ≈10m/sec
D= depth of water in meter

Wave Behavior

- ✓ All types of wave exhibit certain behavior:
- ✓ They exhibit reflection, refraction, diffraction and interference

1. ***Reflection***

- ✓ Reflection: When a wave bounces off an object and changes direction.
- ✓ The angle of incidence equals the angle of reflection
- ✓ (or it can be stated $\theta_i = \theta_r$)



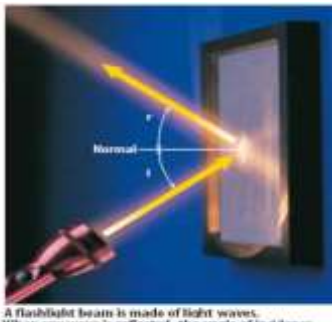
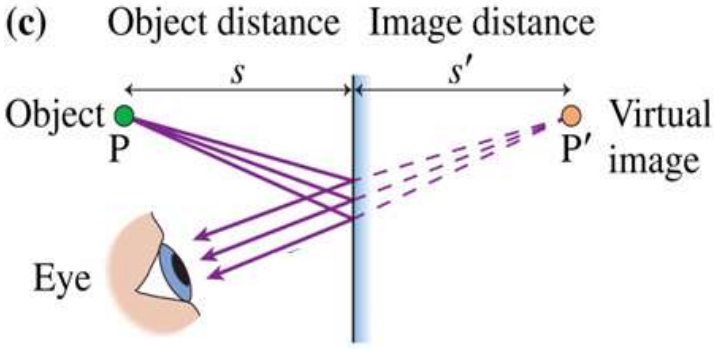




Image Formation by a Plane Mirror

- ✓ *A plane mirror is a flat mirror that reflects light secularly*
- ✓ Due to reflection of light originating from the point object P, an image is formed by the mirror at P'. Two rays from the object are all that are needed to locate the image exactly.
- ✓ Note that light rays only appear to be diverging from the image point P'. Thus, the image is virtual.
- ✓ From the geometry, the object distance (s) has the same magnitude as the image distance (s'). Hence, the image



is as far behind the mirror as the object
is in front.

Types of image

- **Real images** are formed at the point the rays of light actually intersect.
- Real images can be displayed on screens
- **Virtual images** are formed at the point the rays of light appear to originate

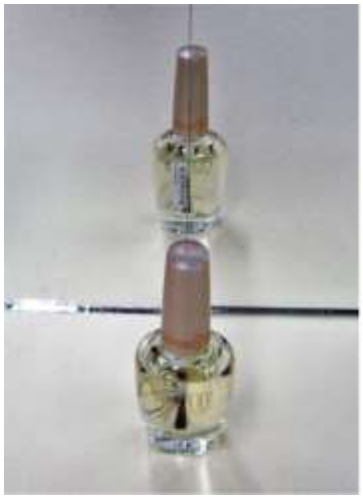
Your image in a flat mirror has four properties:

1. It is upright.
2. It is the same size as you are.
3. The image is as far behind the mirror as you are in front of it.
4. It is reversed, left <--> right(lateral inverted)

❖ The number of images formed between two plane mirrors that forms at an angle of "θ" is given by

$$N = \frac{360}{\theta} - 1$$

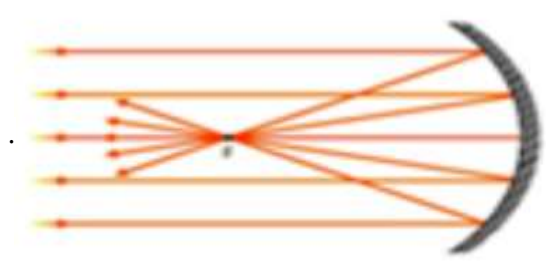
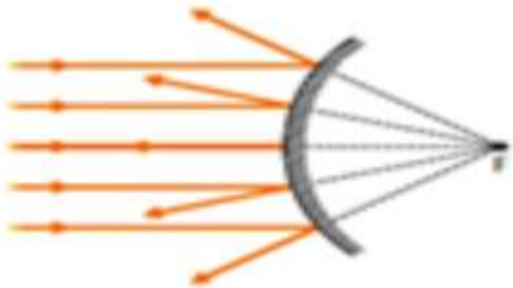
Where: θ is the angle between the mirrors
N is number of images





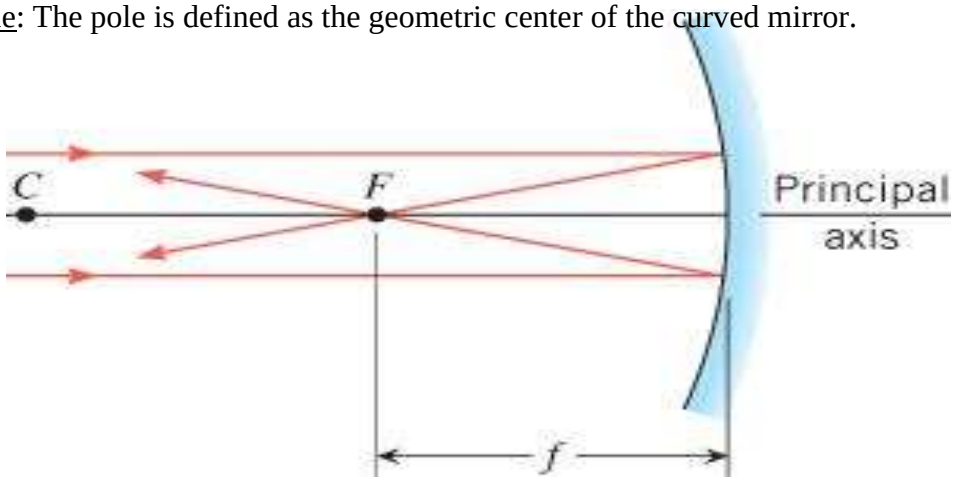

Spherical Mirrors

❖ A spherical mirror has the shape of a segment of a sphere.
❖ A concave spherical mirror has the silvered surface of the mirror on the inner, or concave, side of the curve
❖ A convex spherical mirror has the silvered surface of the mirror on the outer, or convex, side of the curve

Concave (converging) mirror convex (diverging) mirror

- Concave Mirror: A concave mirror is a curved mirror with the reflecting surface on the hollow side (created by depositing silver metal on the outer curved side).
- Convex Mirror : A convex mirror is a curved mirror with the reflecting surface on the outer side
- Centre of Curvature: The center of curvature of a curved mirror is defined as the center of the hollow glass sphere of which the curved mirror was (previously) a part.
- Radius of curvature the radius of curvature of a curved mirror is defined as the radius of the hollow glass sphere of which the spherical mirror was (previously) a part. Note that any line drawn from the center of curvature C to the mirror surface meets it at right angle and equals the radius of curvature.
- Principal Axis :The principal axis of a curved mirror is defined as the imaginary line passing through its pole P and center of curvature C
- Focus :The principal focus is defined as the point on the principal axis where the light rays traveling parallel to the principal axis after reflection actually meet (for a concave mirror) or appear to meet (for a convex mirror)
- The focal length (denoted by FP in the figure) is the distance between the pole P and the principal focus F of a curved mirror. Note that the focal length is half the radius of curvature
- **Focal Length = Radius of Curvature/2 (f = $\frac{R}{2}$)**
- Pole: The pole is defined as the geometric center of the curved mirror.



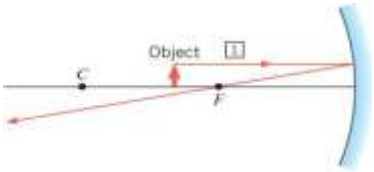
- Light rays **near and parallel to the principal axis** are reflected from the concave mirror and converge at the **focal point F**.
- The **focal length f** is the distance between the focal point and the mirror

The Formation of Images by Spherical Mirrors

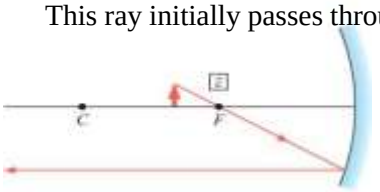
IMAGING WITH CONCAVE MIRRORS

❖ To find the image of an object placed in front of a concave mirror, there are several types of rays which are particularly useful ➔➔ ray tracing

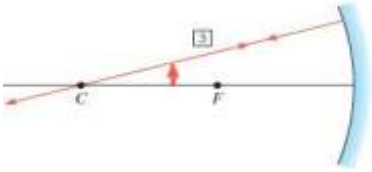
This ray is initially parallel to the principal axis and passes through the focal point.



This ray initially passes through the focal point, and then emerges parallel to the principal axis.



This ray travels along a line that passes through the center and so reflects back on itself



Mirror Equations

- $\frac{1}{f} = \frac{1}{si} + \frac{1}{so}$
- Magnification (M) = $\frac{si}{so}$ or M = $\frac{hi}{ho}$

✓ f – Focal length of the mirror
✓ S_i - Distance of the image from the Pole
✓ S_o- Distance of the object from the Pole
✓ f is +ve in the case of concave mirror.
✓ f is -ve in the case of a convex mirror.
✓ Si is +ve if the image is a real image and located on the object's side of the mirror.
✓ Si is -ve if the image is a virtual image and located behind the mirror

Characteristics of the Image Formed by a Concave Mirror According to the Position of the Object

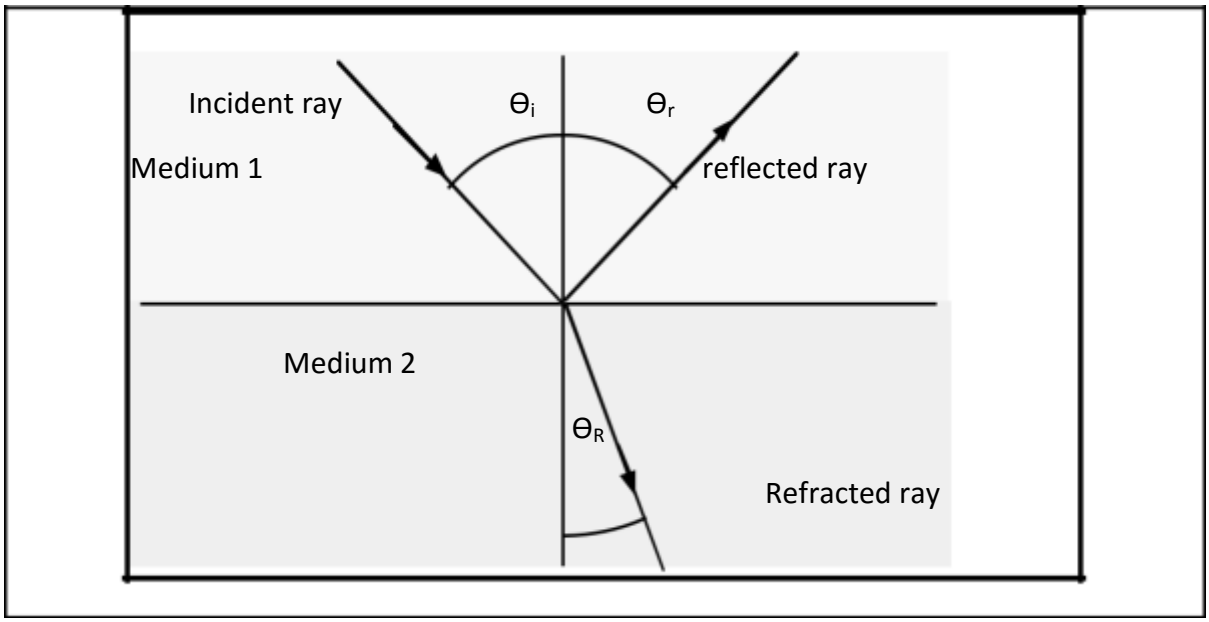
1. When the object is at infinity in the case of a concave mirror, the image formed has the following properties
   - The image is real.

- The image is inverted.
- The image is highly diminished to a point.
- The image is formed at the principal focus in front of the concave mirror.

2. When the object is between infinity and the center of curvature in front of a concave mirror, the image formed has the following properties
   - The image is real.
   - The image is inverted.
   - The image is diminished.
   - The image is formed between the principal focus and the center of curvature in front of the concave mirror.
3. When the object is placed at the principal focus in front of a concave mirror, the image formed has the following properties
   - The image is real.
   - The image is inverted.
   - The image is highly enlarged.
   - The image is formed at infinity in front of the concave mirror
4. When the object is placed between the pole and the principal focus in front of a concave mirror, the image formed has the following properties
   - The image is virtual.
   - The image is erect.
   - The image is enlarged.
   - The image is formed behind the concave mirror
5. When the object is placed between the principal focus and the center of curvature in front of a concave mirror, the image formed has the following properties.
   - The image is real.
   - The image is inverted
   - The image is enlarged.
   - The image is formed beyond the center of curvature in front of the concave mirror, but not at infinity.
6. When the object is placed at the center of curvature in front of a concave mirror, the image formed has the following properties
   - The image is real.
   - The image is inverted.
   - The image is of the same size as the object.
   - The image is formed at the center of curvature in front of the concave mirror.

2. *Refraction*

- ✓ Refraction is the bending of a wave as it passes from one medium to another.
- ✓ Refraction at the water surface gives the "broken pencil" effect shown above.
- ✓ Submerged objects always appear to be shallower than they are because the light from them changes angle at the surface, bending downward toward the water



Law of Refraction (Snell's Law)

- ✓ Consider a ray incident on the interface between two transparent media, 1 and 2. The law of refraction, or, Snell's law, is given by

$$n_1 \sin\theta_1 = n_2 \sin\theta_2 = \frac{\sin\theta 1}{\sin\theta 2} = \frac{V1}{V2} = \frac{n2}{n1} = \frac{\lambda 1}{\lambda 2}$$

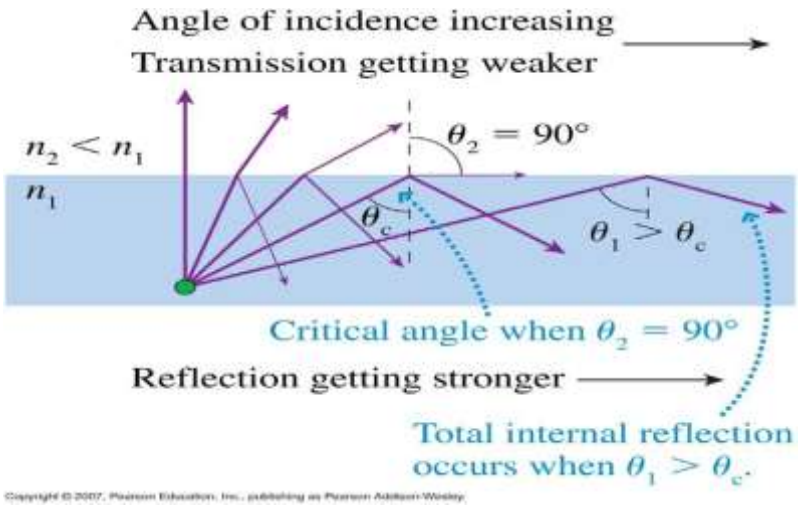
Where:

- ✓ V_1 and V_2 speed of light in medium 1 and 2 respectively
- ✓ n_1 and n_2 the refractive index of medium 1 and 2 respectively
- ✓ λ_1 and λ_2 wave length of the light in medium 1 and 2 respectively
- ✓ θ_1 is the angle with the normal in medium 1 and θ_2 is the angle in medium 2
- ✓ If the medium of incidence (medium 1) has a smaller index of refraction than the second medium, i.e., $n_1 < n_2$, then according to the law of refraction, $\theta_1 > \theta_2$, i.e., the refracted ray is bent toward the normal.
- ✓ If the medium of incidence has a greater index of refraction than the second medium, i.e., $n_1 > n_2$, then according to the law of refraction, $\theta_1 < \theta_2$, i.e., the refracted ray is bent away from the normal.

✓ The index of in refraction of a medium is defined by $n = \frac{speed\,of\ light\ in\ vacuum}{speed\ of\ light\ medium}$

✓ $n = \frac{c}{v}$ *The speed of light in a vacuum is c = 3.00 x 10^8 m/s*

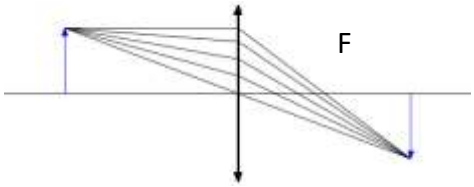
Total Internal Reflection



- As seen before, if the medium of incidence has a greater index of refraction than the second medium, light is bent away from the normal. If the angle of incidence is increased continuously, the angle of refraction increases until it becomes 90°. At this point, the refracted ray travels along the interface between the two media. If the angle of incidence is increased further, the refracted ray disappears and the incident ray is totally reflected. This phenomenon is called total internal reflection.
  - The critical angle is the angle of incidence for which the angle of refraction is 90°. Thus,
    - $n_1 \sin\theta_1 = n_2 \sin\theta_2 = \sin\theta c = \frac{n2}{n2}$

Lenses

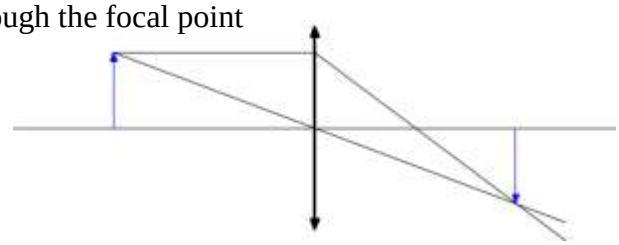
- Lenses are used to form images by refraction of light in optical instruments.
- Optical instruments, such as telescopes or cameras, and your eyes work this way.
- The surface of the lens in the diagram below is shaped so that spherical wave fronts of light coming from a point, F, called the focal point, emerge as parallel wave fronts (so-called plane waves).
- To understand image formation we use ray diagrams. Here is an example for a convex lens:



- For a convex lens, we draw the ray diagram as follows:

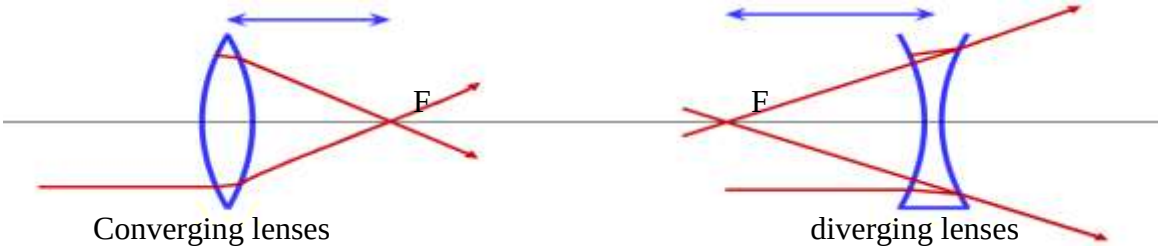
✓ Draw a ray from the top of the object straight through the middle of the lens. Its direction is not changed.

✓ Draw a ray from the top of the object parallel to the principal axis. It is refracted by the lens to pass through the focal point



From the diagram we see that the image in this example is inverted. This is also an example of a real image as the light rays pass through the image's location and may be seen on a screen placed there

- ❖ Note that the line drawn above through the middle of the lens is called the principal axis.
- ❖ Convex (converging) and concave (diverging) lenses are drawn as



Converging lenses diverging lenses

The Lens Equation

- ❖ *The lens equation is similar to the mirror equation and it is given by*

$$\frac{1}{f} = \frac{1}{si} + \frac{1}{so}$$

- Magnification (M) = $\frac{si}{so}$ or M = $\frac{hi}{ho}$

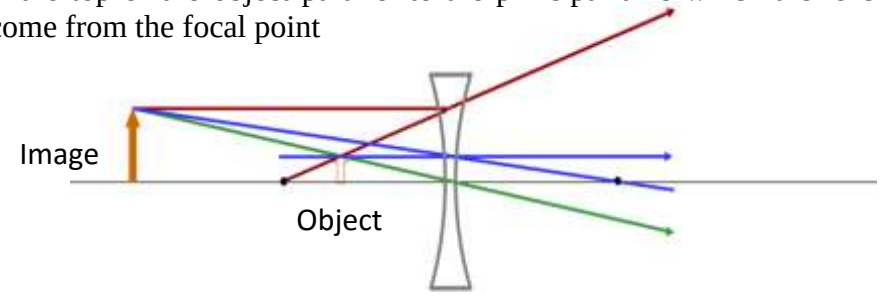
➢ Where $\mathbf{s_o}$ is the distance of the object from the lens; $\mathbf{s_i}$ is the distance of the image from the lens and **f** is the focal length, i.e., the distance of the focus from the lens

Concave Lenses

- Concave lenses always produce upright, virtual images.
- For a concave lens, the lens equation is the same but the value of f is now negative.
- Ray diagrams for such lenses are drawn using:

✓ a ray from the top of the object through the middle of the lens;

✓ a ray from the top of the object parallel to the principal axis which the lens refracts so it seems to come from the focal point



3. **Diffraction**:

✓ Is a phenomena that occurs when a wave passes through the edge of an obstacle

✓ It explains the wave nature of a light

✓ It spread out in the space beyond the gas (small hol)

✓ When waves encounter an obstacle, they bend around it, leaving a "shadow region. " This is called diffraction

4. **Interference**: is a phenomena which occurs two or more waves distribute each other

Types of interference

I. **constructive interference**: when the crest of one wave arrive with the other crest (wave crest) at the same time in a given point

✓ Constructive interference makes a bigger wave, with twice the amplitude

II. **Destructive interference**: when the crest of one wave arrives with the trough of another wave at the same time in a given point

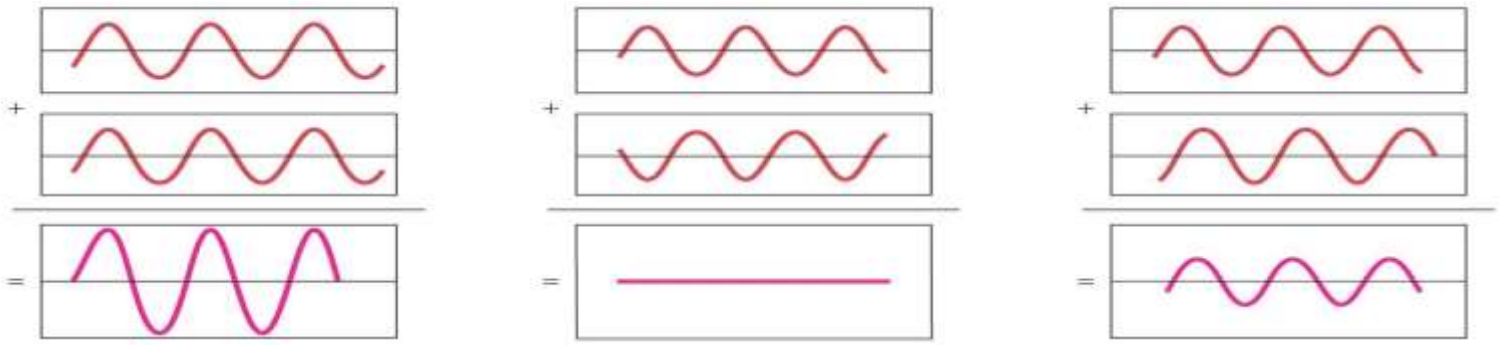
✓ Destructive interference: they cancel each other and there is no wave results

these graphs show the sum of two waves. In

A. They add constructively;

B. They add destructively; and

C. They add partially destructively.



Sound waves

Are longitudinal mechanical waves, produced whenever an object vibration

Hearing

❖ when these vibrations reach our ears, they travel down our ear canal and make our ear drums vibrate

❖ **Audible range**: the range of sound frequency that can be detected by the ear

❖ when we are young we can detect a range of frequencies from 20 Hz to 20,000 Hz

The speed of sound

- The speed of sound in air increase as the temperature of the air increase, and it is given by

Where

$V = \sqrt{YR * T}$

Y= the adiabatic index of the gas it is constant for gas

Y=1.4

R*= the molar gas constant molar mass (R/M)

$=286 m^2/s^2.k$

T= Temperature in k

Then k=Y R*= $1.4 \times 286 m^2/s^2 k = 400 m^2/s^2.k$

$V = \sqrt{400 \times T}$ m/sec

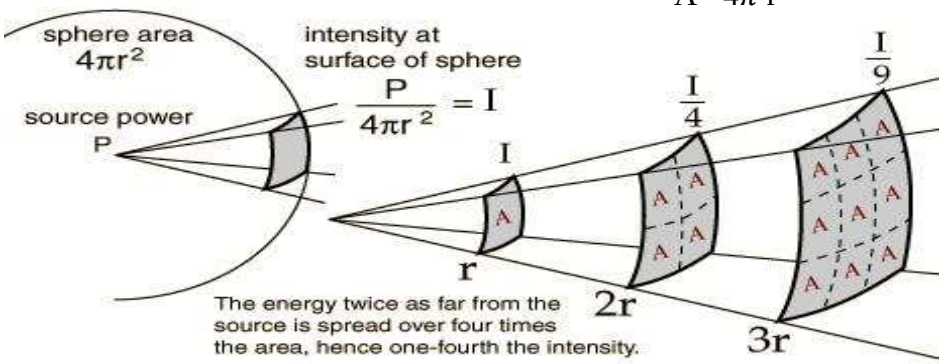
- **Loudness**: the audible strength of sound, which depends on the amplitude of the sound wave
  - The loudness of a sound is measured in decibels (dB)
- **Pitch**: it is highness or lowness of a sound, which depends on the frequency of the sound wave
- **Timbre** (quality) : it is the quality of the sound it refers to the difference in the sound
- **Echoes**: it is the reflection of sound wave

The intensity of sound wave

- The intensity refers the energy incident on each square meter of surface per second

Intensity = $\frac{power}{area}$ I= $\frac{P}{A}$ A=area of sphere

$A = 4\pi r^2$



- $I_1 = \frac{P}{4\pi r2}$, $I_2 = \frac{P}{4\pi r2}$, $I_3 = \frac{P}{4\pi r2}$ --

Then $I_1 * r_1^2 = I_2 * r^2$

The unit of intensity is watt per meter square

Uses of sound waves

- ✓ To determine the depth of sea
- ✓ For ultrasound: it is a sound waves with high frequency and short wave length

(For per – natal scanning)

- ✓ For SONAR –This stands for sound Navigation And Ranging And Ranging

* distance (depth) = $\frac{\text{speed x time}}{2}$

$S = \frac{Vxt}{2}$ ---------- Echoes

Problems

1. A wave has a distance of 1.5m b/n consecutive crests if it takes 2sec for one Complete vibration. Determine

   A) The frequency B) The speed of the wave

   Given =1.5m T=2sec

   solution

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

   $= \frac{1}{2sec}$

   = 0.5Hz

   B) $V = \lambda f$

   = 1.5m x0.5Hz

   = 0.75m/sec

2. A longitudinal sound wave has a speed of 340m/s in air. If the frequency of this wave is 400Hz, what is the wave length?

   Solution $\lambda = \frac{V}{f}$ $\frac{340m/s}{400Hz}$ = 0.85m)

3. The intensity of an earthquake P wave traveling through the Earth and detected 100 km from the source is 1.0 x 10^6 W/m^2. What is the intensity of that wave if detected 400 km from the source?

Solution

$I_2 = \frac{I1 * r1^2}{r2^2} \rightarrow \frac{1x106*10000Km2}{160000km2}$ = 6.25x10^4W/m^2

4. A 2.0 cm high object is placed 7.10 cm from a concave mirror whose radius of curvature is 10.2 cm. Find the location of the image and its size.

   Given $R = 10.20cm$, $ho = 2cm$, $so = 7.10cm$, $f = \frac{R}{2}$ 5.1cm

Solution

$\frac{1}{si} = \frac{1}{f} - \frac{1}{so}$ then $\frac{1}{si} = \frac{1}{5.1cm} - \frac{1}{7.10cm}$ Si =18 cm real image

M = $\frac{18cm}{7.10cm}$ = 2.5 magnified /larger

5. A convex mirror is used to reflect light from an object placed 66 cm in front of the mirror. The focal length of the mirror is 46 cm in back of the mirror. Find the location of the image and the magnification

   Given: Since a convex mirror, the focal length is negative

   f = -46 cm

$$\frac{1}{si} = -\frac{1}{f} - \frac{1}{so}$$

Solution

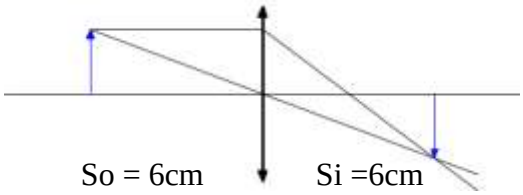
$$\frac{1}{si} = \frac{1}{46cm} - \frac{1}{66cm}$$ Si = -27cm, image is virtual since negative

M = $\frac{27cm}{66cm}$ = 0.4 diminished/ smaller

6. *What image is produced by placing an object 6 cm away from a convex lens of focal length 3 cm?*
   - ✓ The question states that So = 6 cm and f = 3 cm. This can be substituted into the lens equation as follows:
   - ✓ $$\frac{1}{si} = \frac{1}{f} - \frac{1}{so}$$
   - ✓ ***Solution***

$$\frac{1}{si} = \frac{1}{3} - \frac{1}{6}$$

Si = 6cm



So = 6cm Si =6cm

7. If an object is 6 cm from a concave lens with focal length f = 3 cm, what is its position and nature?

   Given: f = -3cm, So = 6cm

   Solution

$$\frac{1}{si} = -\frac{1}{f} - \frac{1}{so}$$

Si = 2m this is a virtual, upright image

Choose the correct answer from the alternatives

1. An object is located far away from a concave mirror. The image is located at:
   A. The distance d>R C.The distance d<F
   B. The distance F<d<R D. The focal point
2. If you run towards a plane mirror at a speed of 2 m/s, at what speed does the apparent distance between you and your image decrease?
   A. 0.5 m/s B. 1 m/s C. 2 m/s D. 4 m/s
3. A student conducts an investigation to determine the focal length of a convex lens. She holds the lens in front of her and looks through it at a distant object. She slowly moves the lens towards her eye. She knows she is holding it the focal length when the image is
   A. Inverted B. Upright C. real D. disappears
4. Identify the list below that contains items that diverge light rays.
   A. Convex mirror and concave lens
   B. Convex lens and concave mirror
   C. Convex mirror and concave mirror
   D. Convex lens and concave lens
5. A what distance from a converging lens of focal length 15cm should an object be placed in order to produce a real image 2.5 times the size of the object?

A. 7 cm B. 28cm C. 14 cm D. 21 cm

6. The image of an object formed by concave mirror of focal length 10 cm is erected and twice the size of the object. What is the distance between the object and the image?
   A. 15 cm B. 10 cm C. 5 cm D. 20 cm
7. A convex lens is inside a transparent liquid whose index of refraction is greater than that of the lens. Light rays traveling through the liquid and incident on the lens will:
   A. pass straight B. diverge C. converge D. back straight
8. An object 5cm high is placed 20cm from a converging lens of focal length 12cm.What is the size of the image?
   A. 12.5cm B. 15cm C. 10 cm D. 7.5 cm
9. A beam of light strikes a glass plate in air at an angle of incidence of 53^0.If the reflected and refracted parts of the beam are at right angles to each other, the index of refraction of the glass will be ($\sin 53^0 = \cos 37^0 = 0.8$, $\sin 37^0 = \cos 53^0 = 0.6$)
   A. $\frac{4}{3}$ B. $\frac{7}{5}$ C. $\frac{3}{2}$ D. $\frac{5}{2}$
10. A light beam initially traveling in air ($n_1 = 1$) strikes a transparent medium. If the angle of incidence and refraction are, respectively, 37^0 and 53^0, what is the speed of the light in the medium?
    A. $2.25\text{x}10^8 \frac{m}{sec}$ B. $4\text{x}10^8 \frac{m}{sec}$ C. $3\text{x}10^8 \frac{m}{sec}$ D. $2.75\text{x}10^8 \frac{m}{sec}$
11. Which one of the following the SI unit of power of lens?
    A. Weber B. Diopter C. meter D. Watt

12. The distance between two nearby crests of a water wave in a pond is measured to be 0.4m. If six crests are pass a point every second without considering the reference crest, what is the speed of the wave?
    A. 24m/sec B. 4.8m/sec C. 2.4m/sec D. 1.2m/sec
13. A certain normal conversation detected an intensity of 10^{-6}w/m^2 at a distance of 2m away from the source. What was the power emitted by the source?
    A. 4×10^{-6} watt B. 2×10^{-6} watt C. 5.02×10^{-5} watt D. 2.5×10^{-5} watt
14. Which one of the following is correct?
    A. The louder the sound the greater the amplitude
    B. The louder the sound the greater the velocity.
    C. The louder the sound the greater the frequency.
    D. The louder the sound the greater the wave length.
15. A man standing between two cliffs, Claps his hand and starts hearing a series of echoes at interval of one second, If the speed of sound in air is 340m/sec, the distance between the two cliffs must be:
    A. 340m B. 780m C. 1020m D. 170m
16. Which of the following is not an example of seismic wave?
    A. P - wave B. S – wave C. L – wave D. Heat wave
17. One of the following is False about interference?
    A. Two sets of waves must have exactly the same wave length and frequency if they are interface
    B. Two sets of waves must have twice the amplitude if they are going to cancel exactly.
    C. If two waves are in phase, then they combine to make a bigger wave
    D. If two waves are out phase with each other, they cance each other, so that there is no wave

18. An object is placed 10cm in front of a concave mirror which has a focal length of 5cm. what is the position of the image formed by the mirror?

A. 4cm in front of the mirror C. 10cm in front of the mirror
B. 5cm in front of the mirror D.10cm behind the mirror

19. Electromagnetic waves are

A. Transverse waves C. longitudinal waves
B. latitudinal waves D. reversal waves

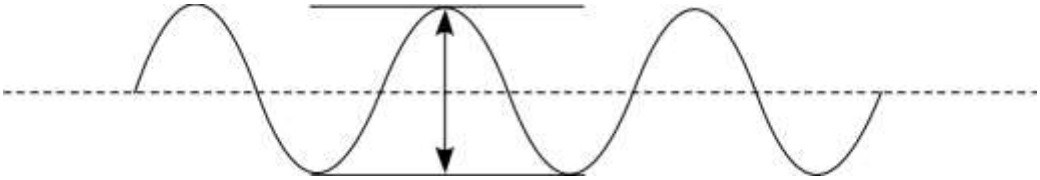
20. If you are four times closer to an explosion than your friend, the sound intensity you detect as compare to that of your friend is

A. 16 times greater C.10 time greater
B. 2 times greater D. 4 times greater

21. Sound waves are:-

A. Longitudinal – mechanical wave C. Electromagnetic wave
B. Mechanical and transverse wave D. Mechanical and electromagnetic waves

22. The diagram below shows a wave. The arrow is showing the distance from the top of the wave to the bottom of the wave.



This arrow represents

A. the amplitude C. twice the amplitude
B. the wavelength D. twice the wavelength

23. The intensity of a sound wave is directly proportional to

A. The frequency. C. The amplitude.
B. The square of the amplitude. D. The square of the speed of sound.

24. A pulse on a spring is moving from the right to the left. There is a circle on the right edge of the pulse.



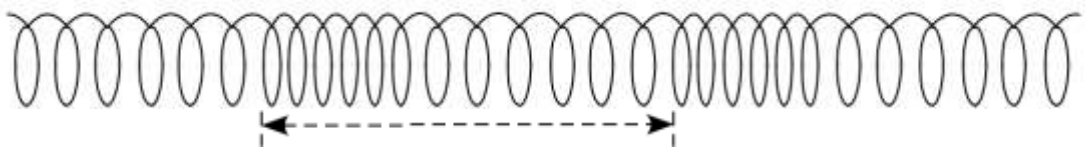
As the pulse moves to the left, the circle on the right edge of the pulse will move

A. to the left B. to the right C.Upwards D. downwards

25. If the frequency of a "C" note in the musical scale is 262 Hz, then we can say that the

A. period will be the inverse of the frequency and the speed of the wave will be changed
B. period will be the inverse of the frequency and the speed of the wave will be constant
C. period will be identical to the frequency and the speed of the wave will be changed
D. period will be identical to the frequency and the speed of the wave will be constant

26. The diagram below shows a longitudinal wave.



The horizontal distance indicated with the double arrow shows

A. one wavelength C. twice one wavelength

B. one amplitude D. twice one amplitude

27. If an electron vibrates up and down 1000 times each second, it generates an electromagnetic wave having

A. Frequency of 1000 Hz. C. Speed of 1000 m/s.

B. Period of 1000 s. D. Wavelength of 1000 m.

28. In microwave ovens, water molecules in food are set into resonance when microwaves of fixed frequency are incident upon them. This causes the molecules to receive energy and hence warm up the food, in order to warm up the food faster, one can

A. Increase the frequency of the incident microwave while keeping its amplitude fixed.

B. Increase the frequency and amplitude of the incident microwave.

C. Increase the amplitude of the incident microwave while keeping its frequency fixed.

D. Keep both frequency and amplitude of the incident microwave the same as before but increase

29 Alice is standing 15 m away from a speaker listening to a music broadcast. Due to a technical fault, the power of the speaker is suddenly reduced by 25%.

How far away from the speaker should Alice stand now in order for the music to be as loud as before? Assume that the speaker is a point source of sound.

A. 13m B 11m C. 7.5m D.3.8m

30 The image formed by an object placed in front of a convex mirror at a distance less than the focal length is ____

A. Real and larger than the object C. virtual and smaller than the object

B. Real and smaller than the object D. Virtual and larger than the object

Solve the following problems

1. What is sound and how is it produced?
2. Describe with the help of a diagram, how compressions and rarefactions are produced in air near a source of sound...
3. Why sound wave is called a longitudinal wave?
4. Which characteristic of the sound helps you to identify your friend by his voice while sitting with others in a dark room?
5. Flash and thunder are produced simultaneously. But thunder is heard a few seconds after the flash is seen, why?
6. A person has a hearing range from 20 Hz to 20 kHz. What are the typical wavelengths of sound waves in air corresponding to these two frequencies? Take the speed of sound in air as 344 m/sec.
7. A coin rests on the bottom of a container filled with water of n = 1.33. The apparent depth of the coin is 20cm. How deep is the container?
8. When an object is placed 6 cm from a concave mirror, its image is formed 2cm in front of the mirror what is the focal length of the mirror?

9. A small object 20cm in front of a plane mirror. If you stand behind the object, 40cm from the place mirror, and look at the image of the object, what distance should you focus your eyes?
10. When an object is placed 6 cm from a concave mirror, its image is formed 2cm in front of the mirror what is the focal length of the mirror?

UNIT 9: ELECTROSTATICS

Electrostatics is a branch of physics that deals with the phenomena and properties of stationary electric charges.

Electric charges (Q)

Electric charge is the property of matter that causes it to experience a force when placed in an electromagnetic field. There are two types of electric charges.

An electric charge is measured by a unit called coulomb (C). The amount of charge carried by a single proton or electron is called elementary charge ($e=\pm 1.6\times 10^{-19}C$).

- *Like charges repel each other and unlike charges attract each other (positive charge attracts positive charge and vice versa).*
- *Charge is neither created nor destroyed but it can be transferred from one object to another object.*
- *The charge on any object is an integral multiple of an elementary charge e.*

Mathematically, $Q = ne$ $n=1, 2, 3 \ldots$

Worked Example1

An object has an excess charge of $-1.92\times 10^{-17}c$. How many excess electrons does it have?

Given	Required
$Q = -1.92\times 10^{-17}c$	n=?

Solution

$Q = ne$ $\quad n = \frac{Q}{e} = \frac{-1.92\times 10^{-17}c}{-1.6\times 10^{-19}c} = 120$ electrons

Charging a neutral object

A neutral object has equal number of protons and electrons (equal number of positive and negative charges). Charging is the process of gaining or losing of electrons. Neutral objects can be charged in three different ways.

- *Charging by friction (rubbing), by conduction (contact) and by induction (grounding)*

Discharging a charged object

Discharging is the way of neutralizing a charged body by placing it in contact with another object having an equal and opposite charges with the charged object to be neutralized. The other method of discharging a charged object is by earthed or grounding the charged object using the conducting wire.

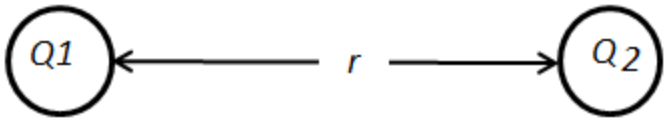
Electrostatic force (F)

Charged objects exert force on one another. If the charges are at rest then this force between them is called electrostatic force. An interesting characteristic of the electrostatic force is that it can be either attractive or repulsive force, unlike gravitational force which is only attractive force.

Coulomb's law

States that "the force acting between two electric charges is directly proportional to the product of charges (Q_1Q_2) and inversely proportional to the square of the separation distance (r^2) between them"

$$F = k\frac{Q_1Q_2}{r^2}$$



K is the electrostatic constant has value 9×10^9 Nm^2/c^2

Worked Example 2

What force does a charge of 4μc exert on a charge of −6μc at a distance of 2cm?

Given	Required
Q_1 =4μc	F =?
Q_2 = -6μc	
r =0.02m	

Solution

$F = k\frac{Q_1Q_2}{r^2} = 9\times10^9\ Nm^2/c^2\ \frac{4\times10^{-6}c\times-6\times10^{-6}c}{4\times10^{-4}m^2} = -540N$ the negative sign indicates that the force is an attractive force (between opposite charges). We can say that 540N attractive force.

Worked Example 3

Compare the electrostatic and gravitational force between electron (m_e=9.1×10^{-31} kg and Q_e=-1.6×10^{-19} c) and proton (m_p=1.67×10^{-27} kg and Q_P=1.6×10^{-19} c) at a distance of 1cm.

Given	Required
m_p =1.67×10^{-27} kg	F_e =?
Q_p =1.6×10^{-19} c	F_g =?

$m_e = 9.1\times10^{-31}$ kg

$Q_e = -1.6\times10^{-19}$ c

$r = 1\times10^{-2}$m

Solution

$F_e = k\frac{Q_pQ_e}{r^2} = 2.3\times10^{-24}$N

$F_g = G\frac{m_pm_e}{r^2} = 1\times10^{-63}$N

$F_e = 2.3\times10^{41}(F_g)$

Worked Example 4

Two equal point charges exert a repulsive force of 1.6N at a distance of 30cm. Find the amount of charge and its sign?

Given	Required
F =1.6N	$Q_1=Q_2=Q$ =?
r =0.3m	
$Q_1=Q_2=Q$	

Solution

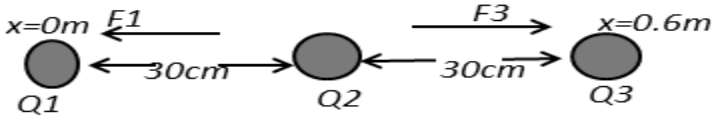
$F = k\frac{Q_1Q_2}{r^2} = k\frac{Q^2}{r^2}$

$Q = \sqrt{\frac{Fr^2}{k}} = \sqrt{\frac{1.6N\times9\times10^{-2}m^2}{9\times10^9Nm^2/c^2}} = \pm4\mu c$

$Q_1=Q_2=4\mu c$ or $Q_1=Q_2=-4\mu c$

Worked Example 5

Three point charges are placed on x-axis; $Q_1 = -4\mu c$ at x=0m, $Q_2=2\mu c$ at x=0.3m and Q_3= -6μc at x=0.6m as shown below. Find the net force on charge Q_2.



Given	Required
$Q_1 = -4\mu c$	F_{net} =?
$Q_2 = 2\mu c$	
$Q_3 = -6\mu c$	
$r_{12} = 0.3m$	
r_{32} =0.3m	

Solution

The force exerted on Q_2 by Q_1 is an attractive force given by

$F_{12} = F = k\frac{Q_1 Q_2}{r_{12}^2} = 9\times10^9\ Nm^2/c^2\ \frac{-4\times10^{-6}c\times2\times10^{-6}c}{9\times10^{-2}m^2} = -0.8N = 0.8N$ towards Q_1 or to the left.

The force exerted onQ_2 by Q_3 is also an attractive force given by

$F_{32} = F = k\frac{Q_3 Q_2}{r_{32}^2} = 9\times10^9\ Nm^2/c^2\ \frac{2\times10^{-6}c\times-6\times10^{-6}c}{9\times10^{-2}m^2} = -1.2N = 1.2N$ towards Q_3 or to the right.

Using vector addition we can find the net force acting on Q_2

F_{net} =1.2N −0.8N =0.4N towards Q_3

Electric field and electric field strength

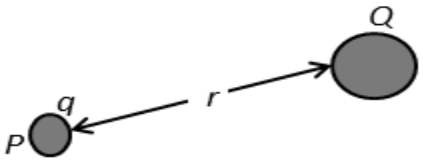
Electric field is a region that allows a charged object to feel a force. We can't feel an electric field, but we can detect its presence by placing a positive test charge at various points in space and measuring the force the test charge feels.

The characteristics of electric field lines are given below.

- *Electric field lines point away from positive charge and towards negative charge*
- *Electric field lines are imaginary lines*
- *Electric field lines don't intersect each other*
- *Electric field lines intersect the surface of conductor at 90°*
- *Stronger fields have closer lines*
- *Field strength and line density decreases as you move away from the charge.*

Electric field strength (E)

Electric field strength is the amount of electrostatic force observed at a given point in a region divided by the test charge q itself.



$$E = \frac{F}{q}$$

The electrostatic force between the test charge q and Q is also given by

$$F = k\frac{Qq}{r^2}$$

$E = \frac{F}{q} = k\frac{Q}{r^2}$ this the formula used to find the electric field strength of a single charge at specific location from the charge. The SI unit of electric field strength is newton per coulomb (N/C).

Worked Example 6

If a test charge of 3.4×10^{-19}c is located in electric field strength of 5×10^{3}N/c. what is the amount of force acting at the point?

Given	Required
$E = 5\times10^{3}$N/c	F=?
$q = 3.4\times10^{-19}$c	

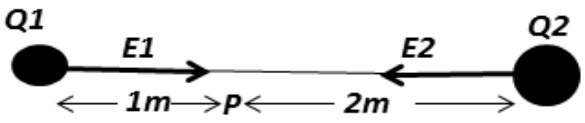
Solution

$E = \frac{F}{q}$

$F=Eq = 5\times10^{3}$N/c $\times 3.4\times10^{-19}$c $= 1.6\times10^{-15}$N

Worked Example 7

Two point charges of Q_1 =6μc and Q_2 =10μc are 3m apart as shown below. Calculate the electric field strength due to the charges at point p which is 1m from Q_1.



Given	Required
Q_1= 6μc	E_{net} =?

$r_1 = 1m$

$Q_2 = 10\mu c$

$r_2 = 2m$

Solution

Both charges are positive and the electric field is away from them and towards point p.

$E_{net} = E_1 - E_2 = \frac{kQ_1}{{r_1}^2} - \frac{kQ_2}{{r_2}^2} = k\left(\frac{Q_1}{r_1^1} - \frac{Q_2}{r_2^2}\right)$

$E_{net} = 9\times10^9 Nm^2/c^2 \left(\frac{6\times10^{-6}c}{1m^2} - \frac{10\times10^{-6}c}{4m^2}\right) = 3.2\times10^4 N/c$

Electric potential energy (U)

A charge's electric potential energy describes how much stored energy it has, when set into motion by an electrostatic force, that energy can become kinetic and charge can do work in joule.

The electric potential energy depends on Charge of the object (Q), Electric field strength (E) and Distance the charge moved parallel to the electric field lines(r)

$$U = QEr$$

The energy needed to move a charge from one potential $V_1$to another V_2 is simply given by

$$\Delta U = q\,(V_2 - V_1)$$

Worked Example 8

How much work is required to carry a charge of 12μc from one point to another point which have a potential difference of 400V?

Given	Required
$Q=1.2\times10^{-5}c$	$U=?$
$V= 400V$	

Solution

$U = QV = 1.2\times10^{-5}c\times400V = 4.8\times10^{-3}J$

Capacitors and capacitance

Capacitance is the ability of the capacitor to store electric charge. The capacitance (C) of the capacitor is the ratio of electric charge (Q) to potential difference (V). Experimentally, the voltage across a capacitor, V, is proportional to the amount of charge on the plates, Q:

$$Q=CV$$

C is the capacitance and has units Coulombs/Volt or Farads

$$C = \frac{Q}{V}$$

The SI unit of capacitance is farad (F). 1F = $\frac{1C}{V}$ farad is a large unit; we use the common units micro farad ($\mathbf{10^{-6}}$F) and Nano farad ($\mathbf{10^{-9}F}$).

Worked Example 9

Calculate the capacitance of the capacitor of 5μC charge is flowing and an applied potential is 2.5V.

Given	Required
Q =5×10^{-6}C	C=?
V =2.5V	

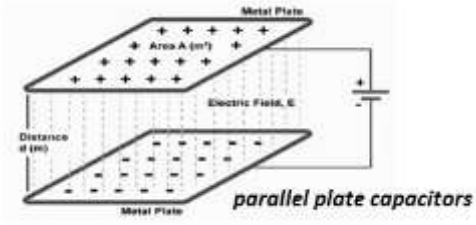
Solution

$$C = \frac{Q}{V} = \frac{5\times10^{-6}C}{2.5V} = 2\mu F$$

Parallel plate capacitor

There are three factors that affect the capacitance of parallel plate capacitor.

- *The area of the plate (A)*
- *The separation distance between the plates(d)*
- *The type of dielectric materials inserted between the plates*



The capacitance of parallel plate capacitor is given by the following formula.

$$C=\epsilon_0 \frac{A}{d}$$

$$\epsilon_0 = 8.85\times10^{-12}F/m$$

If dielectric material of dielectric constant of k is inserted between the plates the capacitance of the parallel plate capacitor increase by a factor of k.

$$C=k\epsilon_0 \frac{A}{d} = \epsilon \frac{A}{d}$$

Where, ϵ is permittivity of the given medium.

Worked Example 10

A parallel plate capacitor is placed in air has plate area of $0.44m^2$ and are separated from each other by a distance of 0.04m. Determine the capacitance of the plate.

Given	Required
$A = 0.44m^2$	$C=?$
$d = 0.04m$	

Solution

$$C=\epsilon_0 \frac{A}{d} = 8.85 \times 10^{-12}F/m \frac{0.44m^2}{0.04m} = 9.7\times10^{-11}F$$

Worked Example 11

Calculate the capacitance of pair of parallel plates of area $25cm^2$, if they are separated by a piece of material (k=3.5) 0.1mm thick.

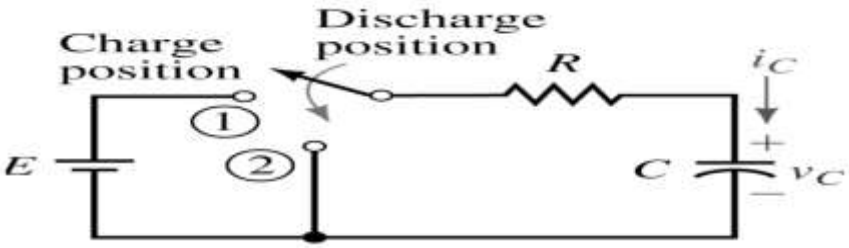
Given	Required
$A=2.5\times10^{-3}m^2$	$C=?$
$k=3.5$	
$d=1\times10^{-4}m$	

Solution

$$C=k\epsilon_0 \frac{A}{d} = 3.5\times8.85 \times10^{-12}F/m \frac{2.5\times10^{-3}m^2}{10^{-4}m} = 7.4\times10^{-10}F$$

Charging and discharging a capacitor

Capacitor can be charged or discharged. When we charge a given capacitor by connecting it with a source but while discharging we can connect it with load used as source. When switch is closed at 1 capacitor is charging. When switch is closed at 2 capacitor is discharging.



Note: for one time constant τ a capacitor charges 63.2%. Charging is the opposite of discharging.

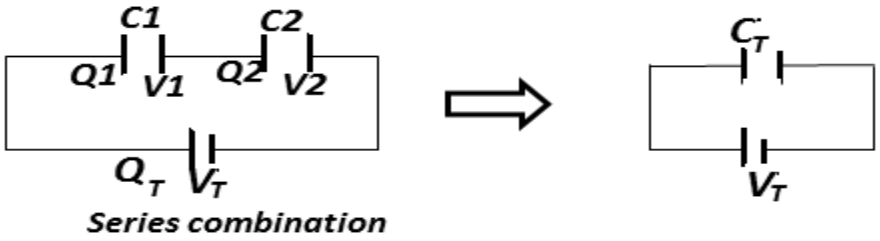
Combination of capacitors

There are two common methods of capacitor combination. These are

a. *Series combination of capacitors*
b. *Parallel combination of capacitors*

Series combination of capacitors

Consider two capacitors of capacitance C_1 and C_2 connected serially as shown below.



Series combination

$$Q_1 = Q_2 = Q$$

$$V = V_1 + V_2 \quad \text{but } V = \frac{Q}{C}$$

$$V_1 = \frac{Q}{C_1} \text{ and } V_2 = \frac{Q}{C_2}$$

$$V = \frac{Q_1}{C_1} + \frac{Q_2}{C_2} \qquad Q_1 = Q_2 = Q$$

$$V = \frac{Q}{C_1} + \frac{Q}{C_2} = Q\left(\frac{1}{C_1} + \frac{1}{C_2}\right) \text{ divide both sides by Q}$$

$$\frac{V}{Q} = \frac{1}{C_1} + \frac{1}{C_2}$$

$\frac{V}{Q} = \frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$ where C is the equivalent capacitance of the capacitor.

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2}$$

Generally for N number of capacitors connected in series the total or equivalent capacitance of the capacitors is calculated as follows.

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3} + \ldots + \frac{1}{C_N}$$

Note: The capacitors are connected in series to decrease the capacitance. The equivalent capacitance of capacitors which are in series combination has smallest value than the smallest individual.

Worked Example 12

Three capacitors of 2μF, 4μF and 8μF are connected in series. Calculate the equivalent capacitance.

Given	Required
C_1=2μF	C=?
C_2 =4μF	
C_3 =8μF	

Solution

$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$

$\frac{1}{C} = \frac{1}{2\mu F} + \frac{1}{4\mu F} + \frac{1}{8\mu F}$

$\frac{1}{C} = \frac{4+2+1}{8\mu F} = \frac{7}{8\mu F}$

Then C= $\frac{8\mu F}{7}$ =1.1μF<2μF

Worked Example 13

Two capacitors of capacitance 2μF and 6μF are connected in series with a potential difference of 12V. Calculate the total charge and voltage across each capacitor.

Given	Required
C_1=2μF	Q=?
C_2 =6μF	V_1=?
V=12V	V_2=?

Solution

$$\frac{1}{C} = \frac{1}{C_1} + \frac{1}{C_2} = \frac{1}{C} = \frac{1}{2\mu F} + \frac{1}{6\mu F}$$

C = 1.5μF

Q = CV =1.5μF×12V =18Mc

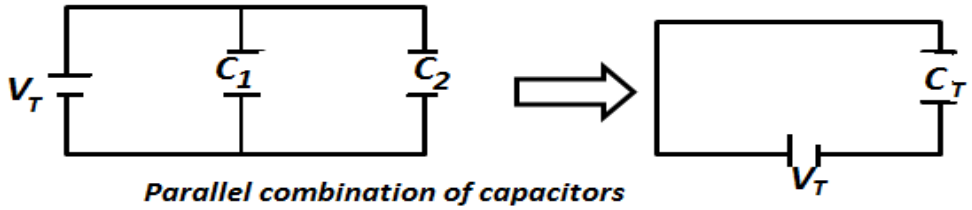
The charge across each capacitor is also $Q_1 = Q_2$ =Q= 18μC

$V_1 = \frac{Q}{C_1} = \frac{18\mu C}{2\mu F}$ =9V

$V_2 = \frac{Q}{C_2} = \frac{18\mu C}{6\mu F}$ =3V

$V=V_1 + V_2$ =9V +3V =12V

Capacitors in parallel



Parallel combination of capacitors

$V_1 = V_2 = V$

$Q = Q_1 + Q_2$ but Q =CV

$Q_1 = C_1V_1 = C_1V$

$Q_2 = C_2V_2 = C_2V$

$Q = Q_1 + Q_2 = C_1V + C_2V$

$Q = V(C_1 + C_2)$ divide both sides by V

$$\frac{Q}{V} = C = C_1 + C_2$$

$$C = C_1 + C_2$$

Generally for N number of capacitors connected in parallel combination the equivalent capacitance is the sum of each capacitance.

$$C = C_1 + C_2 + C_3 + \ldots + C_N$$

For N number of capacitors connected in parallel, the equivalent capacitance is greater than the greatest individual.

Note: The capacitors are connected in parallel to increase the capacitance.

Worked Example 14

Three capacitors of 2μF, 4μF and 8μF are connected in parallel. Calculate the equivalent capacitance

Given	Required
C_1=2Mf	C=?
C_2 =4μF	
C_3 =8μF	

Solution

$C = C_1 + C_2 + C_3$

$C = 2\mu F + 4\mu F + 8\mu F = 14\mu F > 8\mu F$

Worked Example 15

Two capacitors of capacitance 2μF and 6μF are connected in series with a potential difference of 12V. Calculate the total charge and charge across each capacitor.

Given	Required
C_1=2μF	Q=?
C_2 =6μF	Q_1=?
V=12V	Q_2=?

Solution

$C = C_1 + C_2 = 8\mu F$

The total charge $Q = CV = 8\mu F \times 12V = 96\mu C$

The charge across each capacitor is calculated as

$Q_1 = C1V = 2\mu F \times 12V = 24\mu C$

$Q_2 = C_2V = 6\mu F \times 12V = 72\mu C$

$Q = Q_1 + Q_2 = 24\mu F + 72\mu F = 96\mu F$ checks our result

Energy stored in capacitors

The formula that describes this relationship is given by the product of average voltage and charge stored.

$W = \frac{1}{2}QV$ but $Q = CV$

$W = \frac{1}{2}QV = \frac{1}{2}CV^2 = \frac{Q^2}{2C}$ where W is the energy stored on the capacitor measured in joule (J).

Worked Example 17

A 10μF capacitor is charged to 20V. How much energy is stored?

Given	Required
$C = 1\times10^{-5}$ F	W=?
V =20V	

Solution

$W = \frac{1}{2}CV^2 = \frac{1}{2} \times 1\times10^{-5}$ F $\times 20V$

$W = 2\times10^{-3}$J

Review question

1. *Consider four heavily charged plastic rods. Rods 1 and 2 attract each other whereas roads 3 and 4 repel each other. Which one of the following statement is correct?*

A. *If rod 1 repels rod 3, rod 2 also repels rod 4.*
B. *If rod 1 repels rod 4, rod 2 also attracts rod 3.*
C. *If rod 1 attracts rod 3, rod 2 also attracts rod 4.*
D. *If rod 1 attracts rod 4, rod 2 also attracts rod 3.*

2. *The electric potential created by a point charge at a distance r from the charge is V. what is the electric potential at a distance of 4r from the charge?*

A. *4V* B. $\frac{V}{2}$ C. $\frac{V}{6}$ D. $\frac{V}{4}$

3. *With one time constant of a capacitor circuit,*
   A. *The capacitor discharges 37% of its original charge.*
   B. *The capacitor can be charged to about its full capacity.*
   C. *Nearly all of the charge on a charged capacitor will be lost.*
   D. *The charge on a capacitor decreases 63% of its constant.*

4. *Two particles, with charges q_1 and q_2, are on the x-axis, with q_1 at $x=a$, and q_2 at $x=-2a$. for the net force on the third charged particle, at $x=0$ to be zero, q_1 and q_2 must related by*

A. $q_2=2q_1$ C. $q_2=-4q_1$
B. $q_2=-2q_1$ D. $q_2=4q_1$

5. *A 2μF and 1μF capacitors are connected in parallel and a potential difference is applied across this combination. The 2μF capacitor has*
   A. *Half the charge of the 1μF capacitor.*
   B. *Twice the potential difference of the 1μF capacitor.*
   C. *Half the stored energy of the 1μF capacitor.*
   D. *Twice the stored energy of the 1μF capacitor.*

6. *Which one of the following statement is true about a lightning protection provided to a building?*
   A. *An overhead grid of wire conductors extended to the ground*
   B. *A system of lightning rods and conductors extended to the building.*
   C. *An overhead grid of insulators extended to the ground.*
   D. *A system of lightning rods connected to a building's steel frame..*

7. *A positively charged glass rod and a negatively charged rubber rod are place far from each other. What happens to the dry pieces of paper brought nearby the rods before touching them?*
   A. *Repelled by glass and attracted by rubber*
   B. *Attracted by glass and repelled by rubber*
   C. *Attracted by both glass and rubber*
   D. *Repelled by both glass and rubber*

8. *A point charge Q_1 is at $x=0$ and Q_2 is at $x=8cm$. what is the relationship between these charges if the resultant electric field strength is zero at $x=16cm$?*

A. $Q_1=2Q_2$ C. $Q_2=0.25Q_1$
B. $Q_1=0.25Q_2$ D. $Q_1=-4Q_2$

9. *A tangent line to an equipotential surface and electric field of a charged body at any point, on the surface must be*
    - *A. Perpendicular*
    - *B. Parallel*
    - *C. Opposite in direction*
    - *D. Same direction*
10. *A 9V battery is connected to a 2μF capacitor. How much electric energy can be stored in the capacitor?*
    - *A.* $8.1\times10^{-6}J$
    - *B.* $8.1\times10^{-5}J$
    - *C.* $1.62\times10^{-4}J$
    - *D.* $1.62\times10^{-5}J$
11. *Which of the following is NOT true about the effect of electrostatic charge? They*
    - *A. Can be applied to filter the chimney by trapping soot particles so that they will not pollute the air.*
    - *B. Can result in an electric current between objects which is always useful and harmless.*
    - *C. Can be applied for spray painting.*
    - *D. Can be applied in the photo copying process.*
12. *What is an electric potential energy? It is the energy a charge possesses because, it is in the*
    - *A. Region of other charges*
    - *B. Vacuum*
    - *C. Region of zero electric field*
    - *D. Region of other masses*
13. *If a 9V battery is connected to the plates of 3μF capacitor, what will be the charge stored in the capacitor?*

    A. 27μC B. 3μC C. $\frac{1}{3}\mu C$ *D. 54μc*
14. *Which one of the following objects is attracted by a positively charged object?*
    - *A. Only positively charged objects*
    - *B. Only negatively charged objects*
    - *C. Only neutral objects*
    - *D. Neutral and negatively charged objects*
15. *Which one of the following is true?*
    - *A. The electric field lines around isolated negative charge points outward*
    - *B. The electric field lines around isolated positive charge points inward*
    - *C. The electric field lines around isolated negative charge points inward*
    - *D. The electric field lines around an isolated positive charge make circle*

UNIT 10: CURRENT ELECTRICITY

Electric current (I)

Electric current is nothing but the rate of flow of electric charge through a conducting medium with respect to time.

$$I = \frac{Q}{t}$$

Worked Example 1

Suppose total 100 coulombs of charge is transferred through a conductor in 50 seconds. What is the current?

Given	Required
Q=100C	I=?
t=50s	

Solution

$I = \frac{Q}{t} = \frac{100C}{50s} = 2A$

Worked Example 2

A steady current of 20A flowed for 30 minutes. What amount of charge would move through the conductor? How many number of electrons pass across the cross section?

Given	Required
I =20A	Q=?
t=1800s	N=?

Solution

Q =It =20c/s (1800s) $=3.6\times10^{4}$c

$N = \frac{Q}{e} = \frac{3.6\times10^{4}c}{1.6\times10^{-19}c} = 2.25\times10^{23}$ electrons

Drift velocity (V_d)

If a particle moves in a random manner in space that means it continually changes its direction and velocities in a random manner. The resultant of these random motions as a whole is called drift velocity.

$$I = nAeV_D$$

Current density (J)

It is the ratio of current to the cross sectional area of the conductor.

$$J = \frac{I}{A} = neV_d$$

Worked Example 3

The charge carrier densities in a uniform wire of cross sectional area $0.04cm^2$ is 16×10^{27}electrons per meter cube. If the drift velocity is 10^{-3}m/s, what will be the current through the wire? Find the current density.

Given	Required
$A=4\times10^{-4}m^2$	I=?
$V_d=10^{-3}m/s$	J=?
$n=16\times10^{27}m^{-3}$	
$e=1.6\times10^{-19}c$	

Solution

$I= nAeV_d$

$I=16\times10^{27}m^{-3}\times4\times10^{-4}m^2\times1.6\times10^{-19}c\times10^{-3}m/s=10.24A$

$J=neV_d$

$J=16\times10^{27}m^{-3}\times4\times10^{-4}m^2\times1.6\times10^{-19}c=2.56\times10^{-4}A/m^2$

Resistor and resistance

Resistor is an electrical component or device that limits or regulates the flow of electrical current in an electric circuit. Resistors are used in two main application areas.

- *As voltage divider*
- *To limit the flow of current in the circuit*

The circuit symbol of resistor is given by 

Resistance (R) is the opposition to a flow of electric current in an electrical circuit.

It is the ability of a resistor to oppose the flow of electric current.

The SI unit of resistance is ohm (***Ω***).

Ohm's law

Under similar physical conditions and at constant temperature, the current flowing through a conductor is directly proportional to potential difference applied across its ends for Ohmic materials.

$I \propto V$ (where I is current and V is potential difference)

$\frac{V}{I}$ = constant, the proportionality constant is resistance of the resistor (R)

$\frac{V}{I} = R$ (Ohm's law)

Worked Example 4

A resistance of 10 ***Ω*** is placed across a 9V battery. What current flows through the circuit?

Given	Required
V=9V	I=?
R=10 ***Ω***	

Solution

$\frac{V}{I} = R$

$I = \frac{V}{R} = \frac{9V}{10\Omega} = 0.9A$

Worked Example 5

What is the amount of potential difference required to drive a 3A current through a resistance of 22***Ω***?

Given	Required
I=3A	V=?

R=22$\boldsymbol{\Omega}$

Solution

V=IR =3A (22V/A) =66V

Factors affecting resistance of a resistor

Resistance of the conducting wire depends on the following four factors;

- ✓ *Nature of the material (conductivity or resistivity)*
- ✓ *Length of the conductor (l)*
- ✓ *Cross sectional area of the conductor (A)*
- ✓ *Temperature (T)*

$$\rho = \frac{1}{\sigma}$$

Based on the three factors that we had seen above we can write a general equation that relates resistance of the given conductor with its length, area and conductivity.

$$R = \frac{\rho l}{A} = \frac{l}{\sigma A}$$

Worked Example 6

When a 6V is applied to a brass, 30A current flows through the wire of cross sectional area 0.033cm^2. What is the length of the wire? (ρ=6.6 $\times 10^{-8}$ $\boldsymbol{\Omega m}$)

Given	Required
V=6V	R=?
I=30A	l=?
A=3.3 $\times 10^{-6}$m^2	
ρ=6.6 1.7$\times 10^{-8}$ $\boldsymbol{\Omega m}$	

Solution

R = $\frac{\boldsymbol{\rho l}}{\boldsymbol{A}}$ R= $\frac{\boldsymbol{V}}{\boldsymbol{I}}$ R = $\frac{\boldsymbol{6V}}{\boldsymbol{30A}}$ =0.2 $\boldsymbol{\Omega}$

l= $\frac{\boldsymbol{RA}}{\boldsymbol{\rho}}$ I= $\frac{\boldsymbol{0.2\Omega \times 3.3 \times 10^{-6} m^2}}{\boldsymbol{6.6 \times 10^{-8} \Omega m}}$ =10m

Resistance and temperature

$$R \propto T$$

Consider the resistance of a conductor is R_0 at temperature T_0 and its resistance becomes R; at temperature T. the increase in resistance (ΔR) is given by;

$$\Delta R = R - R_0 = \alpha R_0 \Delta T$$

Where; α is the temperature coefficient of the conductor

$$\Delta T = T - T_0$$

$$R = R_0 + \Delta R$$

$$R = R_0 + \alpha R_0 \Delta T = R_0 (1 + \alpha \Delta T)$$

Worked Example 7

If the resistance of a copper wire at 10℃ is 4 $\boldsymbol{\Omega}$, what is its resistance at 80℃? Find the increase in resistance. ($\alpha = 3.9 \times 10^{-3} ℃^{-1}$)

Given	Required
$R_0 = 4\ \boldsymbol{\Omega}$	$R = ?$
$T_0 = 10℃$	$\Delta R = ?$
$T = 80℃$	

Solution

$R = R_0 (1 + \alpha \Delta T)$

$R = 4\ \boldsymbol{\Omega}(1 + 3.9 \times 10^{-3} ℃^{-1} \times 70℃) = 5.092\boldsymbol{\Omega}$

$\Delta R = \alpha R_0 \Delta T$

$\Delta R = 4\boldsymbol{\Omega} \times \mathbf{3.9 \times 10^{-3}} ℃ \times \mathbf{1 \times 70} ℃ = 1.092\boldsymbol{\Omega}$

Measuring current, potential difference and resistance

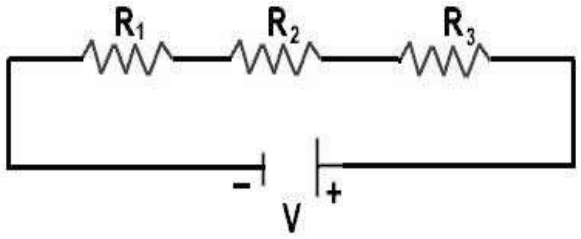
Ammeter is a device used to measure the current in a circuit. The ammeter is connected in series with the circuit, so that the current to be measured flows directly through the ammeter.

Voltmeter is a device used to measure the potential difference between two points in a circuit. The voltmeter is connected in parallel with the elements to be measured.

Combination of resistors

Series combination of resistors

Consider three resistors connected in series as shown below in the figure.



The total current $I=I_1=I_2=I_3$

From ohm's law V=IR

$V_1=I_1R_1=IR_1$

$V_2=I_2R_2=IR_2$

$V_3=I_3R_3=IR_3$

The total voltage $V=V_1+V_2+V_3$

$v= IR_1 + IR_2 + IR_3$

$V= I (R_1+R_2+R_3)$ divide both sides by I results

$\frac{V}{I} = R_1 + R_2 + R_3$ but $\frac{V}{I} = \boldsymbol{R}$

The total resistance $R = R_1 + R_2 + R_3$

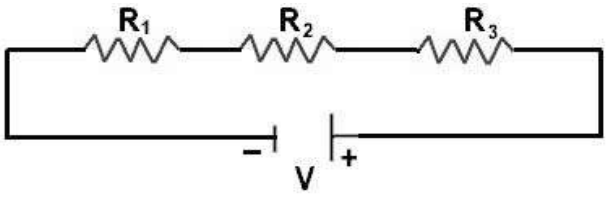
Where, R is the equivalent resistance of R_1, R_2 and R3

Generally, the equivalent resistance of N number of resistors connected serially is given by

$$R = R_1 + R_2 + R_3 + \ldots + R_N$$

Worked Example 8

Calculate the equivalent resistance of the circuit given below ($R_1=2\Omega$, $R_2=3\Omega$, $R_3=4\Omega$ and V=12V)



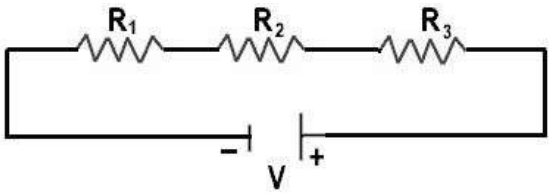
Solution

Since all the three resistors are connected serially

$R = R_1 + R_2 + R_3 = 2\,\boldsymbol{\Omega} + 3\,\boldsymbol{\Omega} + 4\,\boldsymbol{\Omega} = 9\,\boldsymbol{\Omega}$

Worked Example 9

Based on the figure given below, answer the following questions. (R1=2Ω, R_2=6Ω, R_3=4Ω and V=36V)



a. *Find the total resistance*
b. *Find the total current and current across each resistor*
c. *Find the voltage across each resistor*

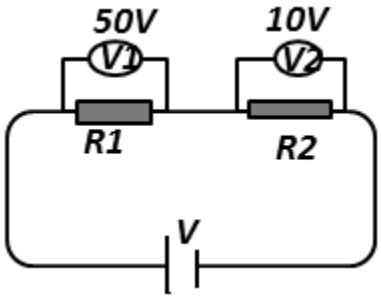
Solution

a. $R= R_1 +R_2 +R_3 =2\,\Omega+6\,\Omega+4\,\Omega=12\,\Omega$
b. $I=\frac{V}{R}=\frac{36V}{12\Omega}=3A$, *the current passes through each resistor is the same as total current.* $I =I_1 =I_2 =I_3 =3A$
c. $V_1 = IR_1 = 3A\times2\,\Omega =6V$
   $V_2 = IR_2 =3A\times6\,\Omega =18V$
   $V_3 = IR3 =3A\times4\,\Omega =12V$

Let's check the total voltage by adding each voltage, 6V +18V +12V=36V

Worked Example10

Find the total resistance and current for the figure given below (R_2=5Ω)



Solution

Current passing through R_1 and 5 Ω is the same, and then we can find the current through 5 Ω as follows

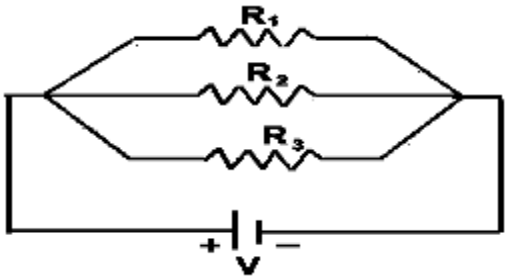
$I=\frac{V}{R}=\frac{10V}{5\Omega}=2A$

$R_1=\frac{50V}{2A}=25\,\Omega$

$R=R_1 +R_2 =25\,\Omega +5\,\Omega =30\,\Omega$

Parallel combination of resistors

.



Total voltage V =V_1 =V_2=V_3 =V=constant

Total current I =I_1 +I_2+I_3

$I = \frac{V_1}{R_1} + \frac{V_2}{R_2} + \frac{V_3}{R_3}$

$I = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V_3}{R_3}$ divide both sides by V

$\frac{I}{V} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$ but $\frac{I}{V} = \frac{1}{R}$

$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$

Generally, for N number of resistors connected in parallel combination, the equivalent resistance becomes

$$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots + \frac{1}{R_N}$$

Worked Example11

Two resistors of resistance 3Ω and 6Ω are connected in parallel. Find the equivalent resistance of the combination.

Given	Required
R_1=3Ω	R=?
R_2=6Ω	

Solution

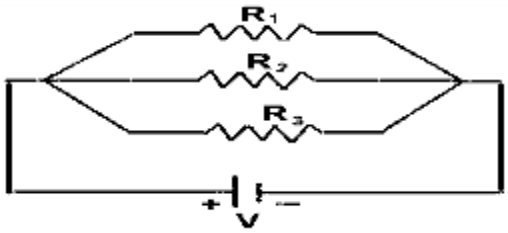
$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} = \frac{1}{3\Omega} + \frac{1}{6\Omega}$

$\frac{1}{R} = \frac{2+1}{6\Omega}$

R=2Ω

Worked Example12

Calculate the total resistance and current across each resistor. (R1=12Ω, R_2=6Ω, R_3=4Ω and V=48V)



Given	Required
R1=4Ω	I_1=?
R2=6Ω	I_2=?
R3=12Ω	I_3=?
V=48V	R=?

Solution

$I_1 = \frac{V}{R_1} = \frac{48V}{4\Omega}$ =12A

$I_2 = \frac{V}{R_2} = \frac{48V}{6\Omega}$ =8A

$I_3 = \frac{V}{R_3} = \frac{48V}{12\Omega}$ =4A

$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{4\Omega} + \frac{1}{6\Omega} + \frac{1}{12\Omega}$

R=2Ω

Worked Example13

The equivalent resistance of two resistors connected in parallel is 4Ω. If either of the resistor has value of 12 Ω. What is the resistance of the second resistor?

Given	Required
R=4 Ω	R_2=?
R_1=12 Ω	

Solution

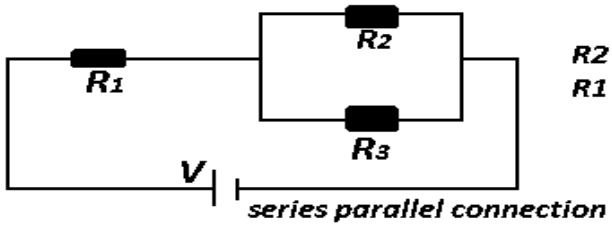
$\frac{1}{R} = \frac{1}{R_1} + \frac{1}{R_2}$

$R = \frac{R_1 R_2}{R_1 + R_2}$

$4 = \frac{12 R_2}{12 + R_2}$

$R_2 = 6\Omega$

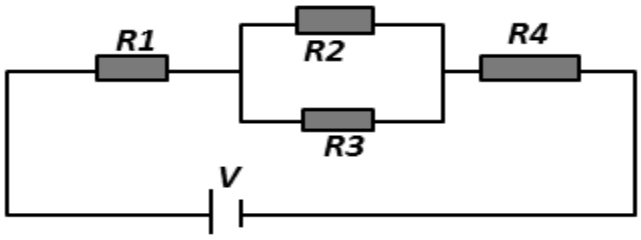
Note; resistors can be connected in a mixture of both series and parallel. In this type of circuit to find the equivalent resistance it is advisable to start from the easiest one.



R2 and R3 are connected in paralle but R1 is in series

Worked Example14

Calculate the equivalent resistance of the circuit given below. ($R1=R3=6\Omega$, $R_2=12\Omega$ and $R_4=10\Omega$)



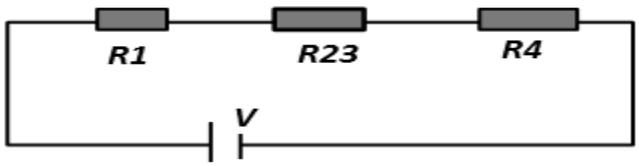
Solution

R_2 and R_3 are in parallel combination

$\frac{1}{R_{23}} = \frac{1}{R_2} + \frac{1}{R_3} = \frac{1}{12\Omega} + \frac{1}{6\Omega}$

$R_{23} = 4\Omega$

R_1, R_{23} and R_4 all are connected serially



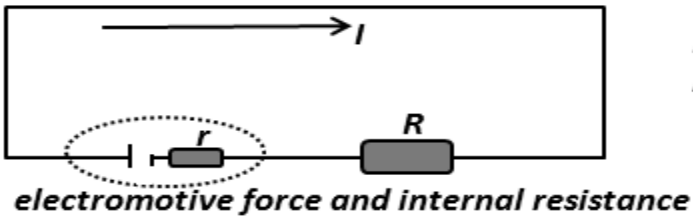
For series connection the total resistance is calculated by the sum of each resistor.

$R=R_1 +R_{23} +R_4 =6\Omega +4\Omega +10\Omega =20\Omega$

Electromotive force and internal resistance

Electromotive force (ε)

The electromotive force EMF is the energy provided by a cell or battery (combination of cells) per coulomb of charge passing through it. It is measured in volt.



R=external resistance
r=internal resistance

electromotive force and internal resistance

$$\varepsilon= IR + Ir$$

$$\varepsilon=V + Ir$$

V is the terminal potential difference measured in volt. It is the potential difference across the terminals of the cell when the current is flowing in the circuit. Terminal potential difference is always less than electromotive force if current is passing through the cell.

Worked Example15

The potential difference across the terminals of a cell is 3V, when it is not connected to a circuit and no current is flowing. When the cell is connected to a circuit and current of 0.37A is flowing and the terminal potential difference falls to 2.8V. What is the internal resistance of the cell?

Given	Required
$\varepsilon=3V$	$r=?$
$V=2.8V$	
$I =0.37A$	

Solution

$\varepsilon = V + Ir$

$r = \frac{\varepsilon - V}{I} = \frac{3V - 2.8V}{0.37A} = 0.54\ \Omega$

Worked Example16

When a 6V emf battery was connected to a 15 Ω resistor, a current of 375mA occurred and the voltmeter reading was 5.625V.

a. *Find the internal resistance of the supply*
b. *If the battery is now connected a 5 Ω resistor, what current will flow?*

Solution

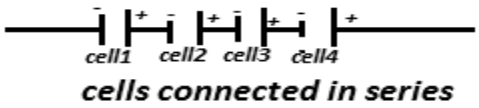
a. $r = \frac{\varepsilon - V}{I} = \frac{6V - 5.625V}{3.75 \times 10^{-4} A} = 1\ \Omega$
b. $\varepsilon = IR + Ir = I(R+r)$

$I = \frac{\varepsilon}{R+r} = \frac{6V}{5\Omega + 1\Omega} = 1A$

Combination of cells

Battery is a combination of two or more cells.

Cells connected in series



cells connected in series

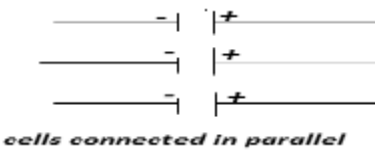
If ε is the total EMF of the battery combined by N number of cells then

$$\varepsilon = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \ldots + \varepsilon_N$$

Similarly the total internal resistance of the battery is the sum of each individual cell's internal resistance.

$$r = r_1 + r_2 + r_3 + \ldots + r_N$$

Cells connected in parallel



cells connected in parallel

$$\varepsilon = \varepsilon_1 = \varepsilon_2 = \varepsilon_3 = \varepsilon_N$$

The resultant internal resistance is given by

$$\frac{1}{r} = \frac{1}{r_1} + \frac{1}{r_2} + \frac{1}{r_3} + \ldots + \frac{1}{r_N}$$

The current delivered by the battery is the sum of currents delivered by individual cells.

$$I = I_1 + I_2 + I_3 + \ldots + I_N$$

Worked Example 17

What is the effective electromotive force of 20 cells of each 1.5V, connected in series and in parallel respectively?

Solution

a. $\varepsilon = \varepsilon_1 + \varepsilon_2 + \varepsilon_3 + \ldots + \varepsilon_{20} = 20(1.5V) = 30V$
b. $\varepsilon = \varepsilon_1 = \varepsilon_2 = \varepsilon_3 = \varepsilon_{20} = 1.5V$

Electrical energy and power

Electrical energy (W)

Electrical energy is caused by moving electric charges are moving electric charges. Since electric charges are moving, electrical energy is one form of kinetic energy.

W=QV the SI unit of electrical energy is joule

$$W = IVt = I^2Rt = \frac{V^2}{R}t$$

Power (P)

Power is the rate of energy transferred by an electric circuit.

Mathematically, $P = \frac{W}{t}$ its SI unit is watt (W)

$$P = IV = I^2R = \frac{V^2}{R}$$

Worked Example 18

If the potential difference across a working electrical motor is 50V and the current passing through it is 2A. What is the power generated from the motor?

Given	Required
V=50V	P=?
I =2A	

Solution

P=IV=50V (2A) =100W

Worked Example 19

An electrical heater is marked 250V, 1000W. Calculate the resistance of the heater and the current it consumes.

Given	Required
P=1000W	R=?
V=250V	I=?

Solution

P= $\frac{V^2}{R}$

R= =$\frac{V^2}{P}$ $\frac{62500V^2}{1000W}$ =62.5Ω

I= $\frac{V}{R}$ =$\frac{250V}{62.5\Omega}$ =4A

Cost of electrical energy

Total cost = number of units used ×cost per unit *or*

Total cost = total energy consumed in kWh ×cost per kWh

Activity: Show that 1kWh =3.6×10^6J

Worked Example 20

A 2kW electrical fire is switched on for 3hours. If 1kWh is sold by 27 cent, what amount of birr will be paid?

Given	Required
P=2Kw	cost?
t=3h	

Solution

W=Pt =2kW×3h =6kWh

Cost= total energy consumed in kWh ×cost per kWh

Cost=6kWh×27cents/kWh=162cents=1.62 birr

Worked Example 21

If the electrical energy costs 28cents per kWh, calculate the cost per month for 60W bulb which is on for 12 hours per day.

Given	Required
P=60	cost=?
t=12×30h=360h	

Solution

W=Pt =60W×360h =21.6kWh

Cost = total energy consumed in kWh ×cost per kWh

Cost = 21.6kWh×28cents/kWh=6.05 birr

Review questions

1. *Suppose a given resistor is connected to a constant voltage supply. When will the current in the resistor decrease?*
    - *A. When the length of the resistor is reduced.*
    - *B. When the cross sectional area of the resistor is increased.*
    - *C. When the length of the resistor is increased.*
    - *D. When the resistance of the resistor increased.*
2. *In experiment 4 resistors of 3Ω, 4Ω, 12Ω and 16Ω are required at different time. But the laboratory technician told you to use only two resistors. Which two resistors do you choose to do the experiment?*

A. 4Ω and 12Ω B. 4Ω and 16Ω C. 3Ω and 16Ω D. 3Ω and 4Ω

3. *Consider a simple series circuit with a cell of emf 4.5V and a resistor of40Ω. The current in the circuit is 0.1A. What will be the current in the circuit exactly identical additional cell of emf 4.5V is connected to the previous cell in series?*
   A. 0.05A B. 0.20A C. 0.18A D. 0.21A
4. *You wish to triple the rate of electrical energy dissipation in a heating device. To do this you could triple*
   A. The potential difference keeping the resistance the same.
   B. The resistance keeping the potential differences the same.
   C. The current keeping the resistance the same.
   D. The resistance keeping the current the same.

5. *In an electric circuit at home, a student wanted to use a fuse to safeguard her radio set that has a 5V transformer supply. If the fuse operates at maximum of 6W, how should it be connected?*
   A. In series with the radio next to the transformer.
   B. In series with the radio before the mains input.
   C. In parallel with the radio next to the transformer.
   D. In parallel with the radio before the main.
6. *A simple circuit consists of resistor of a resistor 10Ω connected to a battery of emf 18V. If the current through the circuit is 1.6A, what is the internal resistance of the battery?*
   A. 10.0Ω B. 8.75Ω C. 1.25Ω D. 11.2Ω
7. *Ethiopian electric power corporation calculates the first 50 kwh consumption at the minimum rate. In this quantity the unit kwh refers to*
   A. Power B. Charge C. Current D. Energy
8. *The terminal potential difference of a battery is maximum when*
   A. The e.m.f of the battery is the minimum.
   B. The battery is being discharged through a wire.
   C. There is a steady current flowing through the battery.
   D. There is no current flowing through the battery.
9. *A voltmeter should be connected in parallel across a resistor in a circuit because*
   A. Its resistance is very small. C. It requires high current.
   B. Its resistance is very high. D. It measures current.
10. *A stove that draws 10A current from 220V line is used for 5 hours. If the electrical company demands 20cents per kilowatt –hour, what is the cost of electrical energy consumed?*
    A. 2 birr and 20 cents C. 1birr
    B. 1 birr and 20 cents D. 55 cents
    C.

11. *The potential difference between the terminal of the battery when the battery is isolated electrically is called*
    - *A. Electromotive force*
    - *C. Electric force*
    - *B. Terminal voltage*
    - *D. Electric field*
12. *Which of the following statement is correct about resistivity and conductivity?*
    - *A. They are dimensionless*
    - *C. One is the reciprocal of the other*
    - *B. They have the same SI unit*
    - *D. They have direct relationship*
13. *One kilo-watt-hour (1kWh) is the same as*

    A. 3.6J *B. 1.0J* *C.* $3.6\times\mathbf{10^6}\boldsymbol{J}$ *D.* $3.6\times\mathbf{10^3}\boldsymbol{J}$
14. *If a battery with emf of 24V is connected to a 6Ω resistor and as a result, a current of 3A exists in the resistor, what is the internal resistance of the battery?*

    A. 6Ω *B.2Ω* *C. 14Ω* *D. 8Ω*
15. *If three equal resistors connected in series are equivalent to 90Ω. What would be their equivalent resistance if they are connected in parallel?*

    A. 270Ω *B. 30Ω* *C. 810Ω* *D. 10Ω*

UNIT 11: MAGNETISM

Electromagnetism is the creation of magnetic field from the movement of electric charges. It usually concerns the use of electric current to make electromagnets, which is called electrodynamics.

Magnetism

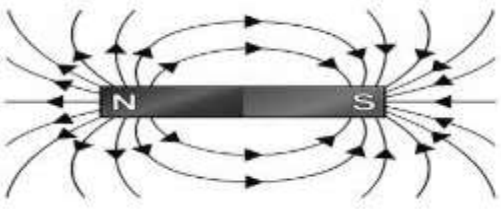
Magnetism is the force of attraction or repulsion between substances made of certain materials such as iron, nickel and cobalt.

Magnetic field and magnetic field strength (B)

Magnetic field is a region in which a magnetic force may be exerted. It is the magnetic effect of electric current and magnetic materials.

Magnetic field lines

Magnetic field lines are imaginary lines drawn as closed loops around magnets, starting from the north pole of a magnet to the south pole of a magnet at the outer part of the magnets. Inside the magnet itself the field lines run from the south pole of the magnet to North Pole of the magnet.



The closest the field lines the strongest the force and the magnetic field strength (B). The magnetic field strength indicates the status of the force. Its SI unit is called tesla T (T=N/Am).

Magnetic field around a current carrying wire

Electric current has magnetic effect and heating effect, Electric currents produce magnetic fields. Therefore, electric current passing through the conductor generates a magnetic field around the wire.

The magnetic field strength (B) around a current carrying wire is depending on the amount of electric current (I) and distance from the wire (r). Away from the conductor the field strength decreases at constant current through the conductor.

$$B = \frac{\mu_0 I}{2\pi r}$$

where $\boldsymbol{\mu_0}$ is magnetic permeability of free space its value is equal to $4\pi\times\mathbf{10^{-7}}$Tm/A.

Worked Example 1

A magnetic field of magnitude $1.3\times\mathbf{10^{-3}}$T is measured at 3cm distance from a long straight current carrying wire. What is the amount of current through the wire?

Given	Required
$B=1.3\times\mathbf{10^{-3}}$T	I=?
r=0.03m	

Solution

$B=\frac{\boldsymbol{\mu_0 I}}{\boldsymbol{2\pi r}}$

$I=\frac{\boldsymbol{B2\pi r}}{\boldsymbol{\mu_0}}=\frac{\boldsymbol{1.3\times10^{-3}T\times2\pi\times0.03m}}{\boldsymbol{4\pi\times10^{-7}Tm/A}}$ = 195A

Magnetic field around a solenoid

Solenoid is a coil of wire designed to create a strong magnetic field inside the coil.

The strength of the magnetic field of solenoid can be increased by:

- *increasing the numbers of turns (windings), N*
- *increasing current flowing through the wire, I*

By considering those factors the magnetic field strength of a solenoid of length L with N number of turns is given by

$B=\frac{\boldsymbol{\mu_0 IN}}{\boldsymbol{l}}$ l= Length



Right hand rule

Wrap your right hand fingers in the direction of the conventional current then your thumb indicates or points to the direction of North Pole of the solenoid, the remaining pole is South Pole because there is no magnetic mono pole.

Worked Example 2

Find the magnetic field produced by 40cm long solenoid if the number of loop is 400 and the current passing through it is 5A.

Given	Required
N=400	B=?
I=5A	
L=0.4m	

Solution

B= $\frac{\mu_0 IN}{L}$

B = $\frac{400 \times 5A \times 4\pi \times 10^{-7} Tm/A}{0.4m}$ = 6.28 ×$\mathbf{10^{-3}}$T

Worked Example 3

A solenoid has 80cm diameter with four loops. The magnetic field produced is 1.2×$\mathbf{10^{-5}}$T. Calculate the current passing through each loop of the wire.

Given	Required
r=0.4m	I=?
B=1.2×$\mathbf{10^{-5}}$T	
N=4	

Solution

B= $\frac{\mu_0 IN}{L}$ but the length L =2πr =0.8πm

I = $\frac{BL}{\mu_0 N}$ = $\frac{1.3 \times 10^{-5} T \times 0.8\pi m}{4 \times 4\pi \times 10^{-7} Tm/A}$ = 6.5A

Worked Example 4

A long cylindrical solenoid with 200 turns per centimeter carries a current of 4A. What is the magnetic field strength inside the solenoid?

Given	Required
n= $\frac{N}{l}$=200/cm=20000/m	B=?
I=4A	

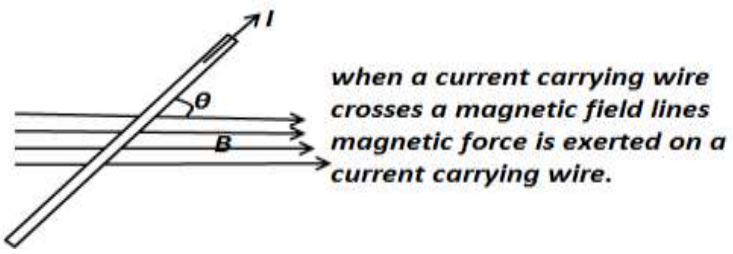
Solution

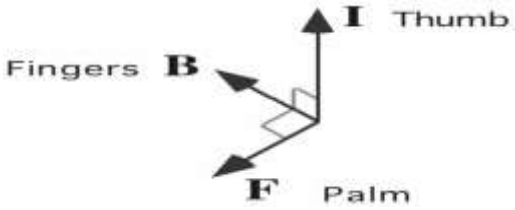
B=μ_0nI

B=4π×10^{-7}Tm/A×20000/m×4A =0.1T

Magnetic force due to straight current carrying wire

The magnetic force F produced is proportional to the current passing through the wire (I), the length of the conductor (l) and the sine of an angle between the magnetic field and current carrying wire.





F=BIL$\boldsymbol{sin\,\theta}$ but I= $\frac{Q}{t}$

F= $\frac{BQL\,sin\,\theta}{t}$

F=BQV$\boldsymbol{sin\,\theta}$

F=BIL$\boldsymbol{sin\,\theta}$

F= BQV$\boldsymbol{sin\,\theta}$

Note: If θ =0° force on current carrying wire is zero and for θ=90° the magnetic force on current wire becomes maximum.

Worked Example 5

A wire of 1m long is perpendicular to a magnetic field of $5\times\mathbf{10^{-2}}$ T. what is the force on the wire when it carries 2A current?

Given	Required
L=1m	F=?
θ=90°	
B=$5\times\mathbf{10^{-2}}$T	
I=2A	

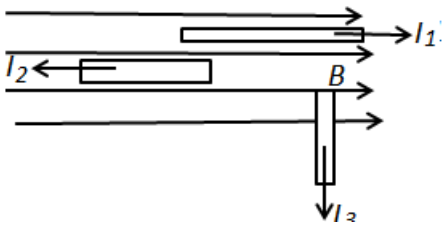
Solution

F=BIL$\boldsymbol{sin\,\theta}$

F=$5\times\mathbf{10^{-2}}$T×1m×2A×$\boldsymbol{sin\,90°}$ =0.1N

Worked Example 6

Which one of the magnetic force acting on a wire is/are zero in the figure given below?



Explanation

No force is exerted on current carrying conductor 1 and conductor2 because of their angle of inclination with the magnetic field.

F_1= BI_1 L$\boldsymbol{sin\,\theta}$=BI_1 L$\boldsymbol{sin\,0°}$ = 0

F_2= BI_2 L$\boldsymbol{sin\,\theta}$= BI_2L$\boldsymbol{sin\,180°}$ = 0

F_3= BI_3 L$\boldsymbol{sin\,\theta}$= BI_3 L$\boldsymbol{sin\,90°}$ = BI_3L which is maximum.

Worked Example7

Calculate the force experienced by an electron while moving with a speed of $\mathbf{10^5}$m/s perpendicular to a magnetic field of $5\times\mathbf{10^5}$ T.

Given	Required
B=5×$\mathbf{10^5}$ T	F=?
V=$\mathbf{10^5}$m/s	
θ=90°	
Q=1.6×$\mathbf{10^{-19}}$ C	

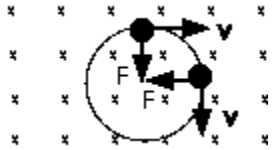
Solution

F= BQV$\boldsymbol{sin\,\theta}$

F= 5×$\mathbf{10^5}$ T×1.6×$\mathbf{10^{-19}}$ C×$\mathbf{10^5}$m/s $\boldsymbol{sin\,90°}$ =8×$\mathbf{10^{-9}}$ N

Motion of charged particle in a uniform magnetic field

If a charged particle enters a strong magnetic field, the curvature of its path may be quite severe, producing a circular path.



$$F=BQV=\frac{mv^2}{r}$$

$$BQV=\frac{mv^2}{r}$$

Where; m=mass of the particle, Q=charge and r=radius of the path or circle.

Worked Example 8

A proton is moving in a circular orbit of radius 14cm in a uniform 0.35T magnetic field perpendicular to the velocity of the proton. Find the linear speed of the proton. (m=1.67 × $\mathbf{10^{-27}}$kg, q= 1.6×$\mathbf{10^{-19}}$ C)

Given	required
m=1.67 × $\mathbf{10^{-27}}$kg	V=?
q= 1.6×$\mathbf{10^{-19}}$ C	
r=0.14m	

B=0.35T

Solution

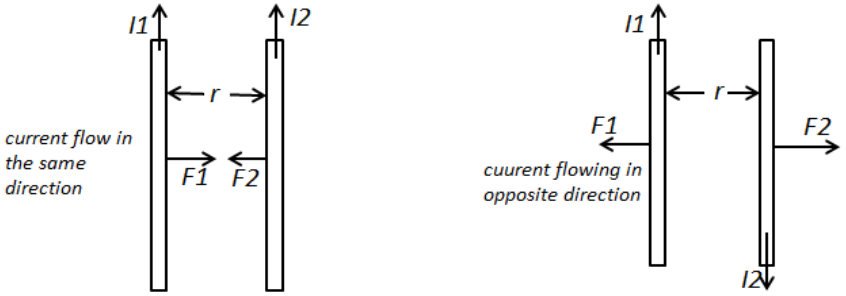
BQV= $\frac{mv^2}{r}$

V= $\frac{BQr}{m}$

V = $\frac{0.35T \times 1.6 \times 10^{-19}C \times 0.14m}{1.67 \times 10^{-27}kg}$ = $4.7 \times 10^6 m/s$

Magnetic force between two parallel current carrying conductors

The force is proportional to the currents I_1 and I_2 and the length l and inversely proportional to the distance r.



F= $\frac{kI_1I_2l}{d}$

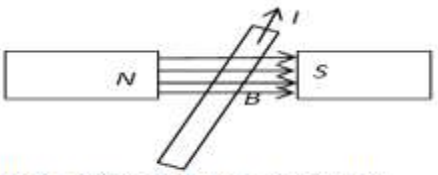
Where; k=$2 \times 10^{-7} NA^{-2}$

Definition of an ampere

Ampere is the constant current which if maintained in two parallel conductors of infinite length of negligible cross sectional area and placed one meter apart in vacuum would produce between these conductors force of 2×10^{-7}N per meter of length.

Fleming's left hand rule and the motor effect

When a wire carrying an electric current is moved in a magnetic field of a magnet, the magnetic field induced by the wire reacts with the magnetic field of the magnet causing the wire to move outward.



Fleming's left hand rule and motor effect



Fleming's left hand rule helps you to predict the movement.

Magnetic flux (Ø)

Magnetic flux is the measurement of the total magnetic field (B) which passes through a given area (A). It is the product of the average magnetic field and the perpendicular area it penetrates. Magnetic flux through a surface is the scalar product of the magnetic field and the area.

Magnetic flux density is also called magnetic field strength.

$$Ø=BA\boldsymbol{cos\,\theta}$$

θ is the angle between magnetic flux density (B) and the area it crosses (A).

The SI unit of magnetic flux is called weber (Wb=T$\boldsymbol{m^2}$).

Worked Example 9

A rectangular loop of a wire that encloses an area of $5\times\mathbf{10^{-5}}\boldsymbol{m^2}$ is in a uniform magnetic field of 0.4T. What is the magnetic flux through the loop if

a. *Its plane is perpendicular to the field*
b. *Its plane is parallel to the field*

Solution

The direction of area unit vector is perpendicular to its plane.

a. $Ø=BA\boldsymbol{cos}\,\mathbf{0}°=0.4T\times5\times\mathbf{10^{-5}}\boldsymbol{m^2}=2\times\mathbf{10^{-5}}\boldsymbol{Wb}$
b. $Ø=BA\boldsymbol{cos}\,\mathbf{90}°=0.4T\times5\times\mathbf{10^{-5}}\boldsymbol{m^2}\times\mathbf{0}=0\boldsymbol{Wb}$

Electromagnetic induction

The phenomena of induction of an emf in a circuit due to change in magnetic flux linked with it is called electromagnetic induction.

Laws of electromagnetic induction

There are two laws of electromagnetic induction.

- *Faraday's law of EM induction and*
- *Lenz's law of EM induction.*

Faraday's law of induction explains the relation between electric circuit and magnetic field. This law is the basic working principle of the most electrical motors, generators, transformers and inductors.

Lenz's law states that the polarity of the induced emf is such that it tends to produce a current which opposes the change in magnetic flux that produced it (i.e. the direction of the induced current is such as to oppose the change that is causing it).

$$\varepsilon = -\frac{N\Delta\emptyset}{\Delta t}$$

The negative sign shows that the direction of induced EMF and direction of change in magnetic field have opposite directions.

Generally faraday's law states about the magnitude of ε and Lenz's law about direction of induced electromotive force ε.

Worked Example10

The magnetic flux in a certain loop of 100 turns changed from0.5Wb to 0.75Wb in 5ms. Calculate the induced emf.

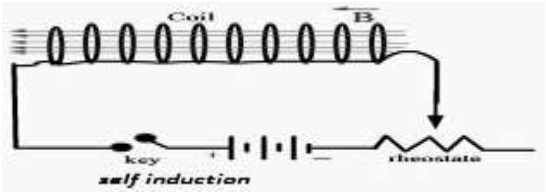
Given	Required
$\emptyset_1$=0.5Wb	ε=?
$\emptyset_2$=0.75Wb	
t=0.005s	
N=100	

Solution

$$\varepsilon = -\frac{N\Delta\emptyset}{\Delta t}$$

$$\varepsilon = -\frac{100(0.75Wb - 0.5Wb)}{0.005s} = -5000V$$

Self-induction



The current through the coil produces a magnetic flux which links with the coil itself. This change in flux indicates an emf in the coil

itself. Such an emf is called self-induced EMF and the phenomenon is called self-induction.

$$\varepsilon = -\frac{L\Delta I}{\Delta t}$$

Worked Example 11

A hollow air cored inductor coil consists of 500 turns of copper wire; which produces a magnetic flux of $\mathbf{10^{-3}}$Wb when passing a DC current of 10A. Calculate the self-inductance of the coil and the induced emf in the coil after $\mathbf{10^{-2}}$s.

Given	Required
N=500	L=?
$\emptyset=\mathbf{10^{-3}}$Wb	ε=?
I=10A	
$L=\frac{N\emptyset}{I}$	
$\boldsymbol{t = 10^{-2}}$s	

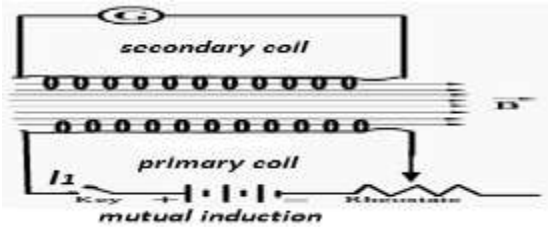
Solution

$L=\frac{N\emptyset}{I}=\frac{500\times10^{-3}Wb}{10A}=5\times \mathbf{10^{-2}}$H

$\varepsilon = -\frac{L\Delta I}{\Delta t} = -\frac{10^{-2}H\times10A}{10^{-2}s}=-0.5$V

Mutual induction

Mutual induction is the phenomenon in which a change of current in one coil causes an induced emf in another coil placed near to the first coil. The coil in which emf is induced is called secondary coil.



Motional emf produced by mutual induction phenomenon is directly proportional to the change of electric current in the primary coil ($\boldsymbol{I_p}$).

$$\varepsilon = -\frac{M\Delta I_p}{\Delta t}$$

M is mutual inductance of two coils.

Worked Example 12

Suppose that two insulated wires wound onto a common cylindrical form of having mutual inductance of 0.0188H. If the current in the primary increases uniformly from 0A to 10A in 0.1s, what emf is generated in the second wire?

Given	Required
M=0.0188H	ε=?
ΔI_p=10A	
Δt=0.1s	

Solution

$$\varepsilon = -\frac{M\Delta I_p}{\Delta t} = -\frac{0.0188H \times 10A}{0.1s} = -1.88V$$

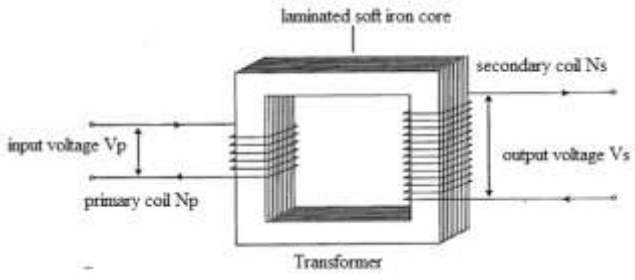
$$\varepsilon = -\frac{0.0188H \times 10A}{0.1s} = -1.88V$$

Simple AC generator

One of the most important applications of Faraday's law of induction is to generators and motors. A generator converts mechanical energy into electric energy, while a motor converts electrical energy into mechanical energy.

Transformer

A transformer is a device that is used for changing the voltage of a supply of alternating current (A.C.) without changing the frequency. It can raise or lower the voltage in a circuit but a corresponding decrease or increase current.



Transformer is used to convert high alternating voltage a low alternating voltage and vice versa. Transformer works on the principle of mutual induction of two coils and AC supply.

There are two types of transformers. These are

1. ***Step up transformer:*** *it is a type of transformer in which the numbers of turns on the secondary (output) are greater than the number of turns in the primary (input)* $N_S > N_P$*. It converts low alternating voltage to a high alternating voltage* $V_S > V_P$*.*
2. ***Step down transformer:*** *it is a type of transformer in which the numbers of turns on the primary (input) are greater than the number of turns in the secondary (output)* $N_S < N_P$*. It converts high alternating voltage to a low alternating voltage* $V_S < V_P$*. Generally the number of turns (N) is directly proportional to voltage (V).*

$$\frac{V_S}{V_P} = \frac{N_S}{N_P}$$

Ideal Transformer

An ideal transformer can be defined as one for which the input and the output powers are equal.

$$P_{OUT} = P_{IN}$$

$$P_{OUT} = P_{IN} \text{ but } P=IV$$

$$I_S V_S = I_P V_P$$

Rearranging the equation we can state that for an ideal transformer

$$\frac{V_S}{V_P} = \frac{I_P}{I_S}$$

$$\frac{V_S}{V_P} = \frac{N_S}{N_P} = \frac{I_P}{I_S}$$

Worked Example13

An ideal transformer has 100 turn on its primary coil and 10 000 turns on its secondary coil. An alternating current of 5A flows though the primary coil when it is connected to a 12V supply.

a. State the type of transformer that is used in the example.
b. Calculate the power input of the transformer.
c. Calculate the EMF induced across the secondary coil.
d. Calculate the maximum current that can flow through the secondary coil.

Given	Required
$N_P=100$	$P_{IN}=?$
$N_S=10000$	$V_S=?$
$I_P=5A$	$I_S=?$
$V_P=12V$	

Solution

a. $N_S > N_P$ *it is step up transformer.*
b. $P_{IN} = I_P V_P = 5A\ (12V) = 60W$
c. $\frac{V_S}{V_P} = \frac{N_S}{N_P} \Rightarrow V_S = V_P \frac{N_S}{N_P} = 12V(100) = 1200V$

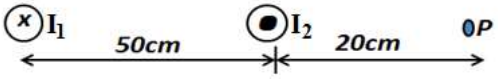
d. $\frac{N_S}{N_P} = \frac{I_P}{I_S} \Rightarrow I_S = I_P \frac{N_P}{N_S} = 5A(0.01) = 0.05A$

Review questions

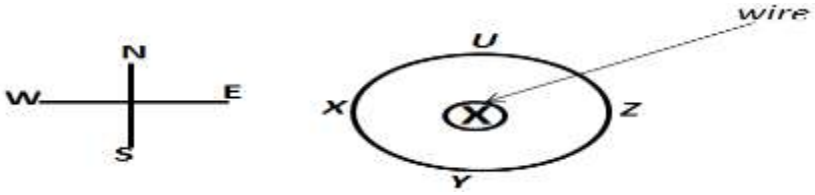
1. *The magnetic field strength inside a long ideal solenoid can be doubled by doubling*
   - *A. The spacing of the windings keeping the current and the number of turns constant.*
   - *B. The length of the solenoid keeping the current and the number of turn constant.*
   - *C. The current keeping the cross sectional area and the number of turns constant.*
   - *D. The cross sectional area keeping the current and the number of turns constant.*
2. *What are magnetic domains?*
   - *A. The possible magnetic poles of a magnet*
   - *B. Microscopic set of magnets within a magnet*
   - *C. Collection of the magnetic poles*
   - *D. Bar magnets arranged in the same direction*
3. *What is the purpose of using transformer in electrical device?*
   - *A. To convert electrical voltage from one value to another.*
   - *B. To transform mechanical energy into electrical energy.*
   - *C. To transform small electrical energy into high electrical energy.*
   - *D. To convert electrical energy into high electrical energy.*
4. *A long solenoid has 1000 turns uniformly distributed over a length of 0.40m. What current is required in the windings to produce a magnetic field of magnitude* $\pi \times \mathbf{10^{-4}}$ *T at the center of solenoid? (*$\boldsymbol{\mu_0} = 4\pi \times \mathbf{10^{-7}}$ *Tm/A)*

   A. 0.01A B. 10A C. 1.0A D. 0.1A
5. *Your teacher tells you to check an unknown sample with a bar magnet. If the sample is attracted by both boles of the magnet, it must be*
   - *A. A magnet*
   - *B. An insulator*
   - *C. A magnetic substance*
   - *D. A non-magnetic material*
6. *Which one of the following statement is NOT true about magnetic lines of force?*
   - *A. They have the same pattern for current carrying wire and solenoid.*
   - *B. They point away from a north pole and back into a south pole.*
   - *C. However large they are, they close up on themselves.*
   - *D. They are close to each other in a strong magnetic field region.*
7. *A metal bar magnet has magnetic field in the region of space around it. The magnetic field is due to*
   - *A. An electric current that runs along the length of the magnet.*
   - *B. The motion of charged particles in the metal.*
   - *C. Magnetic monopoles embedded in the metal.*
   - *D. A hidden voltage source in the metal.*

8. *What is the unit of magnetic flux density?*
   A. T/m^2 B. T/m C. Tm D. T
9. *Two long parallel conductors that are 50cm apart carry currents I_1 =7A and I_2 =10A in opposite direction as shown in the figure below. What is the resultant magnetic field at point P? ($\mu_0 = 4\pi \times \mathbf{10^{-7}} Tm/A$)*



   A. $1.2 \times \mathbf{10^{-5}} T$, down C. $8 \times \mathbf{10^{-6}} T$, down
   B. $1.2 \times \mathbf{10^{-5}} T$, up D. $8 \times \mathbf{10^{-6}} T$, up
10. *If two long parallel wires 1m apart carry the same current and the force per unit length on each wire is $2 \times \mathbf{10^{-7}}$ N/m the current in each wire is defined to be*
    A. 1 ampere B. 1 coulomb C. 2 ampere D. $2 \times \mathbf{10^{-7}}$ ampere
11. *What is the magnetic field strength at the center of the solenoid of 200 turns and 4cm long when it is carrying a current of 2A? (use $\mu_0 = 4\pi \times \mathbf{10^{-7}} Tm/A$)*
    A. $1.256 \times \mathbf{10^{-3}} T$ B. $1.256 \times \mathbf{10^{-2}} T$ C. $1.256 \times \mathbf{10^{-4}} T$ D. 1.256T
12. *The figure given below shows a long straight wire carrying current directed into the page*



    When a compass is placed at points U, X, Y and Z the north end of its needle points to
    A. North when placed at Z. C. south when placed at X.
    B. East when placed at Y. D. east when placed at U.
13. *A bar magnet is divided into two pieces. Which of the following statement is true about the force between the broken pieces if they face each other each other with a small separation?*
    A. There is an electric repulsive force between the broken pieces.
    B. There is an electric attractive force between the broken pieces.
    C. There is a magnetic repulsive force between the broken pieces.
    D. There is a magnetic attractive force between the broken pieces.
14. *A coil consists of 2 turns of wire. Each turn is a square of side d=40cm and a uniform magnetic field is directed perpendicular to the plane of the coil. If the field changes linearly from 0 to 0.5T in 0.25s, what is the magnitude of the induced emf in the coil while the field is changing?*
    A. 0.64V B. 0.32V C. 6400V D.3200V
15. *Which one of the following is correct?*
    A. A magnetic pole can exist alone while cutting it.
    B. Like poles attract and unlike poles repel each other.
    C. Magnet can be produced by an electric current.
    D. Magnetic force is weak at the poles of magnet.

UNIT 12: INTRODUCTION TO ELECTRONICS

Electronics is the branch of physics which deals with development of electron emitting devices, there use and control of electrons flow in electrical circuits. It also deals with semiconductors, diodes, rectifiers, etc.

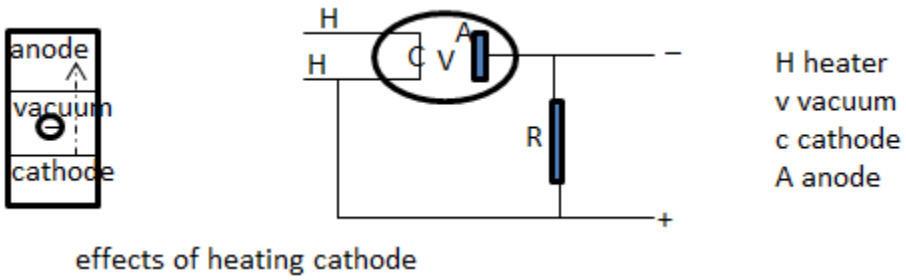
Vacuum tube devices and thermionic emission

Metals contain many free electrons moving at high speed and at random motion between the atoms of the material. If these free electrons are given enough energy they may actually escape from the metal surface. One way to give the free electrons sufficient energy to allow them escape is by heating the metal directly or indirectly. The emission of free electrons from a hot metal surface is called thermionic emission.

Thermionic diode

Diode is the simplest type of vacuum tube with only two electrodes: anode and cathode.

Diode is a two terminal electronic component that conducts in one direction.



effects of heating cathode

The circuit symbol of diode is 

Diode allows unidirectional flow of current and used as rectifier. Rectifier is a device used to change ac current into dc current and the process is called *rectification.*

Semiconductors

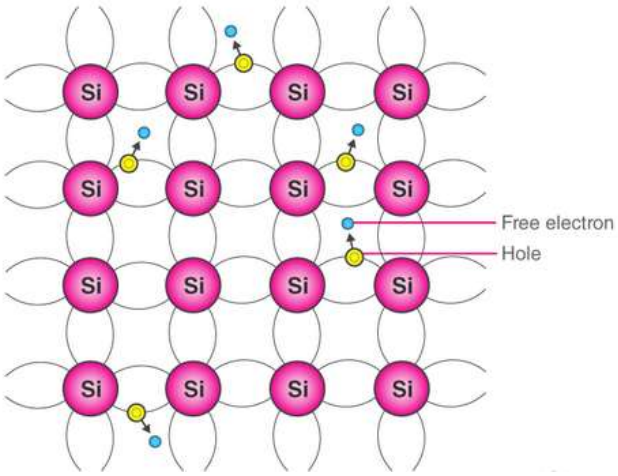
Semiconductors have a small number of free electrons available and allow passing a limited amount of electrical current. Semiconductors are extremely important in modern electronics because they can be used to control the amount of current in an electrical system.

Semiconductors are classified into two main categories.

- *Intrinsic semiconductors*
- *Extrinsic semiconductors*

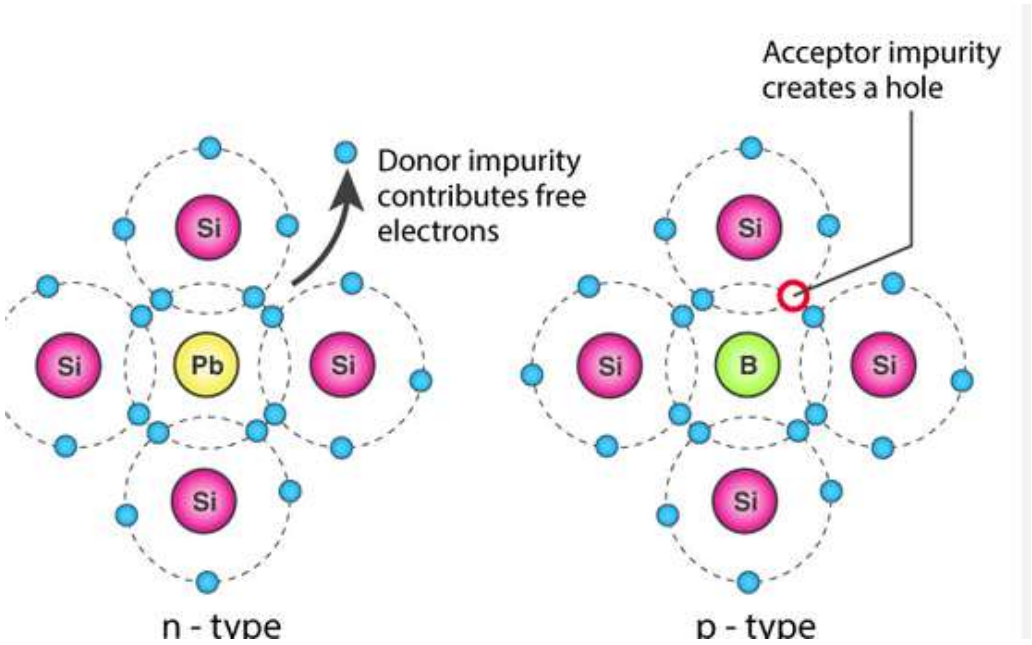
Intrinsic semiconductors

A semiconductor in an extremely pure form is called intrinsic semiconductor. An intrinsic semiconductor is **an un-doped semiconductor**. This means that holes in the valence band are vacancies created by electrons that have been thermally excited to the conduction band, as opposed to doped semiconductors where holes or electrons are supplied by a "foreign" atom acting as an impurity.



Extrinsic (Impure) semiconductors

When an impurity is added to an intrinsic semiconductor its conductivity changes, this process of adding impurity to a semiconductor is called doping or implantation.



Depending on the type of impurity added extrinsic semiconductors are further classified into two main categories.

- *P-type(positive) semiconductor and N-type(negative) semiconductor*

P-type semiconductor

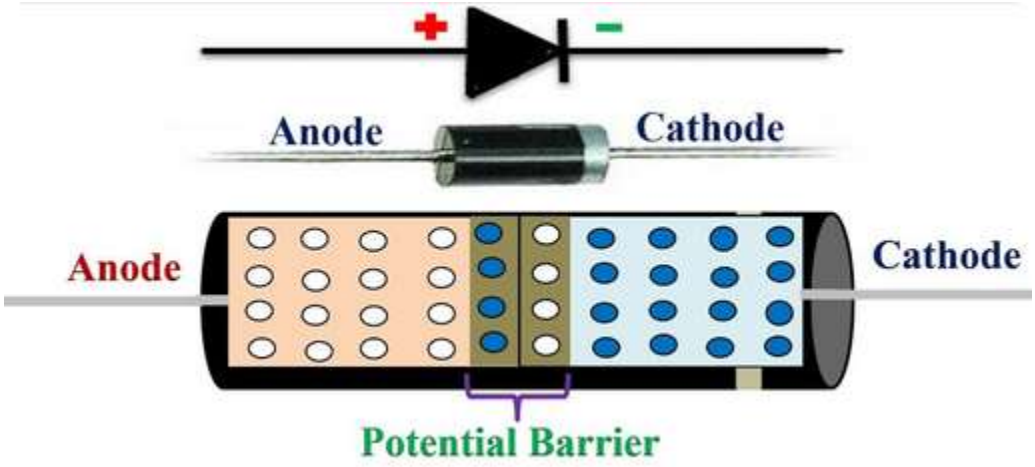
The addition of trivalent impurities (elements having three valence electrons) such as boron, aluminum or gallium to an intrinsic semiconductor creates deficiencies of valence electrons called holes.

N-type semiconductors

The addition of pentavalent impurities (elements having five valance electrons) such as antimony, arsenic or phosphorous contributes free electrons, greatly increasing the conductivity of intrinsic semiconductor.

The P-N junction diode

P-n junction diode is the most fundamental and simplest electronics device formed from p-type and n-type semiconductors. Both ends have different characteristics one end has excess of electrons and the other end has an excess of holes.

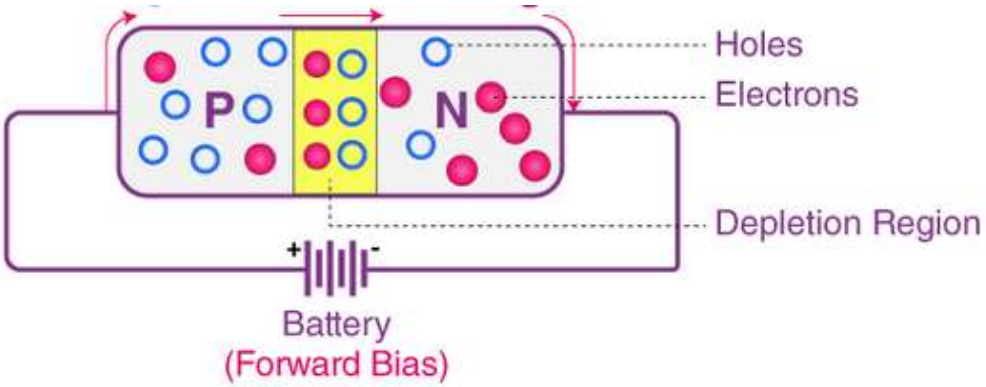


Diode biasing

Biasing refers to the application of DC voltage across the terminals of device to establish certain operating condition for the device. Diode biasing can be done in two different ways; forward biasing and reverse biasing.

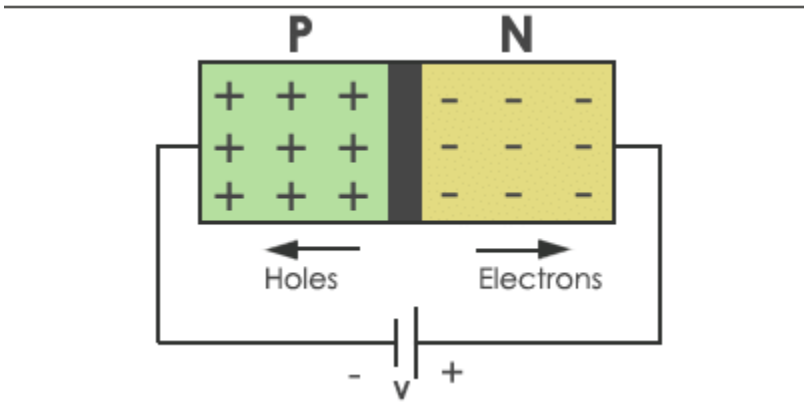
Forward biasing

When the positive terminal of the battery or source is connected to the p- type semiconductor and the negative terminal of the source is connected with the n-type of the semiconductor, such a connection is forward biasing.



Reverse biasing

When the positive terminal of the battery is connected to n-type semiconductor and the negative terminal of the battery is connected to a p-type semiconductor, such connection is called reverse bias.

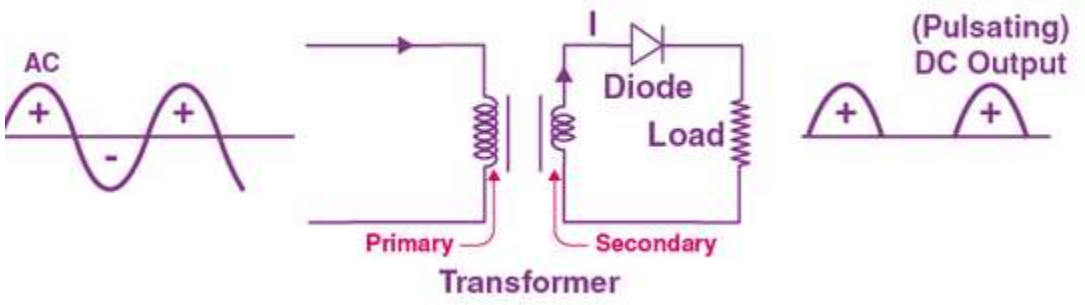


Rectifier and rectification

A rectifier is an electronic device that converts alternating current (ac) into direct current (dc); it current follows only one direction. The process of converting AC into DC is called rectification. Diode acts as rectifier. There are two types of rectification: half wave rectification and full wave rectification.

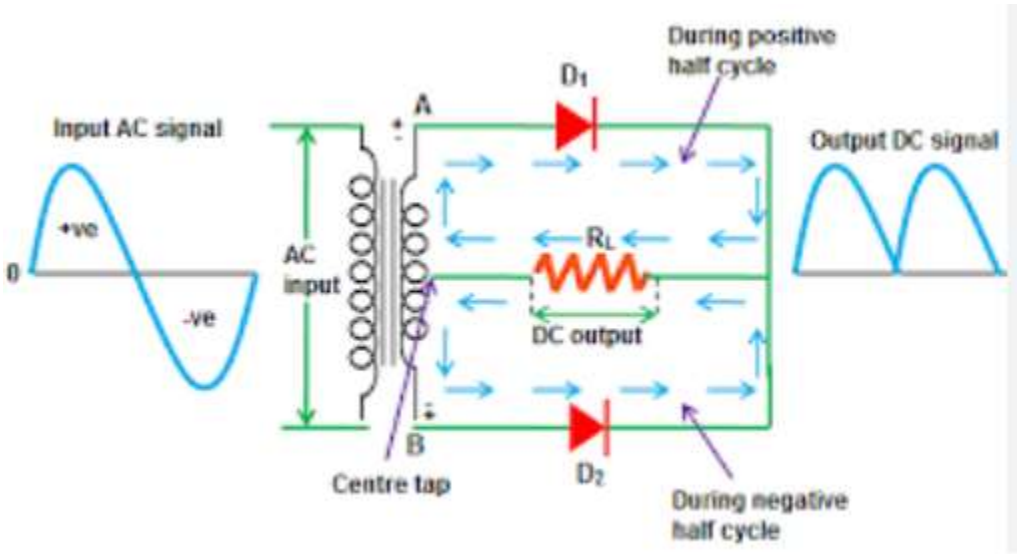
Half wave rectification

In half wave rectifier only one half of the cycle of ac voltage is taking part or converted into dc voltage or current.



Full wave rectification

For a full wave rectification two diodes are used, one for each half of the cycle to convert all the input AC signals into DC output signals and it is more efficient.



Transistors

Transistor is a three terminal semiconductor electronic device widely used in electronic appliances such as computers, radios, audio video equipment, medical instruments, etc. The terminals are called base (B), collector (C) and emitter (E).

Generally there are two basic categories of transistors. These are

a. *Field effect transistor (FET): it is voltage controlled transistor.*

b. *Bi-polar junction transistor (BJT): it is current controlled transistor.*

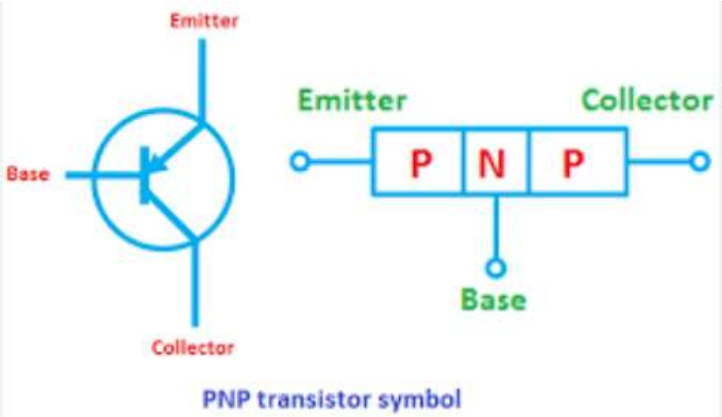
Bi-polar junction transistor (BJT)

It is a three terminal semiconductor device consisting of two p-n junctions which is able to amplify or magnify a signal which is controlled by sandwiching one semiconducting material between two semiconducting materials. BJT is a current controlled device. There are two types BJT these are;

- *PNP transistor*
- *NPN transistor*

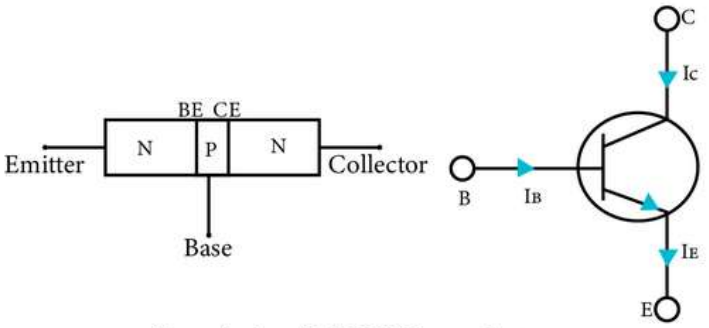
PNP transistor

In this type of bipolar junction transistor n-type semiconductor is sandwiched between two p-type semiconductor layers.



NPN transistor

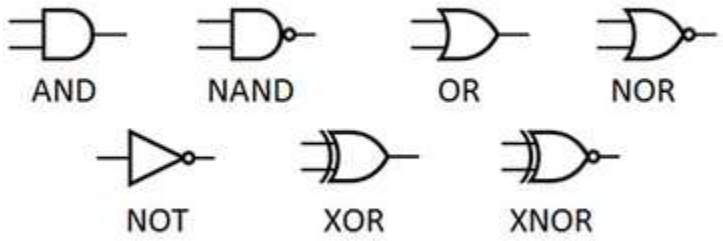
In this type of transistor a p-type semiconductor is sandwiched between two pieces of n-type semiconductor layers.



Symbol of NPN Transistor

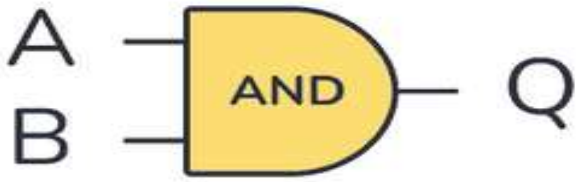
Logic gates

Logic gates are tiny silicon chips on which are etched combination of transistors. They constitute the foundation block for digital logic and digital circuits. Digital systems are said to be constructed by using logic gates. The common logic gates are AND gate, OR gate, NAND gate, NOR gate, EXOR gate and EXNOR gate.



AND gate

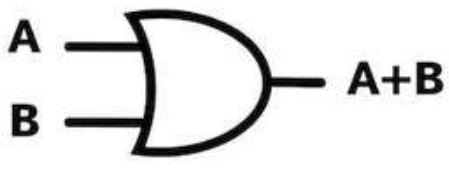
An AND gate has two or more inputs and produce one output. It gives a high output (1) only if all the inputs are high (1).



A	B	Q
0	0	0
0	1	0
1	0	0
1	1	1

OR gate

An OR gate also has two or more inputs and produce one output. It gives a high output (1) if one or more inputs are high (1).

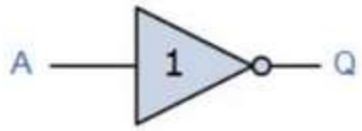


2 input OR gate

A	B	A+B
0	0	0
0	1	1
1	0	1
1	1	1

NOT gate

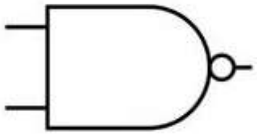
A NOT gate has one input and one output. It produces an inverted version of the input, it is also known as an inverter. For the input of a high (1) the inverted output is low (0) and vice versa.

Symbol	Truth Table	
 Inverter or NOT Gate	A	Q
	0	1
	1	0

NAND gate

The NAND gate has two or more inputs and produces one output. It is NOT-AND gate which is equivalent to an AND gate followed by a NOT gate. The outputs of all NAND gates are high (1) if any of the inputs are low (0). The symbol is an AND gate with small circle on the output, the small circle represents inversion.

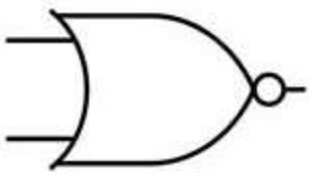
NAND



A	B	Output
0	0	1
1	0	1
0	1	1
1	1	0

NOR gate

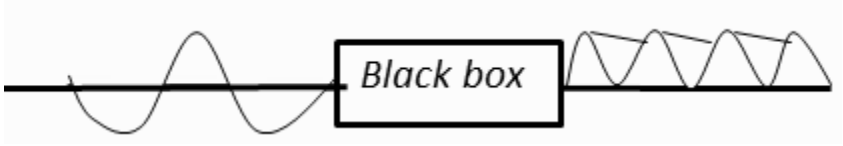
The NOR gate has two or more inputs and produce one output. This is a NOT-OR gate which is equal to an OR gate followed by NOT gate. The output of all NOR gates are low (0) if any of the inputs are high (1). The symbol is an OR gates with small circle on the output represents an inversion.



A	B	Output
0	0	1
1	0	0
0	1	0
1	1	0

Review questions

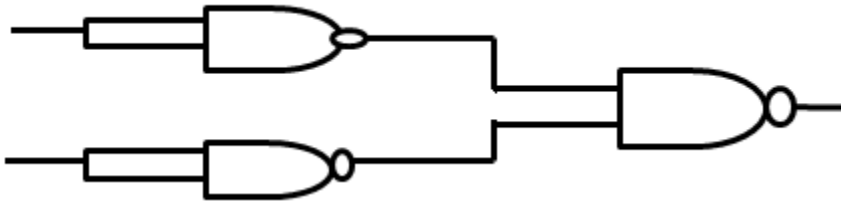
1. *All of the following are vacuum tube devices EXCEPT*
   - *A. X−ray machine*
   - *C. Thermionic diode*
   - *B. Transistor*
   - *D. Cathode ray oscilloscope*
2. *Which one of the following is correct about charge carriers in an intrinsic semiconductor?*
   - *A. There is large number of free electrons than holes at room temperature.*
   - *B. There is large number of holes than free electrons at room temperature.*
   - *C. There are only free electrons no holes in it at room temperature.*
   - *D. There are equal number of free electrons and holes at room temperature.*
3. *Which of the following is true about semiconductors?*
   - *A. Number of charge carriers in semiconductors decreases with temperature.*
   - *B. At a certain temperature semiconductors have positive and negative charge carriers.*
   - *C. Conduction in semiconductors is due to free electrons.*
   - *D. Semiconductors have positive charge carriers.*
4. *The diagram below shows an input alternating current to a "black box" and the resulting output current. The "black box" most likely is*



   - *A. Transistor*
   - *C. Bridge rectifier with capacitor filter*
   - *B. Capacitor*
   - *D. Diode with capacitor filter*
5. *The objective of adding impurity atoms to a pure semiconductor crystal is*
   - *A. To make the crystal impure.*
   - *B. To increase the number of minority carriers.*
   - *C. To decrease the resistance of the crystal.*

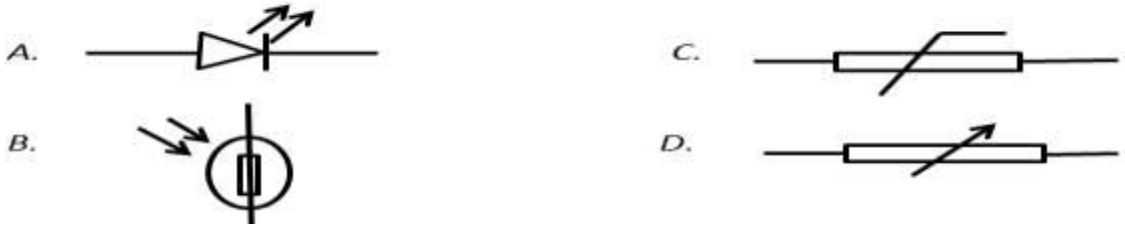
D. *To decrease the number of majority carriers.*

6. *The emission of conduction electrons from the hot metal in a diode value is known as*
   A. *Vacuum emission* C. *Electron emission*
   B. *Thermionic emission* D. *Charge emission*
7. *The diagram below represents a combination of logic gates*

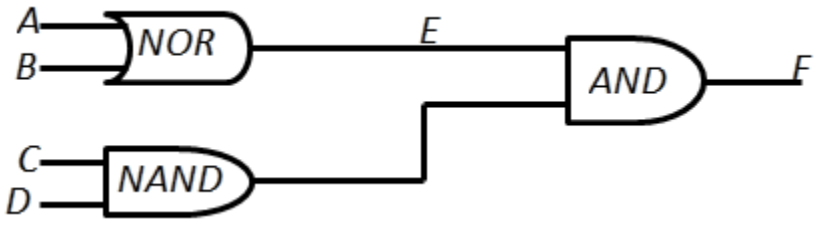


Which one of the following gates is equivalent to the above combination?
A. *AND* B. *OR* C. *NOR* D. *NOT*

8. *When a p-n junction is forward biased*
   A. *Electron flows from p-type to n-type.*
   B. *Current cannot flow through the diode.*
   C. *The depletion layer size decreases.*
   D. *The depletion layer size increases.*
9. *Which symbol of the circuit represents light-dependent resistor (LDR)?*



10. *The following diagram shows the logic gates*



If the inputs at points A, B, C are all 0 and at point D, are 1, what will be the outputs at point E and F respectively?
A. *0,1* C. *1,1*
B. *1,0* D. *0,0*

ANSWER KEY FOR REVIEW QUESTIONS

Unit 1 Physics and measurement

No	Answer	No	Answer	No	Answer
1	D	11	D	21	D
2	D	12	A	22	A
3	B	13	A	23	C
4	B	14	A	24	C
5	B	15	B	25	A
6	A	16	C	26	C
7	D	17	A	27	C
8	A	18	A	28	C
9	D	19	D	29	B
10	D	20	C	30	D

Unit 2 Motion in 1D and 2D

No	Answer	No	Answer	No	Answer
1	B	11	D	21	C
2	B	12	C	22	D
3	B	13	D	23	D
4	A	14	C	24	A
5	A	15	D	25	A
6	D	16	C	26	B
7	B	17	C	27	A
8	C	18	B	28	D
9	C	19	C	29	B
10	A	20	D	30	A

Unit 5 Simple Machine

No	*Answer*	*No*	*Answer*	*No*	*Answer*
1	*B*	*11*	*C*	*21*	*C*
2	*A*	*12*	*C*	*22*	*B*
3	*D*	*13*	*C*	*23*	*C*
4	*C*	*14*	*C*	*24*	*A*
5	*A*	*15*	*B*	*25*	*D*
6	*A*	*16*	*C*	*26*	*A*
7	*C*	*17*	*B*	*27*	*B*
8	*B*	*18*	*D*	*28*	*B*
9	*C*	*19*	*B*	*29*	*B*
10	*A*	*20*	*D*	*30*	*C*

Unit 3: Dynamics

1. C
2. B
3. B
4. B
5. C
6. A
7. B
8. C
9. D
10. A
11. C
12. A
13. D
14. A

Unit 4: Work energy

1. B
2. C
3. A
4. C
5. B
6. C
7. D
8. C
9. D
10. B

Unit 9: Electrostatics

1. B
2. D
3. D
4. D
5. D
6. A
7. C
8. D

Unit 11: Magnetism

1. C
2. B
3. A
4. D
5. C
6. A
7. C
8. D
9. D
10. A
11. B
12. D
13. D
14. A
15. C

Unit7: Temperature and Heat

No	*Answer*	*No*	*Answer*	*No*	*Answer*
1	*C*	*11*	*B*	*21*	*B*
2	*D*	*12*	*A*	*22*	*A*
3	*B*	*13*	*C*	*23*	*D*
4	*A*	*14*	*B*	*24*	*B*
5	*D*	*15*	*A*	*25*	*D*
6	*A*	*16*	*A*	*26*	*C*
7	*A*	*17*	*C*	*27*	*C*
8	*D*	*18*	*C*	*28*	*A*

9	*B*	*19*	*D*	*29*	*B*
10	*B*	*20*	*B*	*30*	*B*

Workout

1. $\Delta V = 0.576 cm^3$
2. A = 59.4cm
3. Q_t = 3057KJ
4. Tm = 3.3^0c
5. Tm = 200K
6. 1/3
7. M = 15kg
8. Q = 244.78 J
9. $\frac{m}{\Delta t}$ = 198.4kg/min
10. e = 189.87

Unit 8: Wave motion, Sound & EM wave & geometrical optics

No	*Answer*	*No*	*Answer*	*No*	*Answer*
1	*D*	*11*	*B*	*21*	*A*
2	*C*	*12*	*C*	*22*	*C*
3	*D*	*13*	*A*	*23*	*B*
4	*A*	*14*	*A*	*24*	*D*
5	*D*	*15*	*D*	*25*	*A*
6	*C*	*16*	*D*	*26*	*A*
7	*C*	*17*	*C*	*27*	*A*
8	*C*	*18*	*C*	*28*	*C*
9	*A*	*19*	*A*	*29*	*C*
10	*A*	*20*	*A*	*30*	*D*