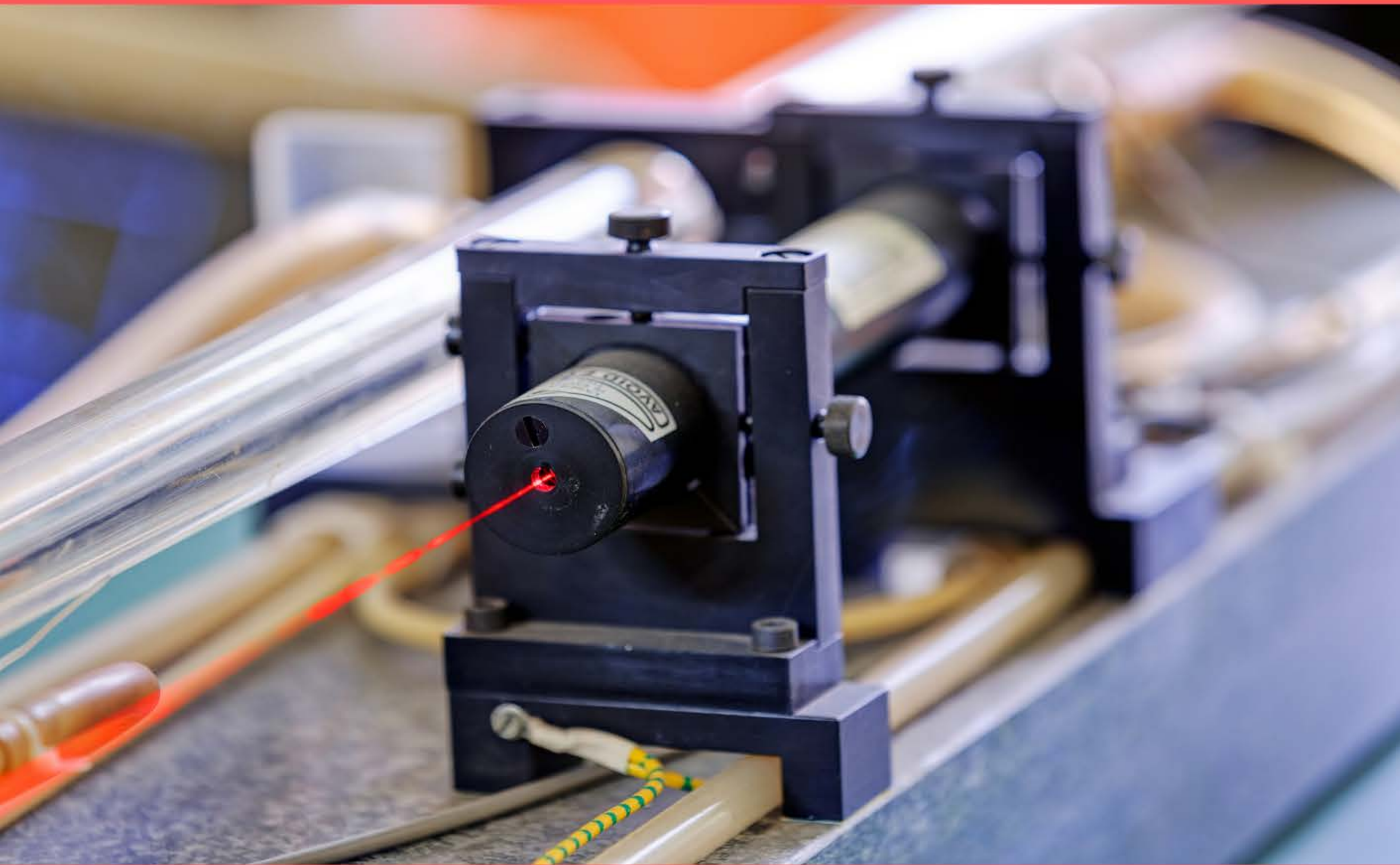
PHYSICS

For
Senior Secondary School

2



EDUBASE

SS2 FIRST TERM NOTES ON PHYSICS

TABLE OF CONTENTS

FIRST TERM

WEEK 1

Topic: CONCEPT OF POSITION, DISTANCE AND DISPLACEMENT IN RELATION TO X – Y PLANE.

The position of a point in space is determined by its distance and direction from other points. The statement of position is accomplished by the means of a frame of reference or a point of reference, which we shall call the origin.

In order to locate the position of a point in a plane (such as a blackboard, the wall of a room, or a drawing paper), it is customary to draw two lines intersecting at an origin O and perpendicular to each other.

More on Position: The position of a point is the distance between two perpendicular lines. The lines are called x – axis and y – axis and their intersection is called the origin. The axis –x is called the x – co-ordinate or the abscissa and the y – co-ordinate is called the ordinate. The abscissa is written next to the ordinate e.g. A (x, y), B (10, 3), C (2, 4) etc.

Distance is one of those innate concepts that does not seem to require explanation. Nevertheless, a preliminary definition might be that distance is a measure of the interval between two locations. (This is not the final definition.) The distance is the answer to the question, "How far is it from this to that or between this and that?"

How far is it	Possible answer	Standard answer
Earth to sun	1 astronomical unit	1.496×10^{11}m
New York to Tokyo	6740 miles	1.084×10^{7} m
Heel to toe on my foot	11 inches	0.28 m

You get the idea. The odd thing is that sometimes we state distances as times. In casual conversation, it's often all right to state distances this way, but in most of physics this is unacceptable, except in Cosmology, where distances are sometimes expressed in terms of light-years. (This is the distance light travels in one year.

Displacement

That being said, let me deconstruct the definition of distance I just gave you. If I walk around my desk, how far have I gone?

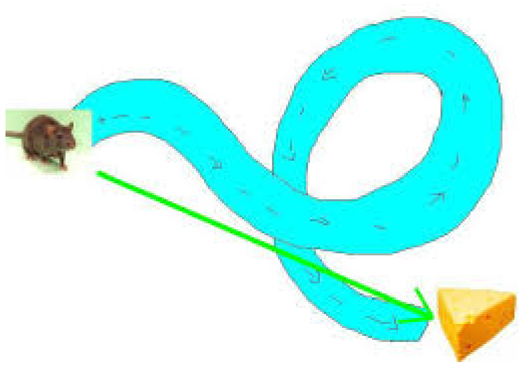
There are two ways to answer this question. On one hand, there's the sum of the smaller motions that I made: assuming path traversed as two meters east, two meters south, two meters west; resulting in a total walk of six meters. On the other hand, the end point of my walk is two meters to the south of my starting point. So which answer is correct? Well, both. The question is ambiguous and depends on whether the questioner meant to ask for the distance or displacement.

Let's clarify by defining each of these words more precisely.

Distance is a scalar measure of the interval between two locations measured along the actual path connecting them.

Displacement is a vector measure of the interval between two locations measured along the shortest path connecting them.

How far does the earth travel in one year? In terms of distance, quite far (the circumference of the earth's orbit is nearly one trillion meters), but in terms of displacement, not far at all (zero, actually). At the end of a year's time the earth is right back where it started from. It hasn't gone anywhere.



Consider the image above.

1. The mouse has the bread as its target.

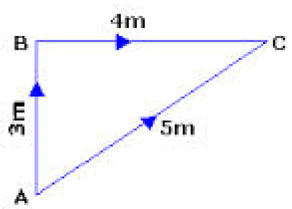
2. The charted path to get to the bread is in green, which is the distance to cover.

3. Yet, the arrow gives the actual displacement between the mouse and the aimed bread.

The safe path (distance) to toe by the mouse is actually longer than the mouse sees (displacement) the bread from where it is.

So, what is distance and what is displacement?

Distance is the length of the path covered in the of motion of a object while Displacement is the length of the straight line between the initial position of the object before movement (or motion) and final position of the object after movement with the direction.



Distance and displacement

Like in the above diagram, movement happened from A to C through B (A to B and then B to C). In this case, Distance is 7 meters (length of the path covered = sum of length AB and length of BC). Although, displacement is 5 meters in the direction of AC (Length of line segment between initial position, A and final position, C = Length of the line segment AC).

Can Displacement be Negative?

Yes, displacement can be negative. If the movement is in the opposite of reference direction, the displacement magnitude will be negative.
A displacement of 10 miles in East direction is same as displacement of -10 miles in West direction since East and West are exactly opposite.

Questions:

Gabby starts at point A and walks 4m to the left and arrives at point B. Then she turns around and walks back to point A from point B. Because point A is 4m from point B.

1. What is the displacement?

A. 8 B. 4 C. 0 D 16

2. What is the distance covered?

A. 8 B. 4 C. 0 D 16.

3**. A girl leaves a history classroom and walks 10 meters north to a drinking fountain. Then she turns and walks 30 meters south to an art classroom. What is the girl's total displacement from the history classroom to the art classroom?**

A. 20 m South B. 20 m North C. 40 m North D. 40 m South

4. **A car travels 20. meters east in 1.0 second. The displacement of the car at the end of this 1.0-second interval is**

A. 20 m/s B. 20 m C. 20 m east D. 20 m/s east

5**. A softball player leaves the batter's box, overruns first base by 3.0 meters, and then returns to first base. Compared to the total distance traveled by the player, the magnitude of the player's total displacement from the batter's box is**

A. Smaller B. Larger C. The same

Answers:

1. C 2. A 3. A 4. D 5. C

Week 2

Topic: SCALAR AND VECTOR QUANTITIES

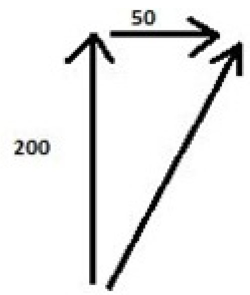
Concept of Scalar and Vector Quantities

A scalar is a measure of something that has only a **magnitude** to define it. A 10 meter length of cable is sufficient to define the length, whether we move it 2 meters to the left or 5 meters to the right. Also, 30 seconds is a scalar, and so is 25 degrees Celsius, and 30 liters. The magnitudes of these quantities are all that are needed to define them. Maybe to better understand that, we need to consider **vectors** as well…

Vectors are quantities that are defined by their magnitude and their direction. This is the CRITICAL point to differentiate the two. Velocity is defined by the magnitude, but also requires the direction. If you are moving 10 m/s, you are moving 10 m/s in some direction. This direction is required to fully define your velocity. The same is true when working with forces. You exert a **magnitude** of force in some **direction**, which fully defines the force. You can say that vectors are made up of a scalar component and a direction component. Of the two, **scalars** are the simpler quantity.

Run for 20 seconds, and then run for another 20 seconds, and you have run 40 seconds. Add 1 cup of water, and then add 2 cups, and you have added 3 cups. Since scalars are just composed of magnitude, you can simply operate on them as you always have. In fact, a lot of the math you have ever done, without problems, has been working with scalar quantities. As I said, just adding a fancy name doesn't make it any more difficult.

Working with vectors, however, is slightly more complex. You must always consider the direction component when doing the math. Introductorily we use example of airplanes flying to demonstrate vectors. If the plane is flying 200 mph straight north (a vector), and the wind is blowing 50 mph straight east (another vector), you can imagine that the combined effect is that the plane is flying slightly at an angle rather than completely north. Actually, you can determine that the plane is actually travelling 206 mph in a direction of 14 degrees east of straight north, using simple trigonometry that you have already studied!



Hopefully, this post has more clearly explained the difference between scalar and vector quantities.

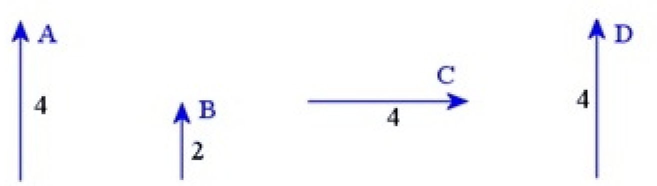
Vector Representation

We will use a **bold capital letter** to name vectors. For example, a force vector could be written as **F**. Some textbooks write vectors using an arrow above the vector name, like this:

You will also see vectors written using matrix-like notation. For example, the vector acting from (0, 0) in the direction of the point (2, 3) can be written

A vector is drawn using an **arrow**. The **length** of the arrow indicates the **magnitude** of the vector. The **direction** of the vector is represented by the direction of the arrow.

Example 1 – Vectors



The displacement vector **A** has direction 'up' and a magnitude of 4 cm. Vector **B** has the same direction as **A**, and has half the magnitude (2 cm).

Vector **C** has the same magnitude as **A** (4 units), but it has different **direction**. Vector **D** is equivalent to vector **A**. It has the same magnitude and the same direction. It doesn't matter that **A** is in a different position to **D** – they are still considered to be **equivalent vectors** because they have the same magnitude and same direction. We can write:

A = **D**

Note: We **cannot** write **A = C** because even though **A** and **C** have the same magnitude (4 cm), they have different direction. They are not equivalent.

Free and Localized Vectors

So far we have seen examples of "free" vectors. We draw them without any fixed position.

Another way of representing vectors is to use **directed line segments.** This means the vector is named using an **initial point** and a **terminal point**. Such a vector is called a "localized vector".

Example 2 – Localized Vectors

A vector **OP** has initial point **O** and terminal point **P**. When using directed line segments, we still use an arrow for the drawing, with **P** at the arrow end. The length of the line OP is an indication of the magnitude of the vector.

We could have another vector **RS** as follows. It has initial point **R** and terminal point **S**.

Because the 2 vectors have the same magnitude and the same direction (they are both horizontal and pointing to the right), then we say they are equal. We would write:

OP = **RS**

Note that we can move vectors around in space and as long as they have the same vector magnitude and the same direction, then they are considered **equal vectors**.

Magnitude of a Vector

We indicate the **magnitude** of a vector using **vertical lines** on either side of the vector name.

The magnitude of vector **PQ** is written |**PQ**|.

So for example, vector **A** above has magnitude 4 units. We would write the magnitude of vector **A** as:

| A | =4

Vectors in Opposite Directions

We have 2 teams playing a tug-of-war match. At the beginning of the game, they are very evenly matched and are pulling with equal force in opposite directions. We could name the vectors **OA** and **OB**.

We can represent the tug of war using a vector diagram:

We note that the **magnitude** of each vector is the same, but they are acting in **opposite directions**. In such a case, we indicate the opposite directions by use of a **negative sign**.

So we write:

OA = −**OB**

Zero Vectors

A **zero vector** has magnitude of 0. It can have any direction.

A vector may have zero magnitude at an instance in time. For example, a boat bobbing up and down in the water will have a **positive** velocity vector when moving up, and a **negative** velocity vector when moving down. At the instant when it is at the top of its motion, the magnitude is **zero**.

In the tug-of-war example above, the teams are evenly matched at a certain instant and neither side is able to move. In this case, we would have:

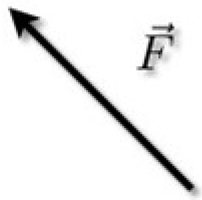
OA + **OB** = **0**

The 2 force vectors **OA** and **OB**, operating in opposite directions, cancel each other out.

Recently, I was talking about vectors. At that time, I had to stop and recall how I had been representing vectors. Ideally, I should stick with the same notation I used in Basics: Vectors and Vector Addition. But let me go over the different ways you could represent a vector.

Graphical

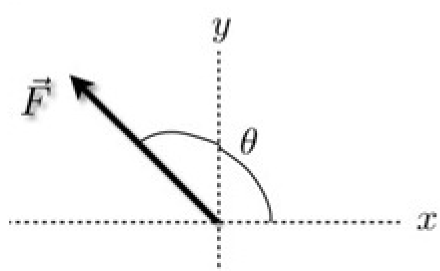
Maybe this is too obvious, but it had to be said. You can represent vectors by drawing them. In fact, this is very useful conceptually – but maybe not too useful for calculations. When a vector is represented graphically, its magnitude is represented by the length of an arrow and its direction is represented by the direction of the arrow. Here is an example:



I think the biggest negative to this representation (other than being difficult to get numerical answers for adding) is that it is not too easy to represent in 3-dimensions. For the following representations, I will try to relate them to the graphical representation.

Magnitude and Direction

In algebra-based courses, maybe this format is popular. Basically, you just give the magnitude of the vector and the angle (from the positive x-axis) that the vector is pointing. Here is an example (using the same vector from before):



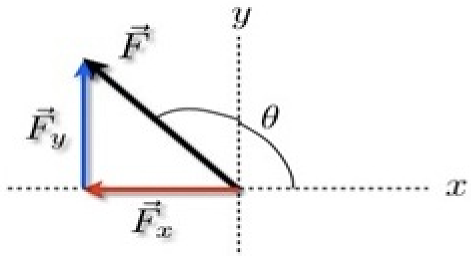
And in magnitude-direction format, it would be:

F = 14N

q = 135^0

I am not too fond of this format. First, if you want to add vectors, you need to find components. Second, students often get confused with this angle always being measured from the same axis (it doesn't have to be the x-axis, that is just what is common). Oh, if you want to do this for a 3-D vector, it really isn't worth it. You would need two angles. Well, in some cases it might be worth it.

With the component method, the idea is to just give the amount the vector is in each of the coordinate directions. Here is an example.



I wrote these components as vectors so that:

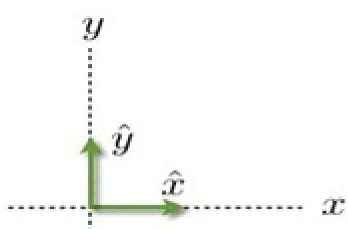
$F = F_x + F_y$

Often you will see textbooks sort of stop here. In this case they may say something like:

$F_x = \cos(135^0)(14N) = -9.9\ N$

$F_y = \sin(135^0)(14N) = 9.9\ N$

It is important to realize that this notation is NOT the magnitude of the vector F_x and F_y. The magnitude of a vector has to be a positive number. To really use these, you need unit vectors. This is what they look like:



The little ^ over the x means that it is a unit vector. *A unit vector is a vector that has a magnitude of 1 with no units.* This means that the F_x vector could be written as:

$$\vec{F}_x = |\vec{F}|\cos(\theta)\hat{x}$$

And maybe now you can see why that negative sign is important. The vector F_x is in the opposite direction as the x-hat vector and that is why you need a negative sign. So, using this notation, you could write the vector F as:

$$\vec{F} = (-9.9\ \text{N})\hat{x} + (9.9\ \text{N})\hat{y}$$

Don't forget units though. Vectors have units. Also, this notation can be expanded to three dimensions by adding a z-hat or k-hat component. Another nice thing is that these vectors are all set up and ready to add. If you have a vector in component notation you are ready to rock.

I guess the reason textbooks use the magnitude-direction format some is that it may be easier to relate to real life. In real life, I would measure the magnitude and direction of a force and then have to calculate the components.

Addition of Scalars and Vectors

Scalars can be added algebraically. However, vectors do not obey the ordinary laws of algebra. This is because vectors possess both magnitude and direction. Vectors are added geometrically. The process of adding two or more vectors is known as addition or composition of vectors. When two or more vectors are added, the result is a single vector called the resultant vector.

The resultant of two or more vectors is that single vector which alone produces the same effect as that produced by the two individual vectors.

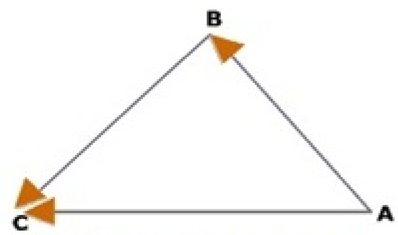
Three laws have been evolved for the addition of vectors:

Triangle law of vectors for addition of two vectors

Parallelogram law of vectors for addition of two vectors

Polygon law of vectors for addition of more than two vectors

Triangle Law of Vectors : Let a particle be at the points A, B, C at three successive times t, t' and t" respectively. *AB*→ is the displacement vector from time t to t'. *BC*→ is the displacement vector from time t' to t". The total displacement vector $\vec{AC}$ is the sum or the resultant of individual displacement vector $\vec{AB}$ and $\vec{BC}$.



Triangle law of vectors

$\therefore \vec{AC} = \vec{AB} + \vec{BC}$

This leads to the statement of the law of triangle of vectors.

If two vectors can be represented both in magnitude and direction by the two sides of a triangle taken in the same order, then the resultant is represented completely, both in magnitude and direction, by the third side of the triangle taken in the **opposite order.**

Vector Addition

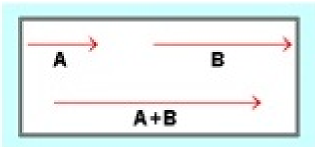
Vector addition is defined as a quantity having both magnitude and direction is called a vector. For examples: displacement, velocity, moment of a force, weight etc. Vectors are denoted by directed line segments such that the length of the line segment is the magnitude of the vector and the direction of arrow marked at one end denotes the direction of the vector.

A vector whose initial and last points are coincident is called a zero or null or a void vector. A vector, whose modulus is unity, is called a unit vector. Vectors are said to be like when they have the same sense of direction and unlike when they have opposite directions. Vectors are said to be collinear points or parallel if they have the same line of action or have the lines of action parallel to one another.

If $\vec{OA}$ and $\vec{OB}$ are the position vectors of A and B, then $\vec{AB} = \vec{OB} - \vec{OA}$

Vector Addition Formula

If we have two vectors say A and B with the same direction then the addition of them is equal to the sum of their magnitude and will have the same direction.

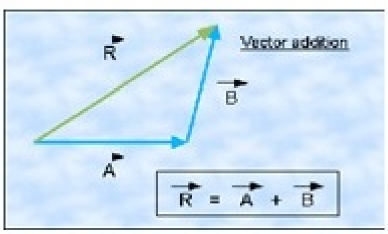


Vector addition can take place by triangle law, parallelogram law and Polygon law.

Triangle Law for Addition of Two Vectors:

Vectors are physical quantities that are completely described by their magnitude and direction in space. Vector sum of vectors can be done by using triangle law.

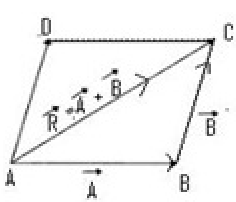
If there are two vectors $\vec{A}$ and $\vec{B}$, their sum $\vec{R}$ can be calculated by the triangle method as follows:



Properties of Vector Addition

Commutative Law

Consider two vectors $\vec{A}$ and $\vec{B}$. Let these vectors represent two adjacent sides of a parallelogram ABCD. The diagonal AC represents the resultant vector $\vec{R}$.



$\vec{R}$ is the sum of vectors $\vec{A}$ and $\vec{B}$. That is,

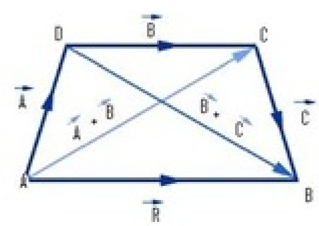
$\vec{R} = \vec{A} + \vec{B}$

$\vec{R} = \vec{B} + \vec{A}$

$\vec{A} + \vec{B} = \vec{B} + \vec{A}$

Associative Law

The law states that the sum of vectors remains same irrespective of their order or grouping in which they are arranged. Consider three vectors $\vec{A}$, $\vec{B}$ and $\vec{C}$. Let the resultant of $\vec{A}+\vec{B}$ and $\vec{B}$ and $\vec{c}$ is $\vec{R}$.



Resultant of these three vectors can be

$\vec{AB} = \vec{AD} + \vec{DB}$

$\vec{R} = \vec{A} + (\vec{B} + \vec{C})$ ……………….(i)

and

$\vec{AB} = \vec{AC} + \vec{CB}$

$\vec{R} = (\vec{A} + \vec{B}) + \vec{C}$ …………………(ii)

From (i) and (ii), we have

$\vec{A} + (\vec{B} + \vec{C}) = (\vec{A} + \vec{B}) + \vec{C}$

Distributive Law

n(A + B) = nA + nB

(m + n)A = mA + nA where m, n be any scalar quantities.

Component Method of Vector Addition

The Component method vector addition is one of the ways to add vectors. Vector addition is just like ordinary addition like component by component. Vectors are added by component method are displacement vectors. Component of vector means the part of a vector mainly we use x-part and y-part or also called its x-component and its y-component. Here we will see how to add x-component and the y-component of vectors.

Component Method for Adding Vectors:

Know the size and direction of two vectors.

Find the x and y components for the first vector.

Find the x and y components for the second vector.

Add the x-component for the first vector to the x-component from the second vector. Which give the sum of x-component.

Add the y-component from the first vector to the y-component from the second. Which give the sum of y-component, we get the sum of components of two vectors.

Use the x and y components of the sum as legs to right angle triangle, which shows the addition of these vectors, using Pythagoras theorem, find the hypotenuse. This is the resultant of vectors.

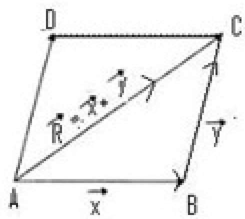
Use the inverse tangent to find the angle of this triangle, angle shows the direction of the resultant.

Finally we know the size and direction for the sum of two vectors.

Parallelogram Law of Vector Addition

Addition of two vectors may take place with the help of the parallelogram law of vector addition, according to which resultant of two vectors is the diagonal of the parallelogram of which vectors are adjacent sides of parallelogram.

Let x and y be the two vectors which represents the adjacent sides of the parallelogram ABCD and R be the resultant vector of vectors. According to law, we have

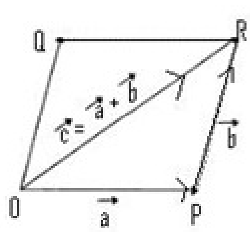


$\vec{R} = \vec{x} + \vec{y}$

Graphical Vector Addition

To add vector graphically, first position them without changing their length and direction so that, the initial point of the second vector $\vec{a}$ coincides with the terminal point of the first vector. The sum $\vec{a+b}$ is the vector formed by joining the initial point of the first $\vec{a}$ with the terminal point of the second $\vec{b}$. Also called Parallelogram law of vector addition because the $\vec{a+b}$ is the resultant of the vector addition, where $\vec{a}$ and $\vec{b}$ are adjacent sides of parallelogram.

If two vectors $\vec{a}$ and $\vec{b}$ are denoted in magnitude and direction by the two adjacent sides of a parallelogram, then their sum $\vec{c} = \vec{a+b}$ is denoted by the diagonal of the parallelogram which is co-initial with the given vectors.



Symbolically we have $\vec{OP} + \vec{PR} = \vec{OR}$

Thus if the vectors are denoted by two adjacent sides of a parallelogram, the diagonal of the parallelogram will represent the sum of the vectors. By repeated use of the triangle law we can find the sum of any number of vectors Let $\vec{OP} = \vec{a}$, $\vec{PR} = \vec{b}$, $\vec{RQ} = \vec{c}$

We observe from the figure that each new vector is drawn from the last point of its previous one.

hus the line joining the initial point of the first vector to the last point of the last vector is the sum of all the vectors. This is called the polygon law of addition of vectors.

Questions:

If the distance he covered in the northern direction is 4km and the eastern direction is 3km, determine

1. The magnitude of his resultant

A. 5km B 6km C. 7km D. 7km

2. His direction

A. 36^0 B. 37.78^0 C. 36.86^0 D. 40^0

3. Scalar quantities are only concerned with

A. Direction B. Magnitude C. Magnitude and Direction D. Length and Direction

A nail on a vertical wall is pulled by means of a cord attached to its head. If the cord makes an angle of 60^0 to the horizontal and it exerts a force of 80N on the nail, find

4. The effective force which tends to pull the nail out of the wall

A. 40 N B. 50 N C. 30 N D. 45 N

5. The force which tends to bend the nail.

A. 72.76 N B. 69.28 N C. 80 N D. 45.65 N

Answers:

1. A 2. C 3. B 4. A 5. B

WEEK 3

Topic: DERIVATION OF EQUATION OF LINEAR MOTION

Equations of Motion

The variable quantities in a uniformly accelerated rectilinear motion are time, speed, distance covered and acceleration. Simple relations exist between these quantities. These relations are expressed in terms of equations called equations of motion.

There are three equations of motion.

1) $v = u+at$
2) $S = ut + 12\ at^2$
3) $v^2 = u^2 + 2as$

Where,
v = Final Velocity
u = Initial velocity
a = acceleration
s = distance traveled by a body
t = time taken.

Derivation of Equation of Motion

$V = s/t$

$A = (v – u)/t$

$at = v-u$

$\Rightarrow v-u = at$

$\Rightarrow v= u + at$ (1)

This is Newton's First equation of motion. As you can you see, we can use this equation to calculate the velocity of a body which underwent an acceleration of a m/s for a time period of t seconds, provided we know the initial velocity of the body. Initial velocity i.e. u is the velocity of the body just before the body started to accelerate i.e. the velocity at t=0.

In case, the body started to accelerate from rest then we can substitute the value of initial velocity to be u = 0.

We sometimes also may want to find the total distance traveled by moving body. A moving body might be either moving with a uniform velocity or with a uniform acceleration or even with a non-uniform acceleration.

In case of a body moving with a uniform velocity v, it is quite simple to calculate the total distance **s** traveled by the body in a time t. we know that

Velocity = distance traveled / time taken

$v = s/t$

$\Rightarrow s = vt$

Thus, distance traveled = velocity x time

Now the situation is slightly different for a body moving with a uniform acceleration a. To calculate the distance traveled by an uniformly accelerating body, we derive the equation as follows.

If u is the initial velocity of a uniformly accelerating body and v is its velocity after a time t, then since the acceleration is UNIFORM, we can find the average velocity of the body as follows

Average velocity = $(u+v)/2$

Now, the distance **s**, traveled in the time t by the body is given by

Distance traveled = average velocity x time

$s = [(u+v)/2]t$

From equation (1) we have $v = u+at$, substituting this in the above equation for v, we get

$s = [(u+u+at)/2]t$

$\Rightarrow s = [(2u+at)/2]t$

$\Rightarrow s = [(u + (1/2)at)]t$

$\Rightarrow s = ut + (1/2)at^2$ – (2)

This is Newton's second equation of Motion. This equation can be used to calculate the distance traveled by a body moving with a uniform acceleration in a time t. Again here, if the body started from rest, then we shall substitute $u = 0$ in this equation.

If you take a close look at the 2 equations of motion we derived just now you can observe that none of these equations carry a relation between distance traveled and final velocity of the body. All other relations are available. So, there is a need to find an equation which relates s and v. We derive it as follows.

We start with squaring equation (1). Thus we have

$v^2 = (u+at)^2$

$\Rightarrow v^2 = u^2 + a^2t^2 + 2uat$

$\Rightarrow v^2 = u^2 + 2uat + a^2t^2$

$\Rightarrow v^2 = u^2 + 2a(ut + (1/2)at^2)$

now, using equation 2 we have

$\Rightarrow v^2 = u^2 + 2as$ – (3)

As you can see, the above equation gives a relation between the final velocity v of the body and the distance s traveled by the body.

Thus, we have the three Newton's equations of Motion as:

(1) $v= u + at$

(2) $s = ut + (1/2)at^2$

(3) $v^2 = u^2 + 2as$

What is motion under Gravity?

The attraction of the earth on the thrown object is called ‘Gravitational attraction’ or ‘gravity’, and the change in velocity of the object, as the result of this attraction, is known as ‘acceleration due to gravity’.

What Effect Does Gravity Have on Motion?

The pull of gravity between two objects depends on more than just the objects. Gravity’s effect also depends on the distance between the objects. Objects that are closer together have a greater attraction between them. The attraction is weaker when they are farther apart. Gravity exists wherever there is mass, such as in stars and planets. The gravity of each of these objects affects other objects in space. Earth’s gravity, for example, reaches millions and millions of kilometers into space. It grows weaker the farther away from Earth you get. Recall that because the moon is less massive than Earth, an astronaut standing on the moon weighs only one-sixth as much as on Earth. The astronaut’s weight would change between Earth and the moon. The effect of Earth’s gravity becomes less as the distance from Earth increases.

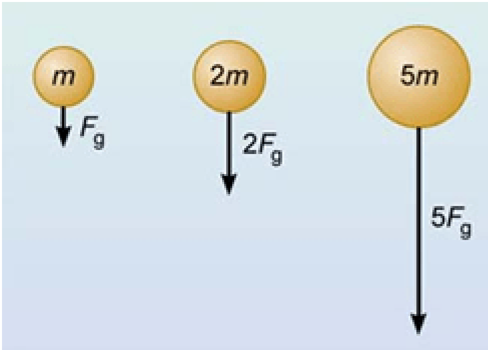
Gravitational force

The gravitational force of attraction exists between objects. This force is the reason you feel yourself pulled towards the Earth.

How does the magnitude of the gravitational force between two objects change when the masses of the objects increase, and when their separation increases?

The gravitational force that you experience depends on the mass of the Earth, and on the separation between you and the mass of the Earth. For a large (approximately) spherical object like the Earth, it is the separation between you and the centre of the Earth that is relevant, and this separation is essentially the same for all objects close to the Earth’s surface.

Does every object on the Earth’s surface experience the same gravitational force?



The above figure shows gravitational force is proportional to mass.

In fact, the gravitational force F_g experienced by an object is *proportional* to its mass *m* (Figure 1), so we can write F_g µ M.

Thus the force of gravity you experience due to the Earth is proportional to your own mass. Someone with a mass of 50 kg experiences only half the gravitational force felt by someone with a mass of 100 kg.

Question

A body starting from rest and executing an accelerated motion covers a distance of 9 cm in 6 seconds. Calculate

1. The acceleration

A. 0.5 m/s^2 B. 1.0 m/s^2 C. 1.7 m/s^2 D. 2.0 m/s^2

2. The final velocity.

A. 4.0 m/s B. 3.0 m/s C. 7 m/s D. 8 m/s

A bullet is fired vertically with an initial velocity of 29.4 m/s

3. How high will it reach?

A. 34 m B. 54.7 m C. 30.9 m D. 44.1 m

4. What is the time taken to reach that height?

A. 5 secs B. 3 secs C. 4.5 secs D. 9.5 secs

5. A body of mass 2kg falls freely from rest through a height of 50 m and comes to rest having penetrated 5.0 cm of sand.

Calculate the velocity with which the body hits the sand.

A. 46 ms^{-1} B. 76 ms^{-1} C. 31.62 ms^{-1} D. 45.53 ms^{-1}

Answer

1. A 2. B 3. 3. D 4. B 5. C

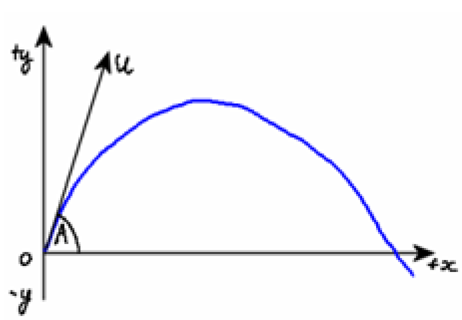
WEEK 4

Topic: PROJECTILE AND ITS APPLICATION

INTRODUCTION

Definition of Projectile Motion: A projectile is anybody that is thrown or projected. The projectile motion has two elements: the horizontal projectile motion and the vertical projectile motion. The path of a projectile object and the projectile motion is captured and illustrated in the diagram below.
A projectile is an object upon which the only force acting is gravity. There are a variety of examples of projectiles. An object dropped from rest is a projectile (provided that the influence of air resistance is negligible). An object that is thrown vertically upward is also a projectile (provided that the influence of air resistance is negligible). And an object which is thrown upward at an angle to the horizontal is also a projectile (provided that the influence of air resistance is negligible). A projectile is any object that once *projected* or dropped continues in motion by its own inertia and is influenced only by the downward force of gravity.

Projectile motion refers to the motion of an object projected into the air at an angle. A few
examples of this include a soccer ball begin kicked, a baseball begin thrown, or an athlete
long jumping. Even fireworks and water fountains are examples of projectile motion.



Path of a projectile showing projectile motion

Consider a projectile launched from 0 (in the projectile motion diagram above) with the initial velocity of magnitude *u* in a direction at angle *A* above the horizontal. 0, u, and A are shown in the projectile motion diagram above. These three variables are often present in projectile motion problems in physics and are used to derive the projection motion equation.

From the graphical diagram of the projectile motion, the formulas of projectile motion are derived as follows. We have previously discussed the definition of projectile motion. There are many ways to study projectile motion in physics. Knowing the formulas for projectile motion and the projectile motion equations help tremendously when solving any projectile motion problems. The analysis below comes from many projectile motion problems and results of projectile motion activities. The results are gathered and developed as physics notes on projectile motion problems.

Deriving formulas of projectile motion

Let **x** denote the horizontal projectile motion or the horizontal component of displacement of the projectile motion.

Let **y** denote the vertical projectile motion or the vertical component of displacement of the projectile motion.

The horizontal projectile motion is analyzed separately from the vertical projectile motion.

Horizontal projectile motion	**Vertical projectile motion**
Initial velocity = u cos A	Initial velocity = u sin A
Acceleration = 0	Acceleration = – g (g = gravity)
Time taken = t	Time taken = t

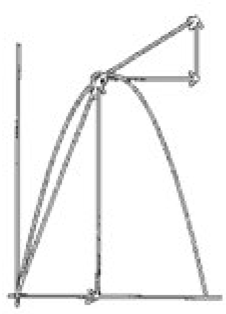
Distance moved = x	Distance moved = y
$x = ut \cos A$	$y = (ut \sin A) – ½ gt^2$
Final speed $v_x = u \cos A$	Final speed $v_y = (u \sin A) – gt$

The horizontal velocity v_x remains constant but the vertical velocity v_y decreases steadily from its initial value at a rate of g (gravity)

Total time taken is $t = 2v_0 \sin q/g$

Maximum Height is $H = v_0 \sin^2 q/2g$

Time of falling equals time of rising i.e. $t_f = t_r;t_r = v_{0y}/g$, distance travelled along the y-axis $y(t) = v_{0y} – gt^2/2$, velocity along the y-axis is $v_y(t) = v_{0y} – gt$.



What follows is a general solution for the two dimensional motion of an object thrown in a gravitational field. This is usually termed a projectile motion problem. The thrown object is called the projectile. Its path is called the trajectory. We will answer all the usual questions that arise in a first year physics class regarding this motion. We will not consider air resistance. Without air resistance, the projectile will follow a parabolic trajectory. We will be throwing the projectile on level ground on planet Earth. It will leave the point of release, arc through the air along a path shaped like a parabola, and then hit ground a certain distance from where it was thrown.

As mentioned above, this is a two dimensional problem. Therefore, we will consider x and y directed displacements, velocities, and accelerations. The projectile will accelerate under the influence of gravity, so its y acceleration will be downward, or negative, and will be equal in size to the acceleration due to gravity on Earth. There will be no acceleration in the x direction since the force of gravity does not act along this axis.

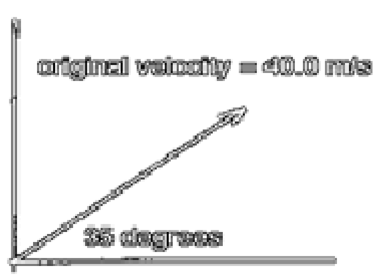
On Earth the acceleration due to gravity is 9.8 m/s^2 directed downward. So, for this presentation acceleration in the y direction, or a_y, will be -9.8 m/s^2, and acceleration in the x direction, or a_x, will be 0.0 m/s^2.

Given the original conditions with which the projectile is thrown we will proceed to find the components of the original velocity and then move on to answer the following questions:

- How much time passes till the projectile is at the top of its flight?
- How high does the projectile rise?
- How much time passes till the projectile strikes the ground?
- How far away does the projectile land from its starting point?

Original or initial conditions:

The original conditions are the size of the velocity and the angle above the horizontal with which the projectile is thrown.



General:

Original size of velocity: v_o, Original angle: q

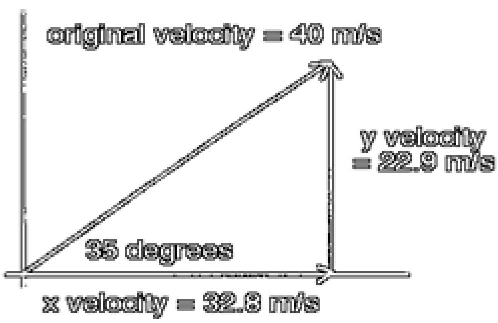
Example:

v_o= 40.0 m/s

q = 35 degrees

Components of original velocity:

The usual first step in this investigation is to find the x and y components for the original velocity.



General:

X component of original velocity: v_{ox}= $v_o$cos(q)

Y component of original velocity: v_{oy}= $v_o$sin(q)

Example:

In the x direction: v_{ox}= $v_o$cos(q)

v_{ox}= (40.0 m/s)(cos(35^0))

v_{ox}= (40.0)(0.8191)

v_{ox}= 32.76

v_{ox}= 32.8 m/s

In the y direction: v_{oy}= $v_o$sin(q)

v_{oy}= (40.0 m/s)(sin(35^0))

v_{oy}= (40.0)(0.5735)

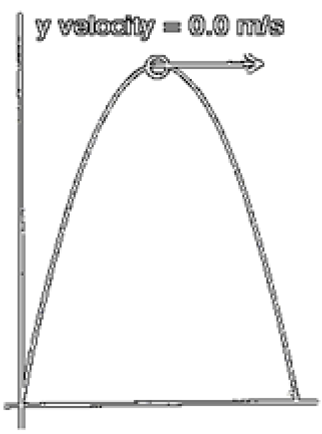
v_{oy}= 22.94

v_{oy}= 22.9 m/s

How much time passes until the projectile is at the top of its trajectory?

At the top of the trajectory the y, or upward, velocity of the projectile will be 0.0 m/s. The object is still moving at this moment, but its velocity is purely horizontal. At the top it is not moving up or down, only across.

Notice that the object is still in motion at the top of the trajectory; however, its velocity is completely horizontal. It has stopped going up and is about to begin going down. Therefore, its y velocity is 0.0 m/s.



We need to find out how much time passes from the time of the throw until the time when the y velocity of the projectile becomes 0.0 m/s. This y velocity at the top of the trajectory can be thought of as the final y velocity for the projectile for the portion of its flight that starts at the throw and ends at the top of the trajectory.

We will call this amount of time 'the half time of flight', since the projectile will spend one half of its time of flight rising to the top of its trajectory. It will spend the second half of its time of flight moving downward.

General:

We can use the following kinematics equation: v_f= v_o+ at

Subscript it for y:

$v_{fy} = v_{oy} + a_y t$

Solve it for t:

$t = (v_{fy} – v_{oy}) / a_y$

Plug in 0.0 m/s for v_{fy}:

$t = (0.0 \text{ m/s} – v_{oy}) / a_y$

If the original y velocity and the y acceleration, i. e., the acceleration due to gravity, are plugged into the above equation, it will solve for the amount of time that passes from the moment of release to the moment when the projectile is at the top of its flight.

Example:

Start with: $t = (v_{fy} – v_{oy}) / a_y$

Plug in 0.0 m/s for v_{fy}:

$t = (0.0 \text{ m/s} – v_{oy}) / a_y$

Plug in values for v_{oy} and a_y:

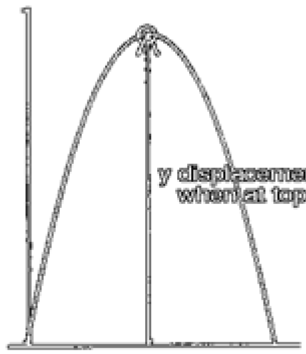
$t = (0.0 \text{ m/s} – 22.9 \text{ m/s}) / – 9.8 \text{ m/s}^2$

$t = -22.9 / -9.8$

$t = 2.3\text{s}$

In this example 2.3s of time passes while the projectile is rising to the top of the trajectory.

How high does the projectile rise?



Here you need to find the displacement in the y direction at the time when the projectile is at the top of its flight. We have just found the time at which the projectile is at the top of its flight. If we plug this time into a kinematics formula that will return the displacement, then we will know how high above ground the projectile is at when it is at the top of its trajectory.

General:

Here is the displacement formula: $d = v_o t + 0.5at^2$

We must think of this displacement in the y direction, so we will subscript this formula for y:

$d_y = v_{oy}t + 0.5a_y t^2$

If now we plug in the half time of flight, which was found above, we will solve for the height of the trajectory, since the projectile is at its maximum height at this time.

Example:

Starting with: $d_y = v_{oy}t + 0.5a_y t^2$

Then plugging in known values:

$d_y = (22.9\text{ m/s})(2.33\text{ s}) + (0.5)(-9.8\text{ m/s}^2)(2.33\text{ s})^2$

$d_y = 53.35 - 26.60$

d_y= 26.75

d_y= 27 m

How much time passes until the projectile strikes the ground?

General:

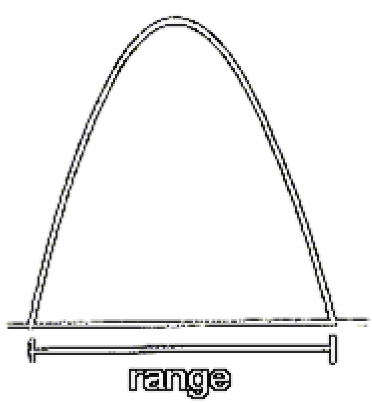
With no air resistance, the projectile will spend an equal amount of time rising to the top of its projectile as it spends falling from the top to the ground. Since we have already found the half time of flight, we need only to double that value to get the total time of flight.

Example:

t = 2(2.33 s) = 4.66 = 4.7 s

This is the total time of flight.

How far away does the projectile land from its starting point?



The distance from the starting point on the ground to the landing point on the ground is called the **range of the trajectory**. This range is a displacement in the x direction. It is governed by the x velocity of the projectile. This x velocity does not change during the flight of the projectile. That is, whatever is the value of the x velocity at the start of the trajectory will be the value of the x velocity throughout the flight of the projectile. The x velocity remains constant because there are no accelerations in the x direction. The only acceleration is in the y direction, and this is due to the vertical pull of gravity. Gravity does not pull horizontally. Therefore, the calculation for the range is simplified.

General:

Let us start with the general displacement formula:

$d = v_o t + 0.5at^2$

Since we are working in the x direction, we should subscript this equation for x:

$d_x = v_{ox}t + 0.5a_x t^2$

Now, since the acceleration in the x direction is 0.0 m/s^2, the second term in the above equation drops out, and we are left with $d_x = v_{ox}t$

The velocity in the x direction does not change. The projectile maintains its original x velocity throughout its entire flight. So, the original x velocity is the only x velocity the projectile will have. We could, therefore, think of the last equation as $d_x = v_x t$

If we plug in the original x velocity for v_x and the total time of flight for t, we will solve for the horizontal displacement, or range, of the trajectory.

Example:

As shown in the general section above, start with $d_x = v_x t$

Plug in values. Remember that the x velocity is constant and always equal to its original value and that the time here is the total time of flight.

$d_x = (32.8 \text{ m/s})(4.66 \text{ s})$

$d_x = 152.84$

$d_x = 150 \text{ m}$

QUESTION

A golfer practicing on a range with an elevated tee 4.9 m above fairway is able to strike a ball so that it leaves the club with a horizontal velocity of 20 m s^{-1}. (Assume the acceleration due to gravity is 9.80 m s^{-2}, and the effects of air resistance may be ignored unless otherwise stated.

1. How long after the ball leaves the club will it land on the fairway?

A. 2.0 s B. 1.0 s C. 3.0 s D. 4.0 s

2. What horizontal distance will the ball travel before striking the fairway?

A. 20 m B. 30 m C. 40 m D. 50 m

3. What is the acceleration of the ball 0.5 s after being hit?

A. 14.6 ms^{-2} B. 9.8 ms^{-2}C. 12 ms^{-2} D. 8.9 ms^{-2}

4. Calculate the speed of the ball 0.80s after it leaves the club.

A. 21.5 ms^{-1} B. 23 ms^{-1} C. 34 ms^{-1} D. 42 ms^{-1}

5. With what speed will the ball strike the ground?

A. 25 ms^{-1} B. 27.3 ms^{-1} C. 26 ms^{-1} D. 22.3 m s^{-1}

Solution

1. B 2. A 3. B 4. A 5. D

WEEK 5

Topic: NEWTON'S LAWS OF MOTION

Newton's First Law of Motion – Idea of Inertia

States that object continues in its states of rest or uniform motion in a straight line unless an external force acts on it.
It is a common experience that a body at rest will remain at rest. For example, a book at rest on top of a table will remain there unless something pushes it or pulls at it. Also as was first pointed out by Galileo, the motion of a body once started, would continue along a straight line path unless some forces cause it to change. This means that a moving object, if left to its self, will move in the same direction forever. That is once a body has been set in motion it is no longer necessary to on it to maintain it in motion. But our everyday experience does not seem to agree with this. We know that any sliding object slows to a stop. Why? Because friction or gravity or other external forces slow moving objects to a stop. But in the absence of any unbalanced force, an object will move forever with the same velocity. It would neither slow down nor deflect.
This tendency of bodies to remain in their state of rest or of uniform linear motion in the absence of applied forces is known as Inertia. Newton's first law shows that inertia is inherent in a body at rest or the one moving in a constant velocity. Inertia is a property of matter. Mass is a measure of inertia, the more massive an object is, the more inertia it has.
Newton's first law explains what force does, but does not suggest how force should be measured.

Newton's Second Law of Motion

The second law of motion states that the rate of change of momentum is proportional to the impressed force and takes place in the direction of that force.

Newton's second law enables us to define an absolute unit of force which remains constant under all conditions. In symbols the law states that

F a change in momentum / time taken for the change

F a mv – mu/t

Where m, u, v, t are mass, initial velocity, final velocity and time respectively of motion of the body acted upon by a force F and the product of m and v is called the momentum.

F a m (v – u/t)

F a ma

Where *v – u/t* = acceleration, a.

Thus, F = *kma*, where *k* is a constant.

The unit of force is chosen so that k = 1. Hence we can write F = ma.

In the SI unit F is in Newton, m is in kilogram, while the acceleration a, is in meter per square second (ms^{-2}). The Newton is the unit of force which gives a mass of 1 kg an acceleration of $1ms^{-2}$.

Thus, F = m (v – u/t) or Ft = mv – mu

The product F.t is the impulse, I of the force.

I = Ft = change in momentum.

Unit of I is Newton-second (Ns). This is also a unit of momentum.

We see that Newton's second law gives a measure of force as the product of mass and the acceleration of a body. Hence acceleration, a, is given by a = *F*/m

This second law of motion also gives an operational definition of force as the rate of change of momentum with time.

Example

An unbalanced force of 20 N acts on a 4 kg mass. What acceleration does it give?

F = ma

20 N = 4a

$a = 5\ ms^{-2}$

A body of mass 2 kg falls freely from rest through a height of 50 m and comes to rest having penetrated 5.0 cm of sand. Calculate (i) the velocity with which the body hits the sand (ii) the time taken in falling (iii) the average force exerted by the sand in bringing the body to rest.

Solution

(i) $v^2 = u^2 + 2gs$

Since u = 0, we have

$v^2 = 2gs = 2 \times 10 \times 50 = 1000$

v = Ö1000 = 31.62 ms^{-1}

(ii) From v = u + gt

u = 0

t = v/g = 31.62/10

= 3.16 s

(iii) The initial velocity (u) when body hits the sand = 31.62 $ms^{-1.}$

Final velocity after penetrating 5.0 cm of sand = 0

Using $v^2 = u^2 + 2as$, we have

$0 = (31.62)^2 + 2 \times a \times 5/100$

\ $-(31.62)^2 = a/10$

$a = -9998\ ms^{-2}$

F = ma

$= 2 \times 9998$ N or 19.996×10^3 N

Newton’s Third Law of Motion

States that action and reaction are equal and opposite. Or to every action there is an equal and opposite reaction.

The law implies that when a body A exerts a force F_A on a body B, the body B always exerts a force F_B on the body A. The force F_A and F_B are equal in magnitude but opposite in direction and since force is a vector, we can write $F_A = -F_B$. F_A is the action force, F_B is the reaction force. For example when you push down on your desk with your fingers, the desk pushes up on your finger with an equal force. If you hit a wall with your head, the force exerted by the head acts on the wall; at the same time the wall exerts an equal and opposite force on your head. You will feel this reaction as pain in your head. In the above examples, either force may be considered the action or the other treated as the reaction.

Conservation of Linear Momentum

Imagine standing on a giant skateboard that is at rest. What is the total momentum of you and the skateboard? It must be zero because it is at rest.

Now suppose you walk on the skateboard, what happens to the skateboard? When you walk in one direction, the skateboard moves in the other direction. This situation can be understood well, if you know the concept of **Conservation of Linear Momentum**.

Conservation of any quantity includes:

1. The quantity to be constant

2. The quantity does not change until and unless any other quantity for example force is applied on it.

3. The density (sigma) of the quantity over the system is a constant term.

The conservation of momentum can be of two types:

1. Conservation of linear momentum

2. Conservation of angular momentum

Principle of Conservation of Linear Momentum

The conservation of linear momentum is based on the principle of Newton's first law of motion. **It implies that for an isolated system, i.e., for a system with no external force, the momentum remains a constant quantity.**
It also implies the Newton's third law of motion, i.e., the law of reciprocal actions which states that the force acting between systems is opposite in sign and equal to each other.

Law of Conservation of Linear Momentum

All the bodies have the power of exerting a force on other bodies that are in their line of motion. The magnitude or quantity that measures this capacity of the bodies is called **Linear Momentum**.

The law of conservation of linear momentum states that the momentum will remain constant no matter what until and unless any external force comes into action.

This results into the fact that the center of mass of the system of objects will move with the same or constant velocity unless and until it is being acted upon by external force.

The Conservation of momentum is mathematically the result of the homogeneity of space, i.e., conservation of momentum implies that the physical laws are independent of the position.

Example: When a gun is fired if we assume that the initial position was at rest and hence the initial momentum to be zero the final momentum should also be zero according to the law of conservation of momentum.

Let us suppose the file cabinet is in the middle of the room, a room with a smooth floor, we give it a push in order to move it close to the wall and before we realize it slams into the wall. It is difficult to stop because it has linear momentum.

Conservation of Linear Momentum Equation

For two objects with initial masses of m_1 and m_2 and initial velocity of u_1 and u_2 with final velocities after collision to be v_1 and v_2, we can write the law as:

$$m_1u_1+m_2u_2 = m_1v_1+m_2v_2$$

The momentum remains conserved, i.e., the momentum that is lost initially is equal to the momentum gained afterwards.

The vector sum of all the given momenta for a closed system with no external force acting on it remains constant:

$$P_1 + P_2 + P_3 + P_4 + .. + P_i = K$$

Where ‘K’ is a constant.

Also **Linear momentum of a system of particles** for a system of particles with a mass of m1, m2, m3 and so on and a velocity v1, v2, v3 and so on the linear momentum can be expressed as:

$$P = \sum mv = m_1v_1+m_2v_2+m_3v_3+m_4v_4+.........+m_iv_i$$

For two objects with initial masses of m_1 and m_2 and initial velocity of u_1 and u_2 with final velocities after collision to be v_1 and v_2 we can write the law as

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

Also $\Delta p_1 = -\Delta p_2$

P-The product of mass and the velocity of a particle

$P = m v$

MAGNITUDE:

P = m v

or $P^2 = m^2v^2 = 2m(1/2mv^2) = 2mK$

Thus, P=Ö2*Km*

K = $P^2/ 2m$

Here, K = kinetic energy.
According to Newton's second law,

$\vec{F} = m\vec{a} = m(dv.dt) = d(mv)dt= dP.dt$

Thus, $\vec{F} = dP.dt$

Considering external force on the particle (or a body) = zero,
we have

$\vec{F} = dP.dt = 0$

The law may be extended to a system of particles or to the center of mass of a system of particles. For example, for system of particles:

If net force (or the vector sum of all the forces) on system of particles = zero, the vector sum of linear momentum of all particles remain conserved:

If $F_1+F_2+F_3+......+F_n=0$

Then, $P_1+P_2+P_3+......+P_n$=constant

The same is the case for the center of mass:
$F_{CM} = 0$, P_{CM} = constant

Collisions

There are two principal types of collisions – the elastic and the inelastic collisions.

Application to collisions

By itself, the law of conservation of momentum is not enough to determine the motion of particles after a collision. Another property of the motion, kinetic energy, must be known. This is not necessarily conserved. If it is conserved, the collision is called an *elastic collision*; if not, it is an *inelastic collision*.

Elastic collisions

An elastic collision is one in which no kinetic energy is lost. Perfectly elastic "collisions" can occur when the objects do not touch each other, as for example in atomic or nuclear scattering where electric repulsion keeps them apart. A slingshot maneuver of a satellite around a planet can also be viewed as a perfectly elastic collision from a distance. A collision between two pool balls is a good example of an *almost* totally elastic collision, due to their high rigidity; but when bodies come in contact there is always some dissipation.

A head-on elastic collision between two bodies can be represented by velocities in one dimension, along a line passing through the bodies. If the velocities are u_1 and u_2 before the collision and v_1 and v_2 after, the equations expressing conservation of momentum and kinetic energy are:

$$m_1 u_1 + m_2 u_2 = m_1 v_1 + m_2 v_2$$

$$\frac{1}{2} m_1 u_1^2 + \frac{1}{2} m_2 u_2^2 = \frac{1}{2} m_1 v_1^2 + \frac{1}{2} m_2 v_2^2$$

A change of reference frame can often simplify the analysis of a collision. For example, suppose there are two bodies of equal mass m, one stationary and one approaching the other at a speed v (as in the figure). The center of mass is moving at speed $v/2$ and both bodies are moving towards it at speed $v/2$. Because of the symmetry, after the collision both must be moving away from the center of mass at the same speed. Adding the speed of the center of mass to both, we find that the body that was moving is now stopped and the other is moving away at speed v. The bodies have exchanged their velocities. Regardless of the velocities of the bodies, a switch to the center of mass frame leads us to the same conclusion. Therefore, the final velocities are given by

$v_1 = u_2$

$v_2 = u_1$.

In general, when the initial velocities are known, the final velocities are given by

$v_1 = (m_1 – m_2/m_1 + m_2)\ u_1 + (2m_2/m_1 + m_2)\ u_2$

$v_2 = (m_2 – m_1/m_1 + m_2)\ u_2 + (2m_1/m_1 + m_2)\ u_1.$

If one body has much greater mass than the other, its velocity will be little affected by a collision while the other body will experience a large change.

Inelastic collisions

In an inelastic collision, some of the kinetic energy of the colliding bodies is converted into other forms of energy such as heat or sound. Examples include traffic collisions, in which the effect of lost kinetic energy can be seen in the damage to the vehicles; electrons losing some of their energy to atoms (as in the Franck–Hertz experiment); and particle accelerators in which the kinetic energy is converted into mass in the form of new particles.

In a perfectly inelastic collision (such as a bug hitting a windshield), both bodies have the same motion afterwards. If one body is motionless to begin with, the equation for conservation of momentum is

$m_1u_1 = (m_1 + m_2)\ v$,

so

$v = (m_1/m_1 + m_2)u_1$

In a frame of reference moving at the speed *v*), the objects are brought to rest by the collision and 100% of the kinetic energy is converted.

One measure of the inelasticity of the collision is the coefficient of restitution C_R, defined as the ratio of relative velocity of separation to relative velocity of approach. In applying this measure to ball sports, this can be easily measured using the following formula:

C_R = Öbounce height/drop height.

The momentum and energy equations also apply to the motions of objects that begin together and then move apart. For example, an explosion is the result of a chain reaction that transforms potential energy stored in chemical, mechanical, or nuclear form into kinetic energy, acoustic energy, and electromagnetic radiation. Rockets also make use of conservation of momentum: propellant is thrust outward, gaining momentum, and an equal and opposite momentum is imparted to the rocket

Application of Newton's and Conservation of Momentum Laws

1. Recoil of a gun

When a bullet is fired from a gun, the gun jerks backward or recoils. Before the gun is fired, the initial momentum of the gun-bullet moves forward with a certain velocity. It has a forward momentum equals to m_1v_1 where m_1 is the mass of bullet and its velocity is v_1. The momentum of the gun is given by m_2v_2 where m_2 is the mass of the gun and v_2 is its velocity. Since the momentum must be conserved we have,

A young boy aims confidently with a target shooting air-rifle

$m_1v_1 + m_2v_2 = 0$; Hence $m_1v_1 = - m_2v_2$

The negative sign shows that the momentum of the gun is directed oppositely to that of the bullet. Therefore the gun jerks backward or recoils or recoils. Because the mass of the gun is much larger than that of the bullet ($m_2 >> m_1$) the velocity and kinetic energy are much smaller than those of the bullet ($v_2 < v_1$).

We can also consider the system of a case of the operation of Newton's third law. The propulsive force (action) acting on the bullet must be equal and opposite to the recoil force (reaction) acting on the gun.

2. Jet and Rocket Propulsion

The principle of conservation of linear momentum is also utilized in the propulsion of jet aircraft and the rockets used for launching satellites. Gases are burnt within the combustion chambers of the engine. As jets of the hot gas are expelled downwards through the tail nozzle at very high speeds from the rockets or aircraft, an equal and opposite momentum is given to the rocket or aircraft which the moves. The principle underlying the propulsion of rocket can be illustrated in the laboratory using an inflated balloon. If the inflated balloon is pierced with a pin in one direction and released, the balloon will be seen to move in the opposite direction.

3. Why Walking is Possible

A person walks by pushing with his or her foot against the ground. The ground exerts an equal and opposite force back on the person.

It is this force on the person due to the reaction of the ground that moves him or her forward. Thus a person walking is actually pushed forward by the reaction force of the ground on him and not by his own push on the ground.

Example

A rocket is burning fuel at the rate of 200g/s and ejecting all the gas in one direction at the rate of 400 m/s. What is the maximum weight of the rocket can have if it is going to move vertically upwards?

Solution

Mass of gas per second = 200/1000 kg/s

Velocity of expulsion = 400m/s

Momentum change per second = 200/1000 x 400kgm/s^2

From Newton's second law, we have

F = W = 200/1000 x 400 N

= 80 N.

Questions:

1. A mass of 4 kg is moving at a speed of 10 m/s in a frictionless surface. It collides with a 3kg mass moving in the same direction at 5 m/s. What is the final velocity of the system after the collision?

1. 7.86 m/s B. 9.86 m/s C. 6.98 m/s D. 3.21 m/s

2. There are two cars moving at a speed of 50 km/s and 70 km/s with mass of 100 kg and 60 kg respectively. Find the final speed of both after collision?

A. 60 km/s B. 57.5 km/s C. 68.5 km/s D. 56 km/s

3. Which of these statements is in incorrect?

A. An elastic collision is one in which no kinetic energy is lost B. Perfectly elastic "collisions" can occur when the objects do not touch each other C. Before the gun is fired, the initial momentum of the gun-bullet reduces with a certain velocity D. A collision between two pool balls is a good example of an *almost* totally elastic collision, due to their high rigidity

4. A body will remain in its state of rest or uniform motion in a straight line unless an external force acts on it. Which of the Newton's laws is this?

A. First Law B. Second Law C. Third Law D. A reflection of both the first and the second laws.

5. Which is correct being the equation **Conservation of Linear Momentum?**

A. $m_1u_1+m_2u_2 = m_1v_1+m_2v_2$ B. $m_1u_1 + m_1v_1 = m_2u_2 + m_2v_2$ C. $m_1u_1 – m_2v_2 = m_2u_2 – m_1v_1$ D. . $m_1u_1 + m_2v_2 = m_2u_2 + m_1v_1$

Answers

1. A 2. B 3. C. 4. A 5. A

WEEK 6

Topic: EQUILIBRIUM OF FORCES

Concept of Equilibrium: Dynamic and Static Equilibrium

An object is in equilibrium when it is not accelerated, that is, there is no net force acting on it in any direction. For such a body in equilibrium, the forces acting on it are so related in magnitude and direction that no acceleration results. Thus the body may either be at rest or may be moving with constant velocity. Such bodies at rest are said to be in static equilibrium. When the body is moving with a constant velocity in a straight line, or when it is rotating with a constant angular velocity about a fixed axis through its center of mass, the equilibrium is said to be kinetic or dynamic equilibrium. This means that the forces that set the body in motion balance the forces that resist the motion. For example a car running at a constant speed for a considerable length of time is in dynamic equilibrium.

A body is said to be in equilibrium when:

(i) the body as a whole either remains at rest or moves with a straight with constant speed and;

(ii) the body is either not rotating at all or is rotating at a constant angular velocity.

When an object is in equilibrium the sum of all the forces is zero. The object is at rest or moving at a constant speed in a straight line.

A single force that will place an object in equilibrium is called the equilibrant. The equilibrant is equal in magnitude to the resultant and opposite in direction.

To determine the equilibrant find the resultant and then reverse the direction.

Resultant and Equilibrant Forces

Students encounter the equation f=ma soon after they begin to study physics. If an object experiences a net force, it will experience a corresponding acceleration proportional to the magnitude of that net force. When multiple forces simultaneously act upon the object, you'll need to add the different forces together to get the resultant force. A force identical in magnitude but in the opposite direction is the equilibrant force

The resultant force is that single force which acting alone will have the same effect in magnitude and direction as to or more forces acting together.

The equilibrant of two or more forces is that single force which will balance all the other forces taken together. It is equal in magnitude but opposite in direction to the resultant force.

If three forces F_1, F_2 and F_3 acting at a point are in equilibrium, the resultant of any two of the forces is equal but opposite in direction to the third force. Anyone of these forces is said to be the equilibrant of the other two. The equilibrant of F_1 and F_2 is F_3, the equilibrant of F_2 and F_3 is F_1 and the equilibrant of F_1 and F_3 is F_2.

Also the line of action of the three forces keeping a body in equilibrium must all pass through one point. Otherwise the resultant of two of the forces cannot be counterbalanced by the third force.

Conditions of Equilibrium under the action of Parallel Coplanar Forces

Coplanar forces are forces that lie in the same plane. Parallel forces are forces whose lines of action are parallel to each other.

A body acted upon by several forces is s aid to be in equilibrium if it does not move or rotate. Under this equilibrium condition, the sum of the forces acting in one direction (e.g. upwards) must be equal to the sum of the forces acting in opposite direction (e.g. downwards). Thus the total forces acting upwards must balance the total forces acting downwards.

Also the body can also remain in equilibrium if the moment of the forces about any point act in such a way as to cancel each other. That is, the total clockwise moments of all the forces about any point of the object must be exactly counterbalanced by the by the total anticlockwise moment about the same point.

Hence the two conditions for equilibrium of parallel coplanar forces can be stated as follows:

1. **Forces**

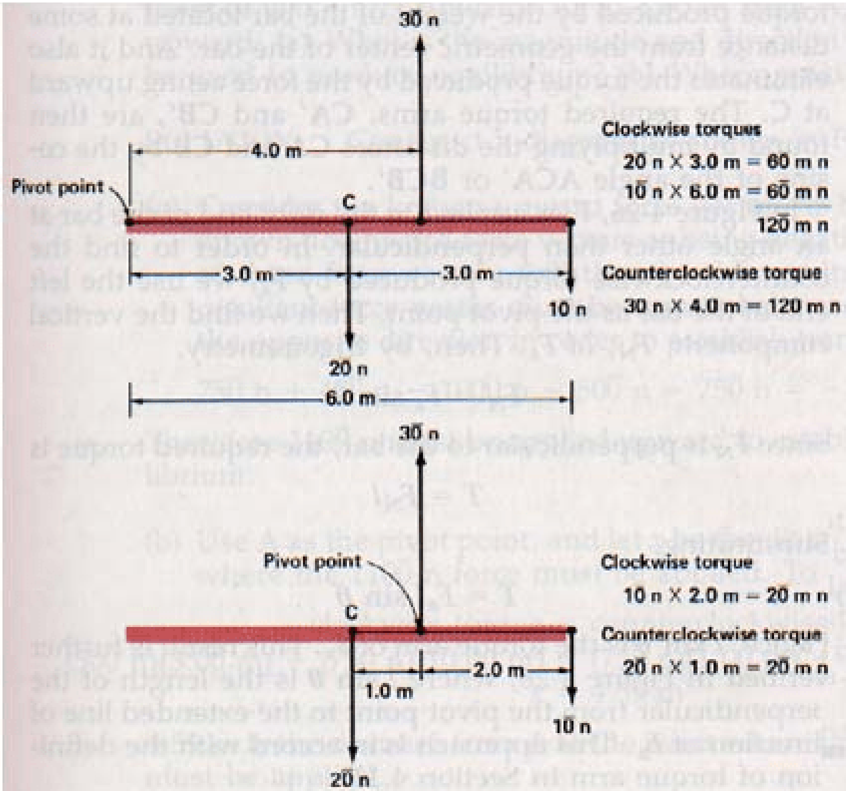
The algebraic sum of the forces acting on the body in any given direction must be zero. That is, the sum of the upward forces must equal the sum of the downward forces or the sum of the forces acting in one direction must be equal to the sum of the forces acting in opposite direction.

2. **Moments**

The algebraic sum of the moments of all the forces about any point on the body must be zero, or the total clockwise moments of the forces about any point on the body must be equal to the total anticlockwise moments of the forces about the same point. The second condition above is known as the

Principle of Moments.

The **Principle of Moments** states that if a body is in equilibrium, then the sum of the clockwise moments about any point on the body is equal to the sum of the anticlockwise moments about the same point.



Turning Effects: When a force is applied a distance away from the centre of mass (COM) then we produce a turning effect or "moment". If you have a situation where an object is in equilibrium then you can solve a problem by equating all the turning effects about any point in the situation…

Clockwise moments = anticlockwise moments

Moments: When a force is applied it has to be **perpendicular** to the distance to be classed at a moment. To solve problems you sum up all the moments applied "perpendicular" to a point…

Clockwise moments = anticlockwise moments

See-Saw: When we have simple see-saw we can sum up by just balancing from the middle of the see-saw and add any Wd from the pivot point..

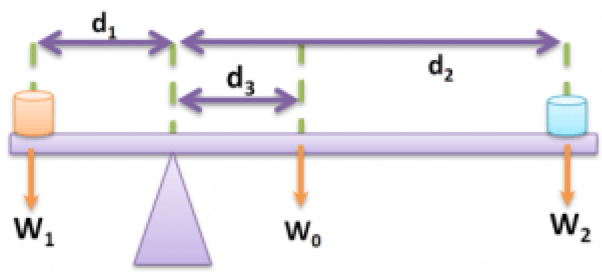
$\mathbf{W_1d_1 = W_2d_2}$

or if you have two people on one side…

$\mathbf{W_1d_1 = W_2d_2 + W_3d_3}$

Complex Moments: Now what happens if the see-saw is not equal on each side. Now the weight of the see-saw must be taken into account when taking moments. This acts from the COM but looks strange at first…

$\mathbf{W_1d_1 = W_2d_2 + W_3d_3}$



Conditions of Equilibrium under the action of non-parallel coplanar forces

Sometimes non parallel forces acts on a body. Such forces can also keep the body in equilibrium. The non parallel forces can easily be resolved into horizontal and vertical components giving rise to two sets of parallel forces at right angle to each other. The problem can then be treated as in **Conditions of Equilibrium under the action of Parallel Coplanar Forces** and its method can be applied to both the vertical and the horizontal components separately. The two conditions of equilibrium under the action of non parallel forces then become:

1. **Forces**

The vector sum of all the forces acting on the body must be zero. In order words the algebraic sum of all the forces or components of the forces acting on the body in any direction must be zero. Thus, (i) the algebraic sum of the horizontal components of the forces must be zero, i.e. $SF_x = 0$, (ii) the algebraic of the vertical components of the forces must be zero, i.e., $SF_y = 0$.

2. **Moments**

The algebraic sum of the moments of all the forces about any axis perpendicular to the plane of the forces must be zero. In other words the sum of the clockwise moments about any such axis equals the sum of the anticlockwise, moments about the same axis.

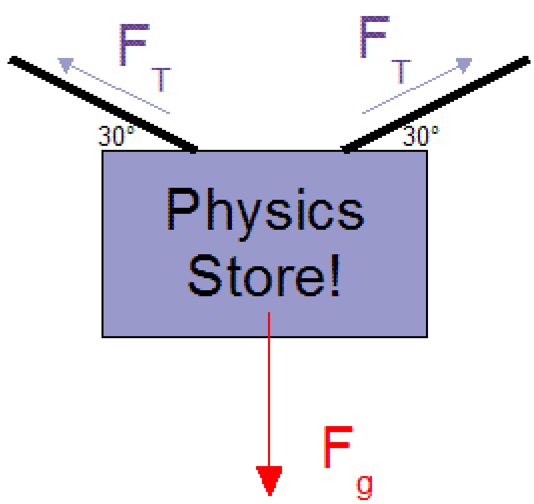
Equilibrium under action of three non-parallel forces

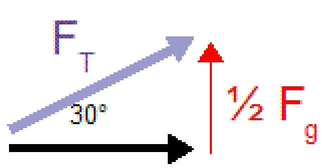
(i) The three forces must lie in a plane.

(ii) Their lines of action must intersect in a common point.

(iii) The vector representing the three forces can be arranged to form a closed triangle with sides respectively parallel to the directions and proportional in length to the magnitude of the forces.

Example 1: A 10 kg sign is being held up by two wires that each make a 30° angle with the ground. **Determine** the tension (force) in each of the wires.





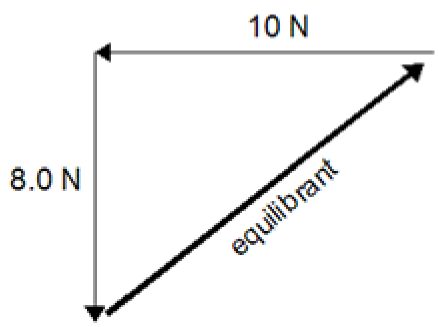
$F_g = mg$

= (10) (9.81)
F_g = 98.1 N

sinq = opp / hyp
sinq = 1/2 F_g / F_T
F_T = (1/2 F_g) / sinq
= (49.05) / sin 30° = 98.1 N

Questions

Two forces are pushing an object along the ground. One force is 10 N [W] and the other is 8.0 N . The diagram below shows the equilibrant of these two forces.



1. Determine the equilibrant.

A. 14 N B. 13 N C. 16 N D. 17

2. Calculate the angle where the 8.0 N force and the equilibrant touch

A. 51^0 B. 54.5^0 C. 56^0 D. 59^0

3. Which of these is not correct about equilibrium?

A. An object is in equilibrium when it is not accelerated   B. An object is in equilibrium when there is no net force acting on it in any direction C. A body is in equilibrium when there is no torque acting on it D. A body is in equilibrium when it is vibrating.

4. Coplanar forces are forces that lie in

A. the same plane B. different planes C. a higher plane D. a lower plane

Btg5

A. Static equilibrium B. dynamic equilibrium C. Elastic equilibrium D. Inelastic equilibrium

Answer

1. B 2. A 3. D 4. A 5. B

WEEK 7

Topic: EQUILIBRIUM OF FORCE

Centre of Gravity

Attempt to balance an object like the one in the picture below (toy) at the top of your right index finger. Note the point on the toy at which the finger is most able to support the toy.

This child's toy uses the principles of center of mass to keep balance on a finger.

Move the finger to another point slightly different from the first point of balance and see if the toy can still be balanced at this new position.

From the above simple experiment we will observe that there is a unique point at which a body of any shape and size may be supported by a pivot.

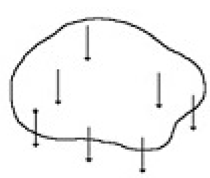
We may explain this point of a body by visualizing the body to be made up of a large number of equal tiny particles each of mass, m. Each of such a mass is pulled towards the earth's centre by a force of gravity equal to mg. The weights of these tiny particles form a system of parallel forces acting in the same direction. The resultant of all these parallel forces which is the total weight(W) of the body appears to act at some point G known as the Centre of Gravity (C.G.) of the body. If the body is supported at this point by an upward force equal in magnitude to the weight W, it will balance and thus be in equilibrium.

Centre of Gravity (C.G.) of a body is defined as the point through which the line of action of the weight of the body always passes irrespective of the position of the body. It is also the point at which the entire weight of the body appears to be concentrated.

The center of gravity of an object is the point you can suspend the object from without there being any rotation because of the force of gravity, no matter how the object is oriented. If you suspend an object from any point, let it go and allow it to come to rest, the center of gravity will lie along a vertical line that passes through the point of suspension. Unless you've been exceedingly careful in balancing the object, the center of gravity will generally lie below the suspension point.

The center of gravity is an important point to know, because when you're solving problems involving large objects, or unusually-shaped objects, the weight can be considered to act at the center of gravity. In other words, for many purposes you can assume that object is a point with all its weight concentrated at one point, the center of gravity.

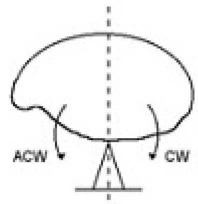
The center of mass of an object is generally the same as its center of gravity. Very large objects, large enough that the acceleration due to gravity varies in different parts of the object, are the only ones where the center of mass and center of gravity are in different places.



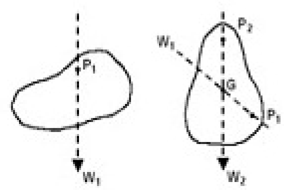
Consider a body as an accumulation of many small masses (molecules), all subject to gravitational attraction. The total weight, which is a **force**, is equal to the sum of the individual masses, multiplied by the gravitational acceleration (g =9.81 m/s^2).

W = mg

The diagram shows that the individual forces all act in the same **direction**, but have different lines of action.



There must be datum position, such that the total moment to one side, causing a clockwise rotation, is **balanced** by a total moment, on the other side, which causes an anticlockwise rotation. In other words, the total weight can be considered to act through that datum position (= line of action).



If the body is considered in two different positions, the weight acts through two lines of action, W_1 and W_2 and these interact at point G, which is termed the Centre of Gravity.

Hence, the Centre of Gravity is the point through which the Total Mass of the body may be considered to act.

For a 3-dimensional body, the centre of gravity can be determined practically by several methods, such as by measuring and equating moments, and thus is done when calculating Weight and Balance of aircraft.

A 2-dimensional body (one of negligible thickness) is termed a lamina, which only has area (not volume). The point G is then termed a Centroid. If a lamina is suspended from point P, the centroid G will hang vertically below 'P_1'. If suspended from P_2, G will hang below P_2. Position G is at the intersection as shown.

Facts about the center of gravity

Fact 1 – An object thrown through the air may spin and rotate, but its center of gravity will follow a smooth parabolic path, just like a ball.

Fact 2 – If you tilt an object, it will fall over only when the center of gravity lies outside the supporting base of the object.

Fact 3 – If you suspend an object so that its center of gravity lies below the point of suspension, it will be stable. It may oscillate, but it won't fall over.

Similarly we can define the centre of mass of a body as the point at which the total mass of the body appears to be concentrated. The centre of mass coincides with the centre of gravity for small objects.

To locate centre of gravity by a balancing method

The centre of gravity of a long thin object such as a ruler or billiard may be found approximately by simply balancing it on a straight-edge.

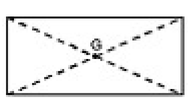
Using a thin sheet or lamina of cardboard or metal, it is necessary to balance in two positions. The thin sheet or lamina of cardboard or metal is balanced on the edge of a straight ruler in two directions AB and CD and the lines of balance are marked with pencil lines. Since the CG is situated on both lines, it must actually lie at their point of intersection.

The edge of the ruler should pass through the intersection of the previous lines.

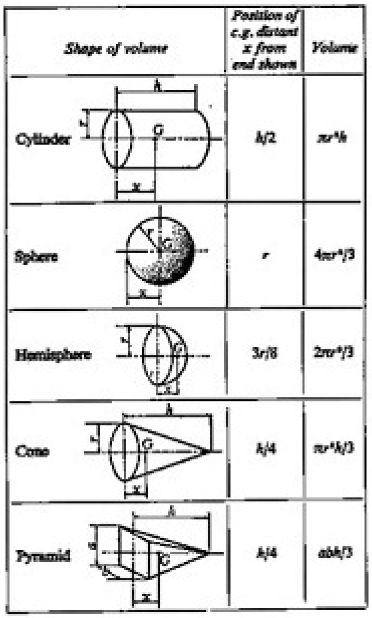
For any object, the x-position of the center of gravity can be found by considering the weights and x-positions of all the pieces making up the object:

A similar equation would allow you to find the y position of the center of gravity.

A regular lamina, such as a rectangle, has its centre of gravity at the intersection of the diagonals.

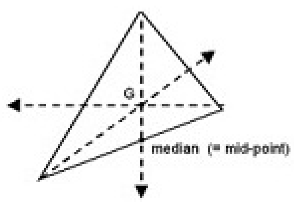


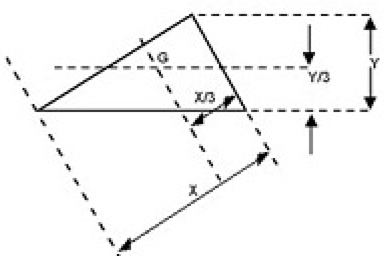
Other regular shapes have their centre of gravity at known positions, see the table below.



Shape of volume	Position of c.g. distant x from end shown	Volume
Cylinder	$h/2$	$\pi r^2 h$
Sphere	r	$4\pi r^3/3$
Hemisphere	$3r/8$	$2\pi r^3/3$
Cone	$h/4$	$\pi r^2 h/3$
Pyramid	$h/4$	$abh/3$

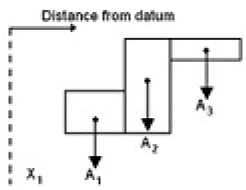
A triangle has its centre of gravity at the intersection of the medians.





The centre of gravity can also be deduced as shown.

If the lamina is composed of a several regular shapes, the centre of gravity of that lamina can be deduced by splitting it into its regular sections, calculating the moments of these areas about a given datum, and then equating the sum of these moments to the moment of the composite lamina.



Expressed as an algebraic formula,

$$A_1 X_1 + A_2 X_2 + A_3 X_3 = (A_1 + A_2 + A_3)X$$

Where X is the position of the centroid, with respect to the datum. This is the principle behind Weight and Balance.

Stability

The centre of gravity of a body is related to its stability due to the following reasons:

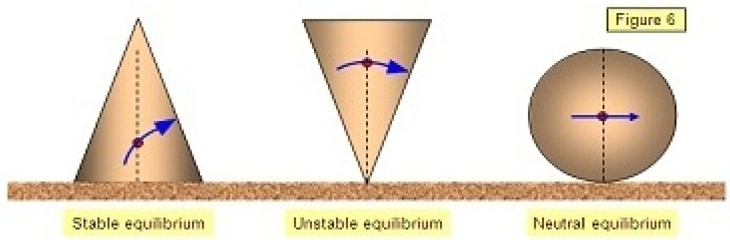
(i) The position of the centre of gravity.

(ii) The moment of the centre of gravity about a given axis when slightly tilted.

Position of centre of gravity

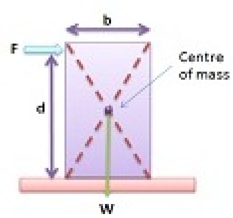
An increase in height of C.G. when slightly displaced produces an increase in potential energy (P.E). The object will fall back to its original position, so that the equilibrium is stable, e.g. slant edge of a cone. A decreasing height of C.G. when slightly displaced produces a decrease in potential energy (P.E.). Then the objet falls farther away so that the equilibrium is unstable, e.g. tip of a cone. But if it is in neutral equilibrium, there will be no change in the height of C.G., when the object is displaced slightly, e.g. the base of a cone or a lamp.

If an object is in equilibrium, i.e., if it is balanced, then if a force is applied to the object it will either tilt, tip over or roll.
These three conditions are known as:
(a) stable equilibrium (it tilts and then falls back to the original position)
(b) unstable equilibrium (it tilts and then falls over)
neutral equilibrium (it rolls)

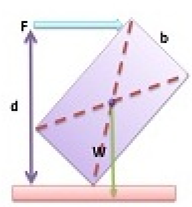


Stable – the centre of gravity is raised as it is tilted
Unstable – the centre of gravity is lowered as it is tilted
Neutral – the centre of gravity stays at the same level if it is pushed

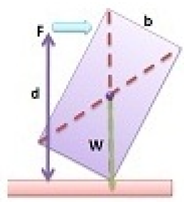
Stable Equilibrium: If an object such as a flower basket or a bookshelf is displaced by a force it will return to that point. This is a situation where the centre of mass must be inside of the pivot point. $Fd < Wb/2$



Unstable Equilibrium: If it is displaced slightly it will not return to that point and will topple over. This is a situation where the centre of mass is outside the pivot point. $Fd > Wb/2$



Unstable Equilibrium Calculations: We can use the dimensions of our problems and the theory of moments to setup an equation about the pivot point. $Fd = Wb/2$



Weight acts through the centre of the base and the force acts a distance d up the side of the block.

Toppling Vehicles: We also find trig and moments useful when deciding at which angle a vehicle will topple over on a slope. If we know the geometry of the centre of mass and middle of the base we can construct a triangle of an angle which creates the ratio of similar forces. The geometry causes the forces to act.

Resolving Forces Parallel to Slope….

hyp x sinθ = opp

F = W x sinθ

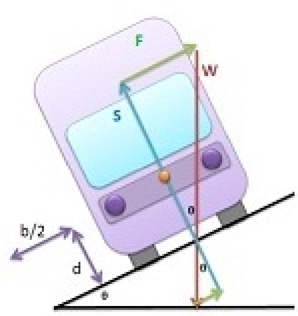
Resolving Perpendicular to Slope….

hyp x cosθ = adj

S = W x cosθ

Divide the two equations….

F/s = sinθ/cosθ = tanθ = (b/2)/d



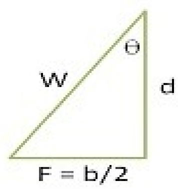
A Simple example would be a lorry has a wheelbase of 2.1 m and centres of mass unloaded of 0.7m from the ground. What is the maximum angle it can drive at before toppling over….

d = 0.7m b/2 = (2.1/2) m = 1.05

Hence…

opp/adj = tanθ

Angle = $\tan^{-1}(1.05 / 0.7) = 56.3°$

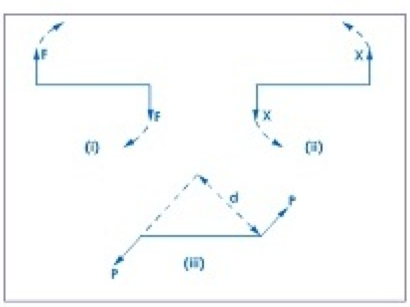


Couple

Two equal and opposite parallel forces acting along different lines on a body constitute a couple.

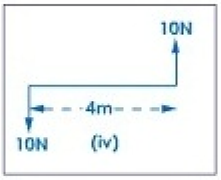
The turning effect of the couple is called its moment and is calculated by the product of either of the forces and the perpendicular distance between them (i.e., between their lines of action).

A body acted upon by a couple will rotate in a clockwise direction or anticlockwise direction as shown [Figure (i), (ii) and (iii) shown below]. If the two forces acting on the body have the same line of action, then the moment becomes zero.



Two equal, unlike and parallel forces acting along different lines form a couple.

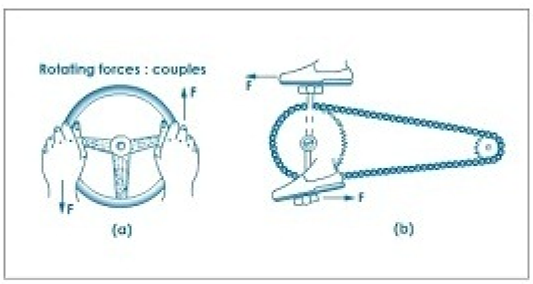
Moment of a couple = Force (N) x Perp. Distance (m) between the forces [shown below].



Moment of the couple = 10 N x 4 m = 40 N m

Steering Wheel and Pedals of a Bicycle

Two examples of the turning effect of two equal and opposite forces not acting in the same straight line are the steering wheel and the pedals of a bicycle. In the figure (a) below, the left hand is pulling with force F on the steering wheel while the right hand is pushing with the same force F. The two forces make the wheel turn in an anticlockwise direction.



In figure (b) shown above, one pedal is being pushed forward while the other is being pushed back. This rotates the sprocket wheel and the attached chain anticlockwise. Can you think of other everyday examples in which a turning effect or rotation takes place?

Examples of Couple

In our day-to-day life, we come across many objects which work on the principle of couple. Winding up the spring of a toy car, opening and closing the cap of a bottle, turning of a water tap, cork screws, door key etc. are some of the common examples of couples.

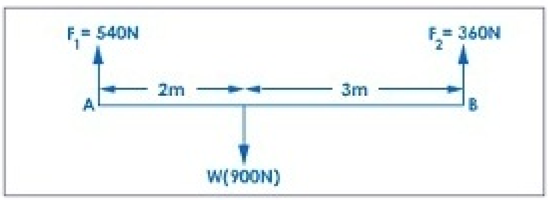
Question

1. The centre of gravity of a long thin object such as a ruler or billiard may be found approximately by simply balancing it on a

A. curved edge B. straight edge. C. circular egde D. Irregular edge

2. Moment of a couple is calculated thus

A. Force x Mass B. Force x Weight C. Force x perpendicular distance D. Weight x Perpendicular distance



3. Find the upward force exerted by the boy at A in the diagram above.

A. 600 N B. 630 N C. 540 N D. 450 N

4. Calculate the force exerted by the boy at B using A as a pivot.

A. 450 N B. 370 N C. 460 N D. 360 N

5. One of the options below, does not belong to the category, which?

A.Unstable Equilibrium B. Stable Equilibrium C. Neutral Equilibrium D. Slanting Equilibrium

Answers

1. B 2. C 3. C 4. D 5. D

WEEK 8

Topic: Simple Harmonic Motion (SHM)

In addition to linear motion and rotational motion there is another kind of motion that is common in physics. This is the to and fro motion of oscillations or vibrations.

When something oscillates, it moves back and forth with time. It is helpful to trace out the position of an oscillating particle with time so we can define some terminology.

Period, Amplitude and Frequency

The time taken for the particle to complete one oscillation, that is, the time taken for the particle to move from its starting position and return to its original position is known as the period. and is generally given the symbol T. The frequency ν is related to the period, it is defined as how many oscillations occur in one second. Since the period is the time taken for one oscillation, the frequency is given by

$f = 1/T$

The frequency is measured in . This unit is known as the Hertz (Hz) in honour of the physicist Heinrich Hertz. The maximum displacement of the particle from its resting position is known as the amplitude. The frequency is also given the symbol f.

Simple Pendulum

An object is undergoing simple harmonic motion (SHM) if;

1. The **acceleration of the object is directly proportional to its displacement** from its equilibrium position.

2. The **acceleration is always directed towards the equilibrium position**.

The frequency (f) of an oscillation is measure in hertz (Hz) it is the number of oscillations per second. The time for one oscillation is called the period (T) it is measured in seconds.

f = 1/T

Acceleration – we can calculate the acceleration of the object at any point in it's oscillation using the equation below.

$$a = -(2\pi f)^2 x$$

In this equation; a = acceleration in ms^{-2}, f = frequency in Hz, x = displacement from the central position in m.

Displacement – When using the equation below your calculator must be in radians not degrees! we can calculate the displacement of the object at any point in it's oscillation using the equation below.

$$x = A \cos 2\pi ft$$

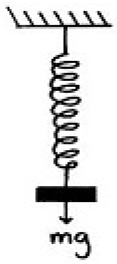
The terms in this equation are the same as the equations above. The extra terms in this equation are: A = the amplitude (maximum displacement) in m, t = the time since the oscillation began in s.

Velocity– we can calculate the velocity of the object at any point in its oscillation using the equation below.

$$V = \pm 2\pi f \sqrt{A^2 - x^2}$$

The terms in this equation are the same as the equations above. The extra term in this equation is: v = the velocity in ms^{-1}.

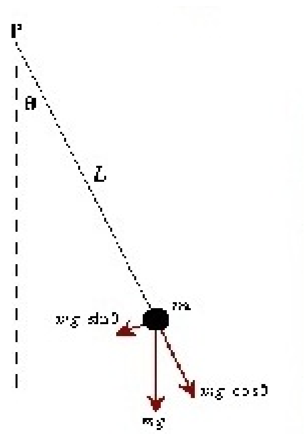
Time period of a mass-spring system



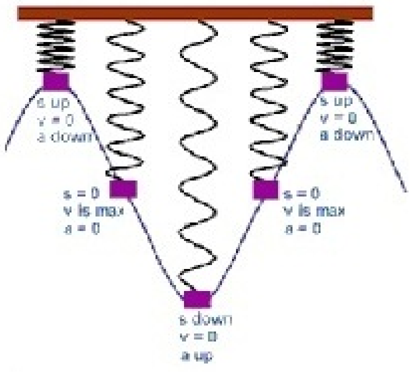
$T = 2\pi\sqrt{m/k}$

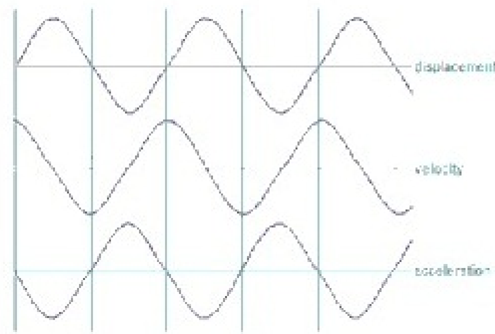
Time period of a Pendulum

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



Suppose that an oscillating spring has one end firmly attached to a base of support and a mass attached to its free end. As the mass vibrates back and forth, we can track the behavior of three instantaneous quantities: the mass' displacement, velocity, and acceleration. Note in the diagrams shown below that when the mass' displacement is at a maximal positive position, its velocity is zero, and its acceleration, which is acting to restore the mass to its undisturbed equilibrium position, has a maximum negative value.





Notice that at the endpoints, when v = 0, the mass has no kinetic energy, $KE = ½mv^2$. Therefore, all of its energy is in the form of elastic potential energy, $PE= ½kx^2$. When $PE_{,}$ is maximum, the restoring force within the spring is also maximized resulting in the mass' acceleration also being maximized as the spring acts to return the mass to its equilibrium position.

There are two formulas at our disposal to quantify the restoring force within the spring as it oscillates: Newton's 2nd Law, net F = ma, and Hooke's Law, F = – ks:

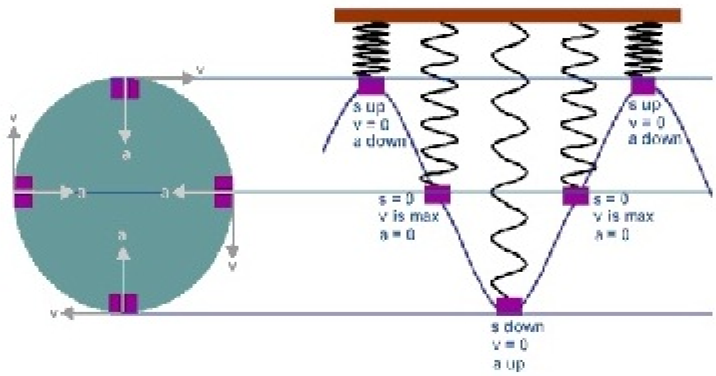
$F_{restoring} = ma_{max}$

$F_{restoring} = -ks_{max}$

$ma_{max} = -ks_{max}$

$a_{max} = -(k / m)s_{max}$

This results tells us that the mass' instantaneous acceleration is directly proportional to, but in the opposite direction as, its instantaneous displacement. To help us understand the substitution which we will need to use next, we are going to return to some relationships which we learned for uniform circular motion. In the following video, note how the motion of the ball's shadow emulates the motion of a mass on the end of a vibrating spring.



In general, the sinusoidal equations for each property graphed at the top of this page are summarized in the following equations.

$s = A \sin(2\pi ft)$

$v = A\omega \cos(2\pi ft)$

$a = - A\omega^2 \sin(2\pi ft)$

Where *f* represents the frequency measured in hertz

and ω, or the angular velocity, equals $2\pi f$ measured in rad/sec

Returning to our previous result of $a_{max} = -(k/m)s_{max}$ please note:

1. that the magnitude of a_{max} is equivalent to the magnitude of the mass' centripetal acceleration, $a_c = v^2/r$

2. the fact that s_{max} equals the radius of the circle, r, or the amplitude, A, of the sine graph

$a_{max} = |-(k/m)s_{max}|$

$v_{max}^2/A = (k/m)A$

$v_{max}^2 = (k/m)A^2$

$v_{max} = A\sqrt{k/m}$

Remembering the relationship from circular motion that

$v = 2\pi r/T$

$v = 2\pi A/T$

We can substitute A for r and complete our derivation.

$v_{max} = A\sqrt{k/m}$

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

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

Relationship between angular acceleration and linear acceleration

$a = \Delta w/t = w_2 - w_1/t$

Recall $v = rw$

$\therefore \alpha = 1/r\ (v_2 - v_1/t)$

Recall $a = v_2 - v_1/t = \Delta v/t$

$\alpha = a/r$

$a = \alpha r$

Summary of SHM

The following list summarizes the properties of simple harmonic oscillators.

1. The oscillator's motion is periodic; that is, it is repetitive at a constant frequency.

2. The restoring force within the oscillating system is proportional to the negative of the oscillator's displacement and acts to restore it to equilibrium.

3. The velocity of the oscillator is maximum as it passes through equilibrium, and zero as it passes through the extreme positions in its oscillation.

4. The acceleration experienced by the oscillator is proportional to the negative of its displacement from

Questions

1. If the period of an oscillatory motion is 2.4 seconds, what is the angular speed in degrees/s

A. 170 B. 150 C. 201 D 230

2. For the information given in practice question 1, calculate the frequency

A. 0.25 Hz B. 0.14 Hz C. 0.42 Hz D. 3.15 Hz.

3. Two simple pendula, X and y, make 400 and 500 oscillations respectively in equal times. If the period of oscillation of x is 15secs, what is the period of oscillation for y?

A. 14.5 secs B. 13 secs C. 12 secs D. 17 secs

An object of mass 0.40kg attached to the end of a string is whirled round in a horizontal circle of radius 2m with a constant speed of 8m/s. Calculate the angular velocity of the object.

A. 6 rad/sec   B. 10 rad/sec C. 4 rad/sec D. 5.6 rad/sec

5. Some examples of simple harmonic motion are, except

A. The prongs of a tuning fork B. mass hanging from a spiral spring C. the swinging of a pendulum bob D. the rolling of a bob

Answers

1. B 2. C 3. C 4. C 5. D

WEEK 9

Topic: MACHINES – TYPES AND EXAMPLES

INTRODUCTION

A machine is essentially a device or tool which allows a force (or effect) applied at one point to overcome a resisting force (or load) at another point.

Consider a simple machine such as a screw. We apply a small turning force at the head and the screw is able to move through a block of wood, against a large resisting force provided by the wood. Generally a machine enables us to overcome a large resistance or load by applying a small effort. A machine enables us to do work more easily and conveniently than it could be done without it. For example, it is easier to roll a drum of oil up an inclined plane onto a lorry than to raise it vertically without the inclined plane.

Examples of machines are the lever, pulleys, pliers, wheel barrows, nut crackers, the inclined plane, the wedge, wheel and axle, screw jack and so on. Many complicated machines are made up of two or more machines.

Before discussing the working principles of simple machines we need to define some terms that apply to the working of the machines.

Mechanical Advantage (MA) or Force Ratio (FR)

We define ***Effort*** as the force applied to a machine and Load as the force or resistance overcome by the machine. The ability of a machine to overcome a large load through a small ***effort*** is known as its Mechanical Advantage (MA) or Force Ratio. It is given by:

MA = Load/Effort

Suppose a load of 20 N is raised by an effort of 4 N, then

MA = Loads/Effort = 20/4 = 5

W e see that the MA is the ratio of the two forces, load and effort, hence it is sometimes referred to as Force Ratio. The load is the output force and the effort is the input force. Mechanical Advantage can also be defined by

MA = Output force/ Input force

The mechanical advantage of a machine is influenced by friction in the parts. In the presence of friction part of the effort applied will be used to overcome friction and another part will be used to overcome the resistance or lift a load. Hence more effort will be required to overcome a load. A machine that has no friction is called an ideal machine or a perfect machine.

This is defined as the ratio of the distances moved by the effort and load in the same time interval.

V.R = distance moved by effort (*a*)/distance moved by load (*l*)

The velocity ratio depends on the geometry of the machines. It is independent of friction. For an ideal or perfect machine, Work done by machine = work done on machine

load x distance moved by load = effort x distance moved by effort

Or load/effort = distance moved by effort (*a*)/ distance moved by load (*l*) = velocity ratio

Hence for an ideal or perfect machine mechanical advantage = velocity ratio.

Efficiency (E_f)

The efficiency (E_f) of a machine is defined as:

E_f = Useful work done by the machine/Work put into the machine

Usually, the efficiency of a machine is expressed as a percentage:

E_f = Useful work done by the machine/Work put into the machine x 100%

Since work (*W*) is given by

W = Load (L)/Effort (E) x distance moved by load (*l*)/distance moved by effort (*e*) x 100%

= L/E x *l*/*e* = L/E ¸ *e*/*l*

= **Mechanical Advantage/Velocity x 100%**

E_f = MA/VR x 100%

A perfect or ideal machine has 100% efficiency. This means that all the work done by the effort is wholly used to overcome the load. In practical machines the efficiency is usually less than 100% because of friction in the moving parts of the machine. In such practical machines, part of the effort applied is used to overcome frictional forces which are always present. Thus the useful work done by the machine is less than the work done by the effort on the machine.

Types of Machines

1. The Lever

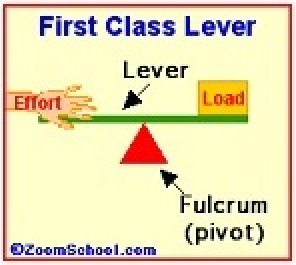
The lever is one of the simplest machines known. With it we can overcome a large resistance by the application of a small force.

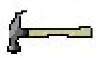
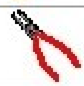
It consists of a steel bar or rigid rod supported at the fulcrum or pivot about which it can rotate. An effort (E) applied at one point of the lever lifts a load (L) or overcomes a resistance at some other points.

The lever operates on the principle of moments.

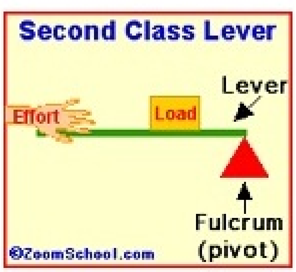
Types of Levers

There are three classes of levers: First order, Second order and Third order. The classification is dependent on the relative positions of the effort, load and fulcrum. In the first order of levers; the fulcrum or pivot is between the load and the effort. Examples of such levers are (i) the crowbar, a pair of scissors or pincers, claw hammers and pliers. Velocity ration is usually greater than 1 but could be less or equal to 1.



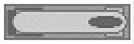
Item		Number of Class 1 Levers Used
see-saw		a single class 1 lever
hammer's claws		a single class 1 lever
scissors		2 class 1 levers
pliers		2 class 1 levers

The Second Class Lever



In a Type 2 Lever, the load is between the pivot (fulcrum) and the effort.

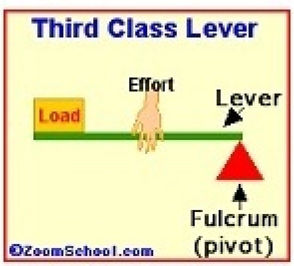
Examples of common tools that use a type 2 lever include:

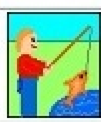
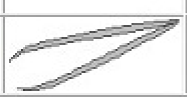
Item		Number of Class 2 Levers Used
stapler		a single class 2 lever
bottle opener		a single class 2 lever
wheelbarrow		a single class 2 lever
nail clippers		Two class 2 levers
nut cracker		Two class 2 levers

The Third Class Lever

In a Type 3 Lever, the effort is between the pivot (fulcrum) and the load.

Examples of common tools that use a type 3 lever include:

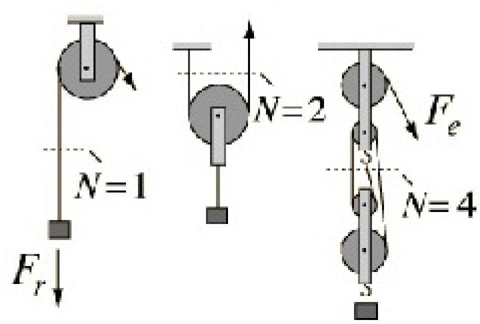


Item		Number of Class 3 Levers Used
fishing rod		a single class 3 lever
tweezers		Two class 3 levers
tongs		Two class 3 levers

The Pulley System

A pulley is a wheel with a groove along its edge, where a rope or cable can be placed. It uses the principle of applying force over a longer distance, and also the tension in the rope or cable, to reduce the magnitude of the necessary force. Complex systems of pulleys can be used to greatly reduce the force that must be applied initially to move an object.

The pulley is one of the so-called "simplemachines" from which many more complex machines are derived. With a single fixed-axis pulley, the ideal mechanical advantage is just N=1. You get the convenience of being able to redirect the effort force F_e, so that you can stand clear of the load. With a suspended pulley as in the middle illustration, the upward forces in the two ropes is equal, and therefore each supports half of the load, giving an IMA of N=2.



Pulley $IMA = N$

With a four-pulley set as shown, you have four ropes supporting the load, so the effort force F_e that establishes the rope tension is just one-fourth of the load in the ideal case, so IMA=4. All these force relationships are obtained from the force equilibrium condition, which in this case just amounts to "forces up = forces down" at any cross-section of the system.

Question:

A block and tackle system of pulleys consisting of 4 pulleys is used to raise a load of 500 N through a height of 20 m. If the total work done against friction in the pulley is equivalent to 800 J, calculate

1. The total work done by the effort

A. 10000 J B. 10800 J C. 12000 J D. 8000 J

2. The efficiency of the system

A. 90 % B. 97 % C. 92.6 % D. 40.5 %

3. The effort applied

A. 176 N B. 145 N C. 153 N D. 167 N

4. How many classes of levers exist in this topic?

A. One B. Two C. Three D. Four

5. Type one lever items include all, except

A. Hammer’s claw B. Scissors C. Screw Driver D. Plier

Answer

1. B 2. C 3. C 4. C 5. C

SECOND TERM NOTES ON PHYSICS

TABLE OF CONTENTS

SECOND TERM

WEEK 1

Topic: HEAT ENERGY AND ITS MEASUREMENTS

Temperature

Temperature is defined as the degree of hotness or coldness of a body. It is the property of an object which determines which way heat energy will flow when it is placed in contact with another object. Heat always flows from a body at higher temperature to a body at lower temperature. Heat is a form of energy – thermal energy. When a body absorbs heat without changing its state, its temperature rises. Heat depends on the mass of a body and its temperature.

Heat is a measure of the total energy of a body. It is a form of energy due to a temperature difference. Temperature is the degree of hotness or coldness of the body and it is related to the energy of movement. It is a measure of the average kinetic energy of the molecules in a body. Unit of Heat is the Joule, unit of Temperature is degree Celcius (^0C) or Kelvin (K).

Methods of Measuring Temperature

Our sense of touch can give us a general impression of the degree of hotness or coldness of a body. This is however not a reliable method of estimating or measuring a temperature, because the response of the human sense of touch to a temperature change tends to be influenced by its previous experience. Thus warm mater will feel cool if a hand initially dipped in hot water is transferred to it. Hence in order to gauge accurately the exact degree of hotness, an instrument called the thermometer is used. Thermometers are much more reliable instruments for measuring temperatures.

Thermometers use any physical property of a substance which varies in a known way with temperature, and is easily measurable as a means of gauging temperature. The substance of whose physical property is so used is known as a thermometric substance.

Fixed Temperature and Temperature Scales of Thermometer

Each thermometer has two reference temperatures or fixed points called the upper fixed temperature point and the lower fixed temperature point.

The **Upper fixed point** is the temperature of steam from pure water boiling at standard atmospheric pressure of 760 mm of mercury.

The **Lower fixed point** is the temperature of pure melting ice at the standard atmospheric pressure of 760 mm of mercury.

The difference in temperature between the two temperature points is called the fundamental interval (or temperature interval) of a thermometer. The calibration of this interval depends on the temperature scale chosen. There are three types of scale in current use

1. The Celcius scale

2. The Fahrenheit scale

3. The Absolute (or thermodynamic or Kelvin) scale

The lower and upper fixed points are ^{o}C and 100^{o}C for the Celcius scale; 32^{o}F and 212 ^{o}F for the Fahrenheit scale. The fundamental interval in the Celcius scale is divided into 100 equal parts,ech part of which defines 1 ^{o}C in this scale. For the Fahrenheit scale, the fundamental interval is divided into 180 units or degrees (^{o}F).

The S.I. unit of temperature is the Kelvin (K) and its scale is called the Absolute or Thermodynamic temperature scale. The fundamental interval for the Kelvin scale goes form a lower fixed point of 273 K to an upper fixed point of 373 K i.e. a difference of 100 K. This interval is divided into 100 equal parts each of which is equal to 1 K. Temperature on this scale are not measured in degrees but in units called Kelvin (K). Hence the unit symbol K is written without the degree sign. The lower fixed point or the aero on the Kelvin scale is equal to -273 ^{o}C. It is called absolute zero.

Hence -273^{o}C = 0 or 0^{o}C = 273 K

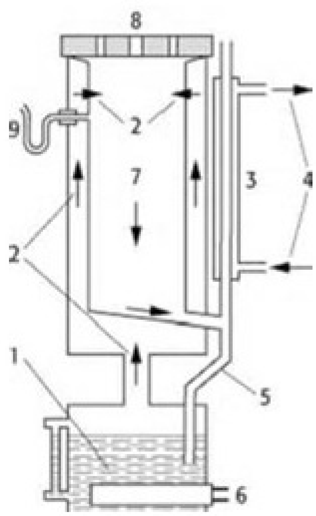
A temperature of q^{o}C in the Celcius scale is related to T of the Kelvin scale by

T = q + 273

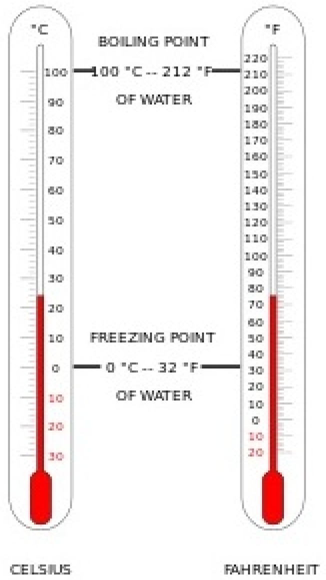
The upper fixed point on the Kelvin scale 373 K or 100°C. Nevertheless a temperature change of 1 K. Thus we can for example say that the thermal expansivity of brass is 18 x 10^{-6}/K or 18 x 10^{-6}/°C or that a heat quantity which has a value of 100J/K in S.I. units.

The Upper Fixed Points

The upper fixed point of an unmarked thermometer can be determined using a hypsometer, a double wallet copper vessel constructed as shown below.



A Hypsometer



Comparison of the Centrigrade and Fahrenheit Scales

Types of Thermometers

Resistance thermometer

A. Resistance thermometer

1.Thermometers which use liquids inside the glass are not suitable to be used for measuring a wide range of temperature. e.g. temperature ranging from -250 degree Celcius to about 700 degree Celsius.

2. A suitable thermometer which is used for the above range of temperatures is a resistance thermometer.

3. A resistance thermometer uses the property of the change in the platinum wire with a change in temperature.

4. The current flowing in the wire experiences more resistance when the wire becomes hot.

5. The change in the resistance of the wire is directly proportional to the change in temperature.

6. A milliammeter can and should be calibrated before hand to measure the temperature.

7. Its calibration of the melting limit of water and the boiling point of water at a pressure of 1 atmosphere is able to convert the milliameter scale to a temperature scale in degree Celsius.

8. Therefore, this thermometer is very accurate.

B. Thermocouple thermometer

1. An electromotive force (e.m.f.) will be produced in a thermocouple when there is a temperature difference between the hot junction and the cold junction. Once this happens, a current will flow.

2. This thermometer is very sensitive and responds towards slight change in temperature.

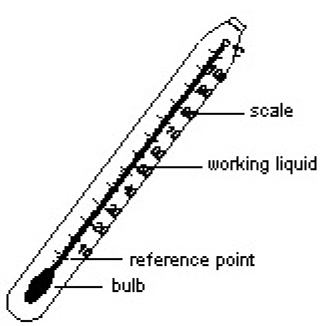
3. Since the physical quantity which is used to measure the temperature is the e.m.f, this thermometer can be connected to other electrical circuits to control or record the surrounding temperature.

4. A thermocouple thermometer is a very sensitive thermometer which is suitable for measuring temperatures ranging from -250 degree Celsius to 1600 degree Celsius.

C. Liquid-in-glass Thermometers

A liquid-in-glass thermometer is widely used due to its accuracy for the temperature range -200 to 600°C. Compared to other thermometers, it is simple and no other equipment beyond the human eye is required. The LIG thermometer is one of the earliest thermometers. It has been used in medicine, metrology and industry. The first thermometer appeared around 1650 and was a development from the thermoscope. The liquid used was spirit from wine. By 1714, thermometers with mercury were found to give a more linear scale than spirits. By 1742, a centigrade scale using 100 steps from the point of boiling water to the melting point of water was suggested by Anders Celsius.

In the LIG thermometer the thermally sensitive element is a liquid contained in a graduated glass envelope. The principle used to measure temperature is that of the apparent thermal expansion of the liquid. It is the difference between the volumetric reversible thermal expansion of the liquid and its glass container that makes it possible to measure temperature.



The accuracy of measurement depends mainly on the extent of immersion of the thermometer into the medium - not just the bulb but also the stem.

D. Mercury

1. The physical quantity that is used to determine the temperature of a body by means of a mercury thermometer is the length of the thread mercury, or to be more exact, the volume of mercury.

2. When the temperature increases, the volume of the mercury increases too.

3. The sensitivity of a mercury thermometer can be increased by

a. reducing the diameter of the capillary tube.
b. increasing the size of the bulb.
c. using a thinner-walled glass bulb.

4. Normally mercury is used in a thermometer because it:

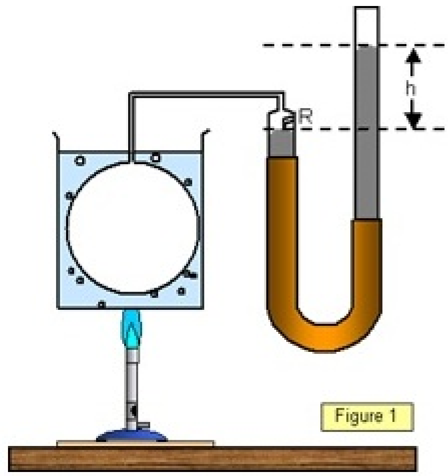
a. Expands uniformly.
b. has a higher boiling limit.
c. is opaque and therefore it is easier to read off the temperature.
d. is a good conductor of heat.
e. does not stick to the glass.

5. One weakness of the mercury thermometer in the measurement of an accurate temperature is that the glass of the capillary tube also expands when the temperature expands.

In addition to that, it is extremely dangerous if the glass tube breaks because mercury is very poisonous.

Mercury thermometer is suitable to measure temperature between -30 degree Celsius to 300 degree Celcius.

E. Gas thermometers



There are two main types of gas thermometer, one operating at constant volume and the other at constant pressure. The constant-volume gas thermometer is by far the more widely used and so we will deal with it alone.
The ideal gas equation states that for n moles of a gas:

PV = nRT

and therefore for a gas at constant volume V the absolute temperature T is directly proportional to the pressure of the gas P.

A simple form of constant-volume gas thermometer is shown in Figure 1. The gas is enclosed in the bulb B and the pressure recorded by the difference in levels (h) of the mercury columns. The mercury level at R is always adjusted so that it coincides with the mark. The pressure of the gas within the bulb is then given by P = A + h, where A is the atmospheric pressure.

If the atmospheric pressure varies during the experiment allowance must be made for this, since it is the total gas pressure that is measured.

The gas in the bulb can be air, hydrogen, helium or nitrogen, although it is the constant-volume

hydrogen gas thermometer that is taken as standard.

The simple form of constant-volume gas thermometer is subject to errors due to changes in volume of the glass and of the mercury (due to temperature variations), to pressure on the bulb and to the exposed column 'dead space', that is, the volume of gas that is outside the region of which the temperature is being measured.

It has the further disadvantages that it is not direct-reading, and that it cannot be used to measure varying temperatures, because gases are such poor conductors of heat.

A more accurate form of constant-volume thermometer has been designed where some of these errors are reduced, the dead space is made as small as possible and the bulb containing the gas is large (1.6 litres).

By using different gas thermometers a wide range of temperatures can be measured:

Hydrogen -200 ^{o}C to +500 ^{o}C
Nitrogen +500 ^{o}C to + 1500 ^{o}C
Helium -270 ^{o}C to + 1500 ^{o}C

These thermometers can be very accurate, to within 0.005 ^{o}C from 0 ^{o}C to 100 ^{o}C, 0.1 ^{o}C around 500 ^{o}C and to within 2 ^{o}C at 1500 ^{o}C

The almost the length of the thermometer hangs freely in the steam in the inner chamber well above the boiling water and is placed in such a way that its mercury thread is just visible above the top of a cork. A manometer is attached to the inner chamber of the hypsometer to ensure that the pressure within it is 760 mm 0f mercury. This is so when the mercury levels in both arms of the manometer are the same. Also attached to the vessel is a steam-outlet to ensure that no steam condenses on the thermometer. The water is heated until it starts boiling.

When the thermometer has been in the steam for some time and the position of the mercury thread has remained steady, its level is marked on the stem by a light scratch. This mark is the upper fixed point or the upper temperature point.

An important precaution is to ensure that the bulb of the thermometer does not come in contact with the boiling water. The thermometer should be suspended only in the steam. Also we must avoid parallax error in locating the boiling point.

The Lower Fixed Point

The lower fixed point is determined by placing the thermometer upright in pure melting ice contained in a glass funnel when the mercury level remains steady for sometime, a mark is made on the stem of the thermometer to indicate this level, which represents the lower temperature level.

There are three modes of transfer of heat

Conduction: The mode of transfer of heat from molecules to molecules without movement of particles.. Conduction takes place in solid as its molecules ate closely packed. Solids, metals and alloy are good conductor. Non metals, plastic glass are bad conductor of heat.

Convection: The mode of transfer of heat from molecules to molecules with movement of particles. In liquids and gasses heat transferred by convection as molecules are far apart from each other.

Radiation: The mode of transfer of heat that does not require any material medium. Heat of sun reach the earth by radiation.

Question

1. These are the effects of heat except

A. Heat increases in temperature B. Heat expands a substance C. Heat changes the state D. Heat brings chain reaction

2. Mercury is preferred in thermometers, which of these is not correct?

A. It expands uniformly B. It turns solid at room temperature. C. It does not stick to wall D. It is shiny and easy to see

3. The lower and upper fixed point for the Celcius scales are (note: all in ^{o}C)

A. 0 and 272 B. 0 and 373 C. 10 and 100 D. 0 and 100

4. There are how many types of scales in current use?

A. 1 B. 2 C. 3 D. 4

5. Which is not correct as part of the types of thermometer?

A. Gas Thermometer B. Plastic Thermometer C. Resistance thermometer D. Thermoelectric thermometer

Answers

1. D. 2. B 3. C 4. C 5. B

Week 2

Topic: Heat Capacity

Introduction

The heat capacity measures the amount of heat necessary to raise the temperature of an object or system by one degree Celsius.

Heat capacity is defined as the ratio of the heat energy added to an object to its change in temperature.

Heat capacity is the measurable physical quantity that characterizes the amount of heat required to change a substance's temperature by a given amount. It is measured in joules per Kelvin and given by $C = Q/\Delta T$

The heat capacity is an extensive property, scaling with the size of the system.

The heat capacity of most systems is not constant (though it can often be treated as such). It depends on the temperature, pressure, and volume of the system under consideration.

Enthalpy the total amount of energy in a system, including both the internal energy and the energy needed to displace its environment

Heat capacity (usually denoted by a capital C, often with subscripts), or thermal capacity, is the measurable physical quantity that characterizes the amount of heat required to change a substance's temperature by a given amount. In SI units, heat capacity is expressed in units of joules per kelvin (J/K).

An object's heat capacity (symbol *C*) is defined as the ratio of the amount of heat energy transferred to an object to the resulting increase in temperature of the object

Heat capacity is an extensive property, so it scales with the size of the system. A sample containing twice the amount of substance as another sample requires the transfer of twice as much heat (Q) to achieve the same change in temperature

(ΔT). For example, if it takes 1,000 J to heat a block of iron, it would take 2,000 J to heat a second block of iron with twice the mass as the first.

The Measurement of Heat Capacity

The heat capacity of most systems is not a constant. Rather, it depends on the state variables of the thermodynamic system under study. In particular, it is dependent on temperature itself, as well as on the pressure and the volume of the system, and the ways in which pressures and volumes have been allowed to change while the system has passed from one temperature to another. The reason for this is that pressure-volume work done to the system raises its temperature by a mechanism other than heating, while pressure-volume work done by the system absorbs heat without raising the system's temperature. (The temperature dependence is why the definition of a calorie is formally the energy needed to heat 1 g of water from 14.5 to 15.5 °C instead of generally by 1 °C.)

Different measurements of heat capacity can therefore be performed, most commonly at constant pressure and constant volume. The values thus measured are usually subscripted (by p and V, respectively) to indicate the definition. Gases and liquids are typically also measured at constant volume. Measurements under constant pressure produce larger values than those at constant volume because the constant pressure values also include heat energy that is used to do work to expand the substance against the constant pressure as its temperature increases. This difference is particularly notable in gases where values under constant pressure are typically 30% to 66.7% greater than those at constant volume.

Thermodynamic Relations and Definition of Heat Capacity

The internal energy of a closed system changes either by adding heat to the system or by the system performing work. Recalling the first law of thermodynamics,

For work as a result of an increase of the system volume we may write,

$dU = dQ - PdV$

If the heat is added at constant volume, then the second term of this relation vanishes and one readily obtains

$(¶U/¶T)_V = (¶Q/¶T)_V = C_V$

This defines the *heat capacity at constant volume*, C_V. Another useful quantity is the *heat capacity at constant pressure*, C_P. With the enthalpy of the system given by

$H = U + PV$

our equation for d*U* changes to

$dH = ¶Q + VdP$

and therefore, at constant pressure, we have

$(¶H/¶T)_P = (¶Q/¶T)_P = C_P$

Specific Heat Capacity

Specific heat capacity of a substance is defined as the heat capacity of the substance per unit mass of the substance. Therefore, if energy Q is given to the substance having mass m, and it results in the change in the temperature of the substance by ΔT. Hence, Specific Heat of the substance is

c = *Q/mΔT*

Heat capacity of a substance is denoted by C. It is defined as the amount of energy which is required to increase the temperature of the substance by 1°C.

Specific heat capacity (*c*) of a substance is the heat required to produce unit temperature rise in unit mass of the substance.

Specific Heat

When energy is given to a substance and the substance is not performing any work, it results into increase in temperature of the substance. (If the temperature of the substance is not increased, when the heat is given to it, and also the substance is not performing any work, it could lead to change in the phase of the substance and this phenomenon is termed as Phase Transition). Amount of heat, required to raise the temperature of a substance by a certain amount, depends on the properties of the substance and this amount of heat varies from substance to substance.

For example, the amount of energy or heat required to increase the temperature of 1 kg of water by 1°C is 4.186 J, but the amount of heat required to increase the temperature of 1 kg of copper by 1°C is only 387 J. There are two methods to increase the temperature of the substance:

1. By transferring heat or energy to it.

2. By doing Work on it.

According to the definition, if heat Q given to the substance increases the temperature of the substance by ΔT, then

$Q = C\Delta T$

Specific Heat Formula

Specific heat is essentially a measure of how thermally insensitive a substance is to the addition of energy. If the specific heat capacity of a substance is more, then for a given mass m of a substance, for a particular ΔT temperature change, more energy Q needs to be transferred to the substance as compared to the second substance having less specific heat capacity. Therefore, more the specific heat capacity, more energy needs to be transferred to the substance if the other conditions (Q, m,ΔT) are same.

Formula for specific heat can be written as $\mathbf{c} = Q/m\Delta T$

Specific Heat Units: SI unit of Specific Heat is Joules per Kilogram Kelvin. (J/kg.K).

Specific Heat Table

Specific Heat Table for some of the substances is given below at 25 ^{0}C and Standard Atmospheric pressure

Substance	Specific Heat(J/kg. °C)
Specific Heat of Beryllium	1830
Specific Heat of Cadmium	230
Specific Heat of Copper	387
Specific Heat of Germanium	322
Specific Heat of Gold	129
Specific Heat of Iron	448
Specific Heat of Lead	128
Specific Heat of Silicon	703
Specific Heat of Silver	234
Specific Heat of Brass	380
Specific Heat of Glass	837
Specific Heat of Ice(-5°C)	2090
Specific Heat of Marble	860
Specific Heat of Wood	1700
Specific Heat of Alcohol(ethyl)	2400
Specific Heat of Mercury	140
Specific Heat of Water(15°C)	4186
Specific Heat of Steam(100°C)	2010
Specific Heat of Aluminium	900
Specific Heat of Tin	540

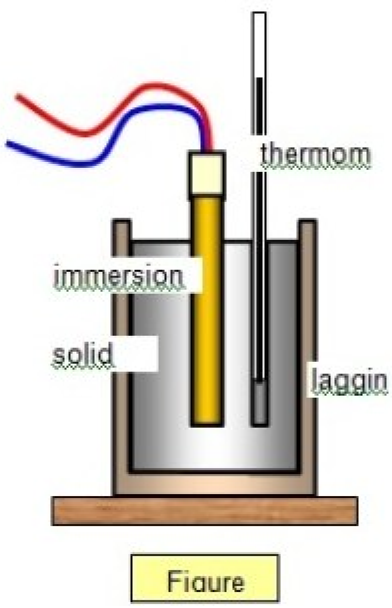
Specific Heat of Steel	120
Specific Heat of Sand	830
Specific Heat of Ethanol (Alcohol, ethyl 32°F)	2.3 K

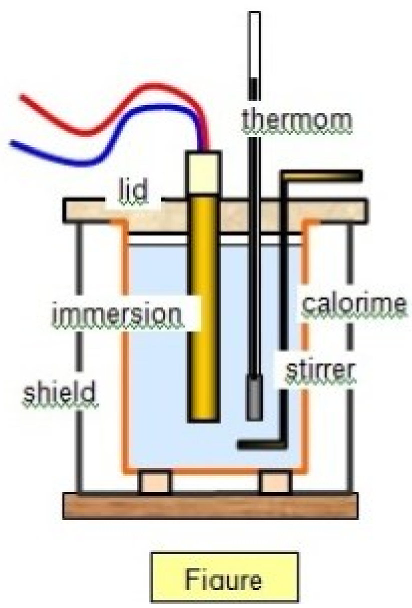
Methods of determining Specific Heat Capacity

There are several simple methods for measuring the specific heat capacities of both solids and liquids, such as the method of mixtures, but we will consider here only electrical methods. Since the specific heat capacity varies with temperature, we have seen it is important to record the mean temperature at which the measurement is made.

Electrical calorimeters

Figure 1(a) and 1(b) show possible arrangements for electrical calorimeters for a solid and a liquid specimen.



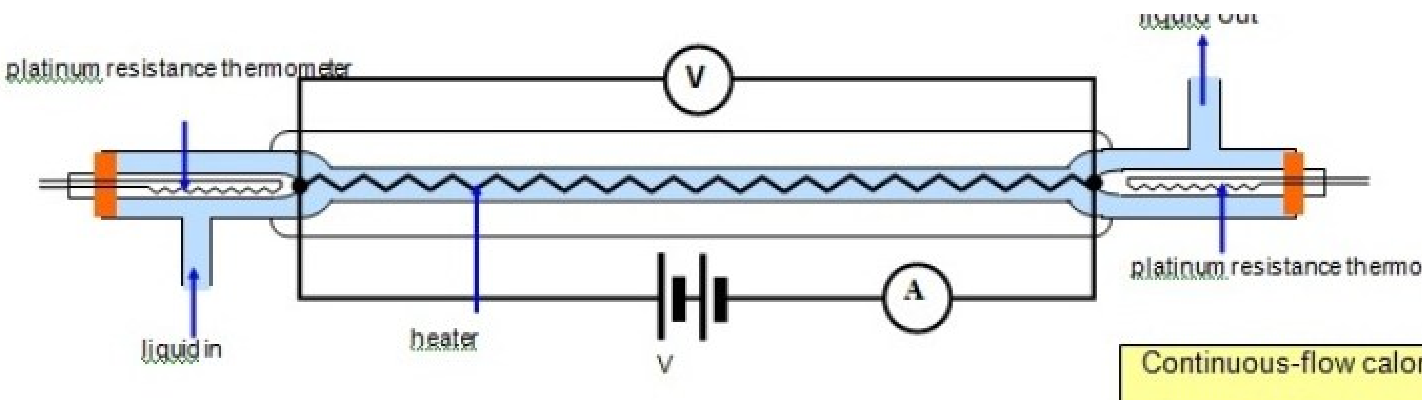


The material under investigation is heated by an electrical immersion heater and the input energy (Q) and the rise in temperature that this produces are measured. If the mass of the specimen (solid or liquid) is m and its specific heat capacity C, then $Q = m\,C\,(q_1 - q_0) + q$

where θ_0 and θ_1 are the initial and final temperatures of the specimen and q is the heat loss. Using the cooling correction, the value of q may be found. This simple method can be used for liquids or solids, although in the case of a liquid, allowance has to be made for the thermal capacity of the container, and the liquid should also be stirred to allow an even distribution of the heat energy throughout its volume. This is necessary since liquids are such poor thermal conductors

The continuous-flow calorimeter

This was first developed by Calendar and Barnes in 1902 for the measurement of the specific heat capacity of a liquid, and is shown in diagram below. Its main advantage is that the thermal capacity of the apparatus itself need not be known.



Liquid flows in from a constant-head apparatus at a constant rate past a thermometer (θ_0). It then flows around the heater coil and out past a second thermometer where the outlet temperature (θ_1) may be measured. When steady-state conditions have been reached (a temperature difference between inlet and outlet points of 5^0C is reasonable) the temperatures and the flow rate of the liquid (m) are measured. A vacuum jacket round the heater coil reduces heat losses.

The electrical energy supplied to the heater coil (E = V I t) may be found readily with a joulemeter or with an ammeter and voltmeter.

Two sets of measurements are carried out.

For a first experiment we have:

Electrical energy supplied (E_1) = $V_1 I_1 t_1 = m_1 C (\theta_1 - \theta_0) + q$

C is the specific heat capacity of the liquid and q the heat loss to the surroundings and to the apparatus.

The flow rate and rate of energy input are now altered to give a second set of results. However, if the inlet and outlet temperatures are the same as in the first experiment the heat loss will also be the same. Therefore:

Electrical energy supplied (E_2) = = $V_2 I_2 t_2 = m_2 C (\theta_1 - \theta_O) + q$

Eliminating the heat loss (q) gives

Specific heat capacity of the liquid (C) = $[E_2 - E_1]/ (m_2 - m_1)(q_1 - q_o)$

Practical advice

A smaller amount of water could be heated in a polystyrene cup than in a calorimeter; this reduces the heating time needed and provides insulation. *The heater must be covered by the water*. The heat absorbed by the polystyrene is also small compared to that absorbed by the calorimeter. However take care that the heater does not touch the cup or it will melt. Thermometers can also overbalance the cup. Always stir liquids before taking a temperature.

It is better to choose an immersion heater that fits all the way into the solid material rather than having part of it in the air. The top of the block should also be lagged. Take the highest temperature reached by the block after the heater has been switched off.

Questions

1. The heat capacity measures the amount of heat necessary to raise the temperature of an object or system by ……………. degree celsius.

A. One B. Hundred C. Ninety D. One thousand

2. Heat Capacity is measured in

A. Kelvin per joules B. joules per Kelvin C. Joules D. Kelvin

3. The specific heat value for Aluminium in J/kg. °C is

A. 800 B. 900 C. 980 D. 450

4. Formula for Specific Heat Capacity can be written a s

A. $Q/m\Delta T$ B. $Qm\Delta T$ C. $Q\Delta T$ D. $m\Delta T$

5. The heat capacity of most systems is not a constant. Rather, it depends on the state variables of the thermodynamic system under study. In particular, it is dependent on

A. Temperature only B. Pressure and Temperature C. Volume and Pressure D. Temperature, Volume and Pressure.

Answers

1. A 2. B 3. B 4. A 5. D

WEEK 3

Topic: SPECIFIC HEAT CAPACITY

CALCULATIONS ON SPECIFIC HEAT CAPACITY

If someone increases the temperature of the substance, there will be an increase in the kinetic energy of its molecules – that is increase in its internal energy. So one needs to supply energy. The energy needed to raise the temperature of an object is proportional to the increase in temperature and mass of the object

Energy $\propto$ mass $\times$Temperature rise

Here the constant of proportionality which is depends on the substance, is called the **Specific Heat Capacity (c).**

So,

Energy=mass $\times$ specific heat capacity $\times$ Temperature rise

$q = m \times c \times \Delta T$

The energy gained or lost as heat when a given mass of a substance is warmed or cooled can be calculated using above equation.

So the specific heat capacity,

$c = q/m \times \Delta T$

Here,
c = The specific heat capacity

q = It is the energy gained or lost.

m = Mass of the substance

$\Delta T = T_{final} - T_{initial}$ = the change in temperature.

The units of the specific heat capacity are J/kgK = $Jkg^{-1}K^{-1}$.

A 43.2 g block of an unknown metal at 89.0 °C was dropped into an insulated vessel containing 43.00 g of ice and 26.00 g of water at 0 °C. After the system had reached equilibrium it was determined that 9.15 g of the ice had melted. What is the specific heat of the metal? (The heat of fusion of ice = 334.166 J g^{-1}.)

Solution:

Comment: this variation of the usual suspects (detailed above) does NOT involve a temperature change in the water, only in the metal. Rather, some ice melts and the whole ice-water system stays at zero Celsius.

1) Determine heat gained by the ice that melted:

9.15 g times 334.166 J g^{-1} = 3057.62 J

2) Then substitute and solve for the specific heat:

q = (mass) (Δt) ($C_{p,\ metal}$)

3057.62 J = (43.2 g) (89.0 °C) (x)

x = 0.795 J g^{-1} $°C^{-1}$

A 35.0 g block of metal at 80.0 °C is added to a mixture of 100.0 g of water and 15.0 g of ice in an isolated container. All the ice melted and the temperature in the container rose to 10.0 °C. What is the specific heat of the metal?

Solution:

1) Determine heat required to melt the ice:

q = (15.0 g) (334.166 J g^{-1}) = 5012.49 J

Note that the 100 g of water is not mentioned yet.

2) Determine heat need to raise 115 g of water from 0 to 10.0 °C:

$q = (115\ g)\ (10.0\ °C)\ (4.184\ J\ g^{-1}\ °C^{-1}) = 4811.6\ J$

Note the inclusion of the melted 15 g of ice. Also, notice that the water was at zero °C. We know this from the presence of the ice.

3) Determine the specific heat of the metal:

$(5012.49\ J + 4811.6\ J) = (35.0\ g)\ (70.0\ °C)\ (x)$

$x = 4.01\ J\ g^{-1}\ °C^{-1}$

A piece of metal weighing 59.047 g was heated to 100.0 °C and then put it into 100.0 mL of water (initially at 23.7 °C). The metal and water were allowed to come to an equilibrium temperature, determined to be 27.8 °C. Assuming no heat lost to the environment, calculate the specific heat of the metal.

$q_{metal} = q_{water}$

$(mass)\ (\Delta t)\ (C_p) = (mass)\ (\Delta t)\ (C_p)$

$(59.047\ g)\ (72.2\ °C)\ (x) = (100.0\ g)\ (4.1\ °C)\ (4.184\ J\ g^{-1}\ °C^{-1})$

$x = 0.402\ J\ g^{-1}\ °C^{-1}$

A 25.6 g piece of metal was taken from a beaker of boiling water at 100.0 °C and placed directly into a calorimeter holding 100.0 mL of water at 25.0 °C. The calorimeter heat capacity is 1.23 J/K. Given that the final temperature at thermal equilibrium is 26.2 °C, determine the specific heat capacity of the metal.

Solution:

1) We know this:

$q_{lost,\ metal} = q_{gained}$

2) However, energy is gained by two different entities (the water and the calorimeter itself). Therefore:

$q_{lost,\ metal} = q_{gained,\ water} + q_{gained,\ calorimeter}$

3) Substituting, we have:

(mass) (Δt) ($C_{p,\ metal}$) = (mass) (Δt) ($C_{p,\ water}$) + (Δt of water) (calorimeter constant)

4) Putting values into place and solving:

(25.6 g) (73.8 °C) (x) = (100.0 g) (1.2 °C) (4.184 J/g °C) + (1.2 °C) (1.23 J/K)

x = 0.266 J/g °C

How much energy must be transferred to raise the temperature of a cup of tea (250 ml) from 293.7 K to 368.8 K. Assume that the tea and water have the same density(1 g/ml), and specific heat capacity (4.184 J/gK).

Solution:

Given,

c = 4.184 J/gK

Mass (m) = 250ml1g/ml = 250g

$\Delta T = T_{final} - T_{initial}$ = 368.8K – 293.7K = 75.1 K

We have,

$q = m \times c \times \Delta T$

$= 250\times 4.184\times 75.1$

= 78.554kJ

A 245.7g sample of metal at 75.2 degrees Celsius was placed in 115.43g water at 22.6 degrees Celsius. The final temperature of the water and metal was 34.6 Celsius. If no heat was lost to the surroundings what is the specific heat of the metal?

$-q_{metal=}q_{water}$
-(mCΔT)=mCΔT
-(mC(Tf-Ti))= mC(Tf-Ti)
– (245.7g x C x (34.6^{o}C-75.2^{o}C))=115.43g(4.18J/g^{o}C)(34.6^{o}C-22.6^{o}C)C x (9975g^{o}C)=5790J0.580J/g^{o}C = CDetermine the final temperature when a 25.0g piece of iron at 85.0°C is placed into 75.0grams of water at 20.0°C. The specific heat of iron is 0.450 J/g°C. The specific heat of water is 4.18 J/g°C.$-q_{metal\ =}\ q_{water}$
-(mCΔT)=mCΔT
-(mC(T_f-T_i))= mC(T_f-T_i)

-(25.0g(0.450J/g^{o}C)(T_f-85.0^{o}C))=75.0g(4.18J/g^{o}C)(Tf-20.0^{o}C)

956.25-11.25T_f=313.5T_f-6270

7226.25=324.75T_f

7226.25/324.75=T_f

22.3^{o}C=T_f

Questions

1. Calculate the amount of heat needed to increase the temperature of 250g of water from 20^{o}C to 46^{o}C

A. 47 KJ B. 38 KJ C. 23 KJ D. 75 KJ

2. Calculate the specific heat capacity of copper given that 204.75 J of energy raises the temperature of 15g of copper from 25^o to 60^o.

A. 400 J g^{-1} $°C^{-1}$ B. 478 J g^{-1} $°C^{-1}$ C. 752 J g^{-1} $°C^{-1}$ D. 245 J g^{-1} $°C^{-1}$

3. What is the quantity of heat required to raise the temperature of 300 g of aluminium cube from 30^{0}C to 70^{0}C? (Specific heat capacity of aluminium is 900 $JKg^{-1}K^{-1}$

23 KJ B. 34 KJ C. 10.8 KJ D. 12.9 KJ

4. 216 J of energy is required to raise the temperature of aluminum from 15^o to 35^oC. Calculate the mass of aluminum.
(Specific Heat Capacity of aluminum is 0.90 $J^oC^{-1}g^{-1}$)

A. 14 g B. 10g C. 12g D. 25g

5. The temperature of a piece of Metal X with a mass of 95.4g increases from 25.0°C to 48.0°C as the metal absorbs 849 J of heat. What is the specific heat of Metal X?

A. 0.49 $Jg^{-1}\ {}^0C^{-1}$ B. 3.7 $Jg^{-1}\ {}^0C^{-1}$ C. 0.39 $Jg^{-1}\ {}^0C^{-1}$ D. 4.2 $Jg^{-1}\ {}^0C^{-1}$

Answers

1. B 2. B 3. C 4. C 5. C

WEEK 4

Topic: EVAPORATION, BOILING AND MELTING POINTS AND THEIR DETERMINATION

WHAT IS EVAPORATION?

In liquids, the molecules of the liquid are always in a state of random motion, within its surface. Some molecules may have sufficient kinetic energy to escape from the surface of the liquid. This process is known as **evaporation**. Evaporation takes place at all temperatures. Rate of evaporation increases with rise in temperature and becomes maximum at the boiling point of the liquid. The process of evaporation also increases with increase in surface area of the liquid.

Evaporation is a process where a liquid turns spontaneously into vapour below its boiling point.

Evaporation requires energy. A liquid draws heat energy from the surrounding thereby cooling the surrounding.

Example 1: Water placed in a porous pot becomes very cool after some time. This is because water molecules draw energy from the water itself for evaporation and hence, the temperature of water in the pot falls.

Example 2: If we smear our hand with spirit that portion feels cold because spirit evaporates quickly using heat energy from the skin.

Example 3: During summer process of perspiration keeps the body cool. When we perspire, the sweat evaporates using heat from our body thereby keeping it cool.

Example 4: Water cycle in nature is initiated by the evaporation of water from lakes, ponds, rivers, sea, etc. Water evaporates due to sun's heat. Water vapor rises to the sky to from clouds. Clouds condense to form raindrops, which fall on the earth. And the water cycle continues.

Molecular Explanation of Evaporation

According to the kinetic molecular theory of matter, a liquid consists of molecules that are in constant motion. The average velocity and hence the average kinetic energy of the molecules is related to the temperature of the liquid. When the temperature increases, the molecules gain more kinetic energy.

Molecules with high speed near the surface of the liquid may have enough kinetic energy to break away from the attraction of other molecules and move outside the liquid surface as molecules of vapour. Some of these molecules stay outside the liquid, some however return to the liquid due to the attractive forces from the molecules in the liquid. As more and more molecules stay outside the liquid surface, the liquid evaporates more and more. High temperatures increase the velocities of all the molecules, thus allowing more molecules to escape from the surface, hence increasing the rate of evaporation by sweeping away the molecules of vapours above the liquid surface, thus making for fresh supply of escaping molecules.

Cooling by Evaporation

Whenever methylated or petrol is spilled over any part of our body, we usually a cooling effect as the liquid evaporates. The body becomes cooler because the latent heat needed to convert the liquid to the vapour is extracted from the liquid or any other in contact with it. This extraction from of the latent heat from the liquid leads to a fall in its temperature. The faster the evaporation the greater is the fall in temperature.

The human body utilizes the effect of evaporation for cooling. Perspiration cools the body as sweat evaporates from the surface of the skin. As the latent heat of vaporization is extracted from the body, it is cooled in the process. Cooling by evaporation is also utilized by doctors from numbing pains from needle points. Volatile either methylated spirit is usually dabbed on the skin before the body is injected with some drug. As the methylated spirit evaporates, it cools the part of the skin and numbs it so that the pain from the needle prick during an injection process is not much felt.

Boiling point of certain liquids

Liquid	Boiling point
Water	100°c
Mercury	357°C
Ethyl alcohol	79°C
Methyl alcohol	64°C
Glycerol	290°C
Turpentine	156°C

Melting Point Determination

Pure, crystalline solids have a characteristic **melting point**, the temperature at which the solid melts to become a liquid. The transition between the solid and the liquid is so sharp for small samples of a pure substance that melting points can be measured to $0.1^{o}C$. The melting point of solid oxygen, for example, is $-218.4^{o}C$.

Liquids have a characteristic temperature at which they turn into solids, known as their **freezing point**. In theory, the melting point of a solid should be the same as the freezing point of the liquid. In practice, small differences between these quantities can be observed.

It is difficult, if not impossible, to heat a solid above its melting point because the heat that enters the solid at its melting point is used to convert the solid into a liquid. It is possible, however, to cool some liquids to temperatures below their freezing points without forming a solid. When this is done, the liquid is said to be *super cooled*.

An example of a super cooled liquid can be made by heating solid sodium acetate trihydrate ($NaCH_3CO_2$ 3 H_2O). When this solid melts, the sodium acetate dissolves in the water that was trapped in the crystal to form a solution. When the solution cools to room temperature, it should solidify. But it often doesn't. If a small crystal of sodium acetate trihydrate is added to the liquid, however, the contents of the flask solidify within seconds.

A liquid can become super cooled because the particles in a solid are packed in a regular structure that is characteristic of that particular substance. Some of these solids form very easily; others do not. Some need a particle of dust, or a seed crystal, to act as a site on which the crystal can grow. In order to form crystals of sodium acetate trihydrate, Na^+ ions, $CH_3CO_2^-$ ions, and water molecules must come together in the proper orientation. It is difficult for these particles to organize themselves, but a seed crystal can provide the framework on which the proper arrangement of ions and water molecules can grow.

Because it is difficult to heat solids to temperatures above their melting points, and because pure solids tend to melt over a very small temperature range, melting points are often used to help identify compounds.

Measurements of the melting point of a solid can also provide information about the purity of the substance. Pure, crystalline solids melt over a very narrow range of temperatures, whereas mixtures melt over a broad temperature range. Mixtures also tend to melt at temperatures below the melting points of the pure solids.

Boiling Point

When a liquid is heated, it eventually reaches a temperature at which the vapor pressure is large enough that bubbles form inside the body of the liquid. This temperature is called the **boiling point**. Once the liquid starts to boil, the temperature remains constant until all of the liquid has been converted to a gas.

The normal boiling point of water is 100^oC. But if you try to cook an egg in boiling water while camping in the Rocky Mountains at an elevation of 10,000 feet, you will find that it takes longer for the egg to cook because water boils at only 90^oC at this elevation.

In theory, you shouldn't be able to heat a liquid to temperatures above its normal boiling point. Before microwave ovens became popular, however, pressure cookers were used to decrease the amount of time it took to cook food. In a typical pressure cooker, water can remain a liquid at temperatures as high as 120^oC, and food cooks in as little as one-third the normal time.

To explain why water boils at 90°C in the mountains and 120°C in a pressure cooker, even though the normal boiling point of water is 100°C, we have to understand why a liquid boils. By definition, a liquid boils when the vapor pressure of the gas escaping from the liquid is equal to the pressure exerted on the liquid by its surroundings, as shown in the figure below.

The normal boiling point of water is 100°C because this is the temperature at which the vapor pressure of water is 760 mmHg, or 1 atm. Under normal conditions, when the pressure of the atmosphere is approximately 760 mmHg, water boils at 100°C. At 10,000 feet above sea level, the pressure of the atmosphere is only 526 mmHg. At these elevations, water boils when its vapor pressure is 526 mmHg, which occurs at a temperature of 90°C.

Liquids often boil in an uneven fashion, or *bump*. They tend to bump when there aren't any scratches on the walls of the container where bubbles can form. Bumping is easily prevented by adding a few boiling chips to the liquid, which provide a rough surface upon which bubbles can form. When boiling chips are used, essentially all of the bubbles that rise through the solution form on the surface of these chips.

Difference between Boiling and Evaporation

Evaporation	**Boiling**
It occurs at all temperature	It occurs at the boiling point of the liquid
It causes cooling	It does not cause cooling
It occurs only at the surface	It occurs in every part of the liquid
It is not affected by the mass of the liquid exposed	It is affected by the mass of the liquid exposed
It does not depend on the container of the liquid	It depends on the container, because they

	absorb their own energy first
Wind assists evaporation	Wind has no effect on boiling

Effects of Impurities on Boiling

Impurities affect the boiling point of a liquid, because their presence increases the boiling point of the **liquid, compared to the boiling point of a pure solvent.**

Effect of Pressure on Boiling

Pressure affects the boiling point of a liquid, because an increase in pressure will lead to a decrease in boiling point. This explanation has a practical application in pressure cooker which is a sauce-pan with lid that can be held be down.

Application of Pressure on Boiling Point

1. It is used in the principle of pressure cooker

2. The aircraft flying at high altitude, where air is of lower pressure than normal, needs to be pressurized so that the people can be at their normal pressure.

3. Astronauts must wear space suits not only for breathing but for them to be at right pressure.

Sublimation

This is a process by which a solid is heated straight to vapour without passing through the intermediate liquid state. The solid molecules acquire some kinetic energy which is very great and instead of the solid melting into a liquid phase, it is converted into gaseous or vapour state at a very high temperature, e.g. ***dry ice when changed to vapour*.**

Effect of Pressure on Melting Point

The increase in pressure on a substance lowers it melting point. Consider an ice placed on a insulator and a thin wire with heavy weight attached to both ends and hung over the block., after sometime, it is observed that the wire starts passing through the ice, but the block remains solid behind it and the water above the wire passes through the ice block and the block does not slip. As the wire passes through the ice, the pressure above it decreases, thus raising the freezing point of melted ice above it when freezes again. This process is called *regelation*.

Effect of Impurities on Melting Point

When there are impurities, e.g. salt, sand, etc in a substance, this lowers the melting point. For example, when a salt is mixed with ice, the ice melts taking heat from the salt and freezes at a temperature below 0^oC – 23^oC, from normal freezing point of ice. The mixture is also called *freezing mixture*.

Application of Pressure and Impurities

(i) In temperature climate, the sea which is made of salt will not freeze even when it is covered with ice. This explains how the aquatic animals adapt to it.

(ii) Salt thrown on the road full of ice brings down the freezing point and the melting point of the ice, so as to become droplet of water.

Questions

1. Molecules with high speed near the surface of the liquid may have enough …………………. to break away from the attraction of other molecules and move outside the liquid surface as molecules of vapour.

A. Potential Energy B. Kinetic Energy C. Mechanical Energy D. Electrical Energy

2. Which of these is not correct about Boiling Point?

A. It is affected by the mass of the liquid exposed B. It does not cause cooling C. It

3. Which of these is not correct about Evaporation?

A. It does not cause cooling

B. It occurs at all temperature

C. It does not depend on the container of the liquid

D. It is not affected by the mass of the liquid exposed.

4. The boiling point of water is at

A. 100°C B. 90°C C. 75°C D. 120°C

5. The boiling point of Mercury is at

A. 345°C B 357°C C. 405°C D 250°C

Answers

1. B 2. C 3. A 4. A 5. B

WEEK 5

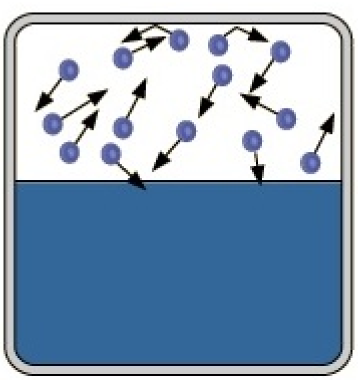
Topic: VAPOUR PRESSURE

INTRODUCTION

Vapour pressure– pressure exerted by a vapour when the vapour is in equilibrium with the liquid or solid form, or both, of the same substance – *i.e.,* when conditions are such that the substance can exist in both or in all three phases. Vapour pressure is a measure of the tendency of a material to change into the gaseous or vapour state, and it increases with temperature. The temperature at which the vapour pressure at the surface of a liquid becomes equal to the pressure exerted by the surroundings is called the boiling point of the liquid.

Saturated Vapour Pressure

The process of evaporation in a closed container will proceed until there are as many molecules returning to the liquid as there are escaping. At this point the vapor is said to be saturated, and the pressure of that vapor (usually expressed in mmHg) is called the saturated vapor pressure.



Since the molecular kinetic energy is greater at higher temperature, more molecules can escape the surface and the saturated vapor pressure is correspondingly higher. If the liquid is open to the air, then the vapor pressure is seen as a partial pressure along with the other constituents of the air. The temperature at which the vapor pressure is equal to the atmospheric pressure is called the boiling point

Vapour Pressure Relation to boiling point of liquids

As a general trend, vapor pressures of liquids at ambient temperatures increase with decreasing boiling points. This is illustrated in the vapor pressure chart that shows graphs of the **vapor pressures versus temperatures** for a variety of liquids.

For example, at any given temperature, methyl chloride has the highest vapor pressure of any of the liquids in the chart. It also has the lowest normal boiling point (−24.2 °C), which is where the vapor pressure curve of methyl chloride (the blue line) intersects the horizontal pressure line of one atmosphere (atm) of absolute vapor pressure.

Although the relation between vapor pressure and temperature is non-linear, the chart uses a logarithmic vertical axis to produce slightly curved lines, so one chart can graph many liquids. A nearly straight line is obtained when the logarithm of the vapor pressure is plotted against 1/(T+230) where T is the temperature in degrees Celsius. The vapor pressure of a liquid at its boiling point equals the pressure of its surrounding environment

Saturated and Unsaturated Vapour

Saturated vapour is one in which the vapour is in a state of dynamic equilibrium with its own liquid in a closed space.

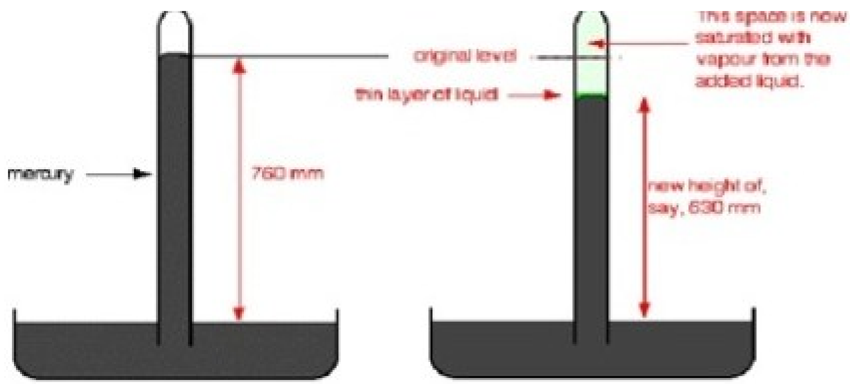
Consider a tube immersed upside down in a bath of mercury. The mercury which is concave to glass rises through the tube, leaving the empty space above it. This vapour which is in contact with its own liquid in space is called saturated vapour while the pressure exerted by the saturated vapour is called saturated vapour pressure. The saturated pressure varies with temperature and does not obey the gas law.

The saturated vapour pressure of water is equal to the external pressure at which water boils approximately and it is 760mmHg at 100^{o}C for pure water. This enables the boiling point of a liquid to be defined as the temperature at which the saturated vapour pressure becomes equal to the external atmospheric pressure.

During evaporation, the number of molecules leaving and returning to the liquid is equal and this is best explained by the kinetic theory's explanation of saturated vapour.

Measurement of Saturated Vapour Pressure

In the diagram below a small amount of liquid introduced at the top of the mercury column results in the column dropping from 760 mm to 630 mm. The saturated vapour pressure of the liquid is 130 mm.



Unsaturated Vapour

Unsaturated vapour is one in which the vapour is not in contact with its own liquid in a closed space.

Here, the vapour is not in equilibrium with its liquid. The pressure is less than the s.v.p and at higher temperature.

During evaporation, the number of molecules leaving is greater than the number of those returning to the liquid and this is best explained by the kinetic theory explanation of unsaturated vapour.

Differences between a Saturated and an Unsaturated Vapour

Saturated Vapour	Unsaturated Vapour
Saturated vapour is in contact with its own liquid.	Unsaturated vapour is not in contact with its liquid.
The pressure of a saturated vapour is independent of its volume.	The pressure of an unsaturated vapour is approximately inversely proportional to its volume.

Similarities

1. Both are directly proportional to its absolute temperature.

Properties of Saturated Vapour Pressure

I. The saturated vapour pressure increases with a rise in temperature and decrease with a fall in temperature.

II. The saturated pressure of a liquid does not depend on the surface occupied by the vapour

III. The saturated vapour pressure depends on the nature of the substance.

IV. The total pressure exerted by the vapours of all substances is equal to the sum of the pressures exerted by the vapour of individual substances, i.e.,

$P_T = P_1 + P_2 + P_3 + \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots + P_n$

V. The saturated vapour pressure of a liquid is independent of the pressure of the vapour of other liquid

VI. The vapour must not have any chemical action.

Humidity

Humidity of the air refers to the amount of water vapour present in the air. If the air in an environment is dry, the sweat from our body evaporates faster than when the air is damp and made up of water vapour. We describe a moist air as *humid air*.

Relative Humidity

The amount of water vapor in the air at any given time is usually less than that required to saturate the air. The relative humidity is the percent of saturation humidity, generally calculated in relation to saturated vapor density.

Relative humidity is the amount of moisture in the air compared to what the air can "hold" at that temperature. When the air can't "hold" all the moisture, then it condenses as dew.

Relative humidity is the term used to describe the humidity of the air. It is defined as the ratio of the mass of vapour actually present in a certain volume of air, at a room tempertaure to the mass of water vapour required to saturate the same volume of air at the same temperature.

Relative humidity can be mathematically represented as

Relative humidity = m/M x 100%

Since the mass of the water in a given volume is roughly proportional to its pressure, the relative humigity is also given by the ratio:

S.V.P at dew point/S.V.P at air temperature x 100%

The relative humidity is usually expressed in %. Relative humidity of air can be measured using hygrometer. Example of hygrometer are

(i) Regnault's hygrometer

(ii) Daniel's hygrometer

(iii) Wet & dry hygrometer

(iv) Dew point bulb hygrometer

The commonly used hygrometer is the wet and dry hygrometer.

Dew Point

Dew point is the temperature at which the water vapour present in the atmosphere is just sufficient to saturate. This means that the actual vapour pressure at a room temperature is equal to the saturated vapour pressure at a dew point. Dew point can be measured using the dew point hygrometer can also be used to find the humidity of the air.

If the temperature falls below the dew point, condensation will form.

If the temperature stays above the dew point, condensation will not form.

Air consists in part of water vapour. The amount of water vapour present in the air varies, depending on temperature, the amount of evaporation from surface water, whether or not it has rained… The air can only hold so much water. The amount of water the air can hold depends on temperature.

In general the temperature increases by day and decreases by night. Water evaporates during the day, when the temperature is above the dew point and the air can absorb the water, and falls during the night. If the temperature falls below the dew point, condensation will form. Dew is common – in the desert some animals get most or all of the water they need from dew.

Dew can be a very localized phenomenon. A person entering a warm room from the cold outside may have condensation form on their glasses. Because their glasses are cold, they will lower the temperature in the region of their glasses, maybe below the dew point, in which case condensation will form.

Every liquid has a dew point for a specific pressure of vapour. The phenomenon has a wide range of uses:

To determine the humidity of the air – how much water it holds. The temperature is lowered until condensation begins to form. The temperature at which this happens is the dew point. The humidity can then be determined.

To extract substances from the air. The air is a mixture of substances, all with differing dew points. We can extract them all one by one by cooling the air. As the temperature passes each dew point, the corresponding substance will condense.

Question

1. Vapour pressure ispressure exerted by a vapour when the vapour is ……………….. with the liquid or solid form, or both, of the same substance.

A. Lower B. In equilibrium C. Higher D. at variance

2. Vapor pressures of liquids at ambient temperatures ……………………………………… boiling points.

A. Increase with decreasing B. decrease with increasing C. Increase with increasing D. decrease with decreasing.

3. Vapour pressure is a measure of the tendency of a material to change into the …………………………… state, and it increases with temperature.

A. gaseous or solid B. gaseous or vapour C. solid or liquid D. liquid or gaseous

4. Which of this is not correct about Relative Humidity?

A. The amount of water vapor in the air at any given time is usually less than that required to saturate the air.

B. The relative humidity is the percent of saturation humidity, generally calculated in relation to saturated vapor density.

C. Relative humidity can be mathematically represented as 'Relative humidity = m/M x 100%'

D. Relative humidity is the term used to describe the humidity of the moisture.

5. To determine the humidity of the air – how much water it holds. The temperature is ……………………….. until condensation begins to form.

A. Made higher B. Made higher C. lowered D. Extinct from existence

Answers

1. B 2. A 3. B 4. D 5. C

WEEK 6

Topic: LATENT HEAT – FUSION, VAPORIZATIONS AND VERIFICATION

INTRODUCTION

Any substance will undergo a change in the temperature if the energy is transferred between the substance and its environment. In some instances the transfer of energy does not result in a change in temperature and can occur or take place when the physical characteristics of the substance change from one form to another or undergo phase change.

If there is a phase change due to the change in the internal energy but no overall temperature change then we are definitely dealing with **Hidden Heat** or **Latent Heat.**

When energy is transferred to a substance, usually, temperature of the substance increases. If the substance is at higher temperature then the surroundings, temperature of the substance decreases, as heat is transferred from the system or substance to the surroundings. From this we can conclude that a substance undergoes change in temperature whenever flow of energy transfer between system and its surroundings takes place.

But there are scenarios during which energy transfer between system and its surroundings does not result in the change in temperature of the system. This occurs whenever system changes from one of its phase to another or we can say that when the transfer of energy results in the change in the physical properties of the system. This change is termed as **Phase Change** or **Phase Transition**. Two main Phase transitions are,

1. Solid to Liquid

2. Liquid to Gas

Other phase transition is when change takes place in the crystalline structure of the solid. When phase Transition occurs temperature of the system does not change but change in the internal energy of the system takes place.

At the boiling point of the water when heat is transferred to the water it results in the breaking of molecular bonds in water. As a result, the molecules become apart as their potential and kinetic energies get increased and water gets converted to the gaseous state. Every substance has different molecular and atomic structure. So, for the phase transition to occur every substance requires different amount of energy depending on their internal structure. It also depends on the mass of substance involved for the phase transition. The substance of a particular type with larger quantity and mass requires more heat for phase transition as compared to the other. It takes less energy to boil water in cooking pan than to boil a lake.

If a Q amount of energy needs to be transferred for phase change of a substance having mass m, the ratio symbolizes an important property of that substance. As the energy added or removed is not resulting in the change of temperature, the quantity L is termed as the latent heat. It can also be termed as the hidden heat of the substance.

Latent heat for a substance depends mainly on two factors:

1. Phase change Nature

2. Properties (atomic, molecular structure of the substance)

Latent Heat Formula

From the definition, it is clear that the amount of heat required for a phase transition is latent heat. The mathematical representation of the given statement is,

$Q = mL$
$L = Qm$

Where,
L = Latent heat of the substance
Q = Amount of energy transferred for the Phase change
m = Mass of the substance

Latent Heat of Vaporization

Latent heat of Vaporization is the Latent heat (explained above) when phase of the substance changes from Liquid to gaseous state. Latent heat of vaporization is denoted by $\mathbf{L_V}$.

Definition of the specific latent heat of vaporization

The specific latent heat of vaporization of a substance is the quantity of heat required to change unit mass of the substance from the liquid to the vapour state without change of temperature. (Symbol = L).

The SI unit of specific latent heat of vaporization is the **Joule per kilogram (J / kg)**. However, in order to avoid having to write every large numbers the alternative units Kj / kg or MJ / kg may be used instead.
1 Kj = 1000 j

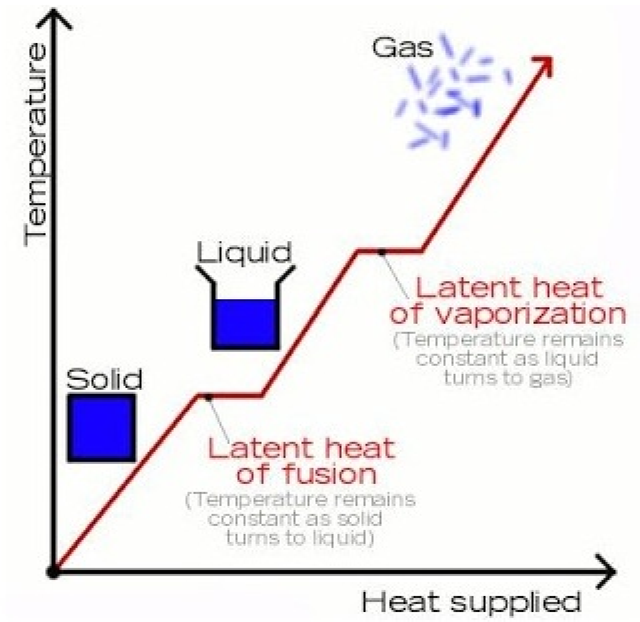
1 Mj = 100000 j

So we may express the specific latent heat of vaporization of water as 2260 Kj / kg or 2.26 Mj / kg. The old thermal unit was calorie per gram (cal / g)).

Latent Heat of Fusion

Latent Heat of Fusion is the latent heat (explained above) when phase of the substance changes from Solid to Liquid phase. Latent heat of Fusion is denoted by L_F. Also fuse means melting.

Just as latent heat is taken in when water changes to vapour at the same temperature, so the same thing occurs when ice melts to form water. But in this case the latent heat is not so great. It requires only 336000 j to convert 1 kg of ice at 0 °C to water at the same temperature. Likewise, when water at 0°C freezes into ice, the same quantity of heat is given out for every 1 kg of ice formed. This is called the *specific latent heat of ice.*
As already mentioned, the phenomenon of latent heat is not confined to water alone. Other substances also absorb latent heat when they melt; conversely, they give out latent heat on solidifying. This heat is called *latent heat of fusion.*



Latent Heat of Substances

Latent Heat of Water, Latent Heat of Ice and Latent Heat of Steam are given in the tables below. Latent Heat of Fusion and Latent Heat of Vaporization for different substances are given in the below tables.

Substance	**Melting Point (°C)**	**Latent Heat Of Fusion (J/kg)**	**Boiling Point (°C)**	**Latent heat Of Vaporization (J\kg)**
Helium	-269.65	5.23×10^3	-268.93	2.09×10^4
Nitrogen	-209.97	2.55×10^4	-195.81	2.01×10^5
Oxygen	-218.79	1.38×10^4	-182.97	2.13×10^5
Ethyl Alcohol	-114	1.04×10^5	78	8.54×10^5
Water	0.00	3.33×10^5	100.00	2.26×10^6
Sulphur	119	3.81×10^4	444.60	3.26×10^5
Lead	327.3	2.45×10^4	1750	8.70×10^5
Aluminum	660	3.97×10^5	2450	1.14×10^7
Silver	960.80	8.82×10^4	2193	2.33×10^6

Gold	1063.00	6.44×10^4	2660	1.58×10^6
Copper	1083	1.34×10^5	1187	5.06×10^6

Questions

1. If the specific latent heat of vaporization for water is 2.25 kJ/g, then the amount of heat required to vaporize 4 g of boiling water to steam at 100^{o}C is

A. 9 J B. 90 J C. 900 J D. 9000 J

2. The heat gained or lost by a body during a change of state is the product of its _______ and the specific latent heat.

A. Weight B. Volume C. Mass D. Breadth

3. Vaporization point and _______ have the same numerical value

A. Fusion point B. Solidification point C. melting point D. liquefaction point

4. If 1625 J of energy are expended to rub two ice blocks against each other and the specific latent heat of ice is 325 J/g, then the mass of the melted ice is

A. 5 g B. 10 g C. 15 g D. 20 g

5. The fixed temperature at which a gas changes into its liquid state is called the _______.

A. Fusion Point B. Solidification Point C. Vaporization Point D. liquefaction point

Answer

1. D 2. C 3. D 4. A 5. D

Week 7

Topic: GAS LAWS

INTRODUCTION

The early gas laws were developed at the end of the 18th century, when scientists began to realize that relationships between the pressure, volume and temperature of a sample of gas could be obtained which would hold for all gases. Gases behave in a similar way over a wide variety of conditions because to a good approximation they all have molecules which are widely spaced, and nowadays the equation of state for an ideal gas is derived from kinetic theory. The earlier gas laws are now considered as special cases of the ideal gas equation, with one or more of the variables held constant.

Boyle's Law

Boyle's law shows that, at constant temperature, the product of an ideal gas's pressure and volume is always constant. It was published in 1662. It can be determined experimentally using a pressure gauge and a variable volume container. It can also be found through the use of logic; if a container, with a fixed number of molecules inside, is reduced in volume, more molecules will hit the sides of the container per unit time, causing a greater pressure.

As a mathematical equation, Boyle's law is:

$P_1V_1 = P_2V_2$

where P is the pressure (Pa), V the volume (m^3) of a gas, and k_1 (measured in joules) is the constant from this equation—it is not the same as the constants from the other equations below.

This is known as Boyle's law which states: the volume of a given mass of gas is inversely proportional to its pressure, if the temperature remains constant. Mathematically this is:

$V = k/P$

where k is a constant (NOT Boltzmann's constant or Coulomb's constant).

Charles's law

Charles's Law, or the law of volumes, was found in 1787 by Jacques Charles. It says that, for an ideal gas at constant pressure, the volume is directly proportional to its temperature.

$V_1/T_1 = V_2/T_2$

Gay-Lussac's law, or **the pressure law**, was found by Joseph Louis Gay-Lussac in 1809. It states that the pressure exerted on the sides of a container by an ideal gas of fixed volume is proportional to its temperature.

$P_1/T_1 = P_2/T_2$

Avogadro's law states that the volume occupied by an ideal gas is proportional to the number of molespresent in the container. This gives rise to the molar volume of a gas, which at STP is 22.4 dm^3 (or litres). The relation is given by

$V_1 / n_1 = V_2 / n_2$

where n is equal to the number of moles of gas (the number of molecules divided by Avogadro's Number).

The combined gas lawor general gas equation is formed by the combination of the three laws, and shows the relationship between the pressure, volume, and temperature for a fixed mass of gas:

$PV = K_5T$

This can also be written as:

$P_1V_1/T_1 = P_2V_2/T_2$

With the addition of Avogadro's law, the combined gas law develops into the ideal gas law:

$PV = nRT$

where

P is pressure

V is volume

n is the number of moles

R is the universal gas constant

T is temperature (K)

where the constant, now named R, is the gas constant with a value of .08206 (atm·L)/(mol·K). An equivalent formulation of this law is:

PV = kNT

where

P is the absolute pressure

V is the volume

N is the number of gas molecules

k is the Boltzmann constant (1.381×10^{-23} $J \cdot K^{-1}$ in SI units)

T is the temperature (K)

These equations are exact only for an ideal gas, which neglects various intermolecular effects (see real gas). However, the ideal gas law is a good approximation for most gases under moderate pressure and temperature.

This law has the following important consequences:

1. If temperature and pressure are kept constant, then the volume of the gas is directly proportional to the number of molecules of gas.

2. If the temperature and volume remain constant, then the pressure of the gas changes is directly proportional to the number of molecules of gas present.

3. If the number of gas molecules and the temperature remain constant, then the pressure is inversely proportional to the volume.

4. If the temperature changes and the number of gas molecules are kept constant, then either pressure or volume (or both) will change in direct proportion to the temperature.

Other Gas Laws

Graham's law states that the rate at which gas molecules diffuse is inversely proportional to the square root of its density. Combined with Avogadro's law (i.e. since equal volumes have equal number of molecules) this is the same as being inversely proportional to the root of the molecular weight.

Dalton's law of partial pressures states that the pressure of a mixture of gases simply is the sum of the partial pressures of the individual components. Dalton's Law is as follows:

$P_{total} = P_1 + P_2 + P_3 + ... + P_n$

OR

$P_{total} = P_{gas} + P_{H2O}$

where P_{Total} is the total pressure of the atmosphere, P_{Gas} is the pressure of the gas mixture in the atmosphere, and P_{H2O} is the water pressure at that temperature.

Henry's law states that:

At constant temperature, the amount of a given gas dissolved in a given type and volume of liquid is directly proportional to thepartial pressure of that gas in equilibrium with that liquid.

Questions:

A mass of gas at 7^0C and 70cm of mercury has a volume of 1000 cm^3. Determine its volume at 27^0C and pressure of 85 cm of mercury.

A. 788.35 cm^3 B. 782.35 cm^3 C. 882.35 cm^3 D. 805.54 cm^3

2. A vessel is filled with a gas at a temperature 30^0C and a pressure of 76 cm Hg. Calculate the final pressure if the volume of the gas is doubled while it is heated to 80^0C.

A. 55.56 cm Hg B. 23.44 cm Hg C. 44.27 cm Hg D. 34.57 cm Hg

3. A fixed mass of gas is heated at constant pressure from 10^0C to 90^0C. If its volume at 10^0C is 200 cm^2, calculate the volume at 90^0.

A. 256.54 cm^3 B. 735.56 cm^3 C. 345.24 cm^3 D. 400.45 cm^3

4. The pressure of a gas at constant volume is 90 cm Hg at 20^0C. Calculate its pressure at 70^0C.

A. 205.90 cm Hg B. 105.3 cm Hg C. 45.24 cm Hg D. 237.6 cm Hg

5. In this equation PV = nRT, what does n stands for?

A. number of base B. number of moles C. universal gas constant D. temperature constant

Answers

1. C 2. C 3. A 4. B 5. B

Week 8

Topic: PRODUCTION AND PROPAGATION OF WAVES

WHAT IS A WAVE?

A wave is a disturbance which travels through a medium transferring energy from one point to another without causing any permanent displacement of the medium.

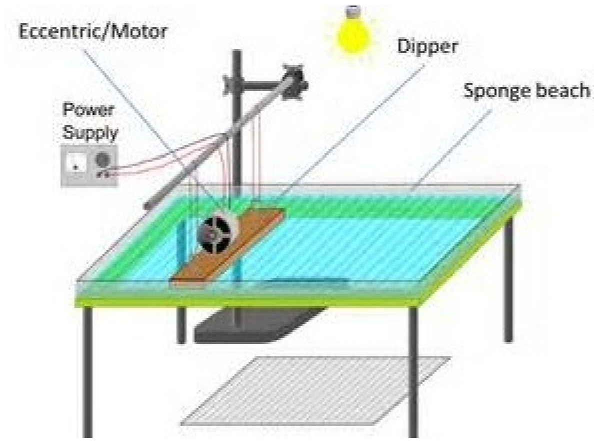
Not all waves, however, requires a material for their propagation.

Mechanical waves are those waves that require a material a material medium for their propagation. Examples of such waves are water waves, sound waves, waves on a rope or string.

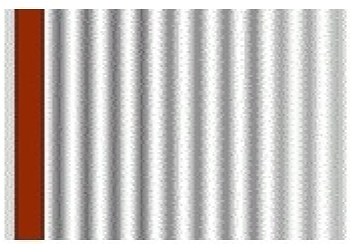
Electromagnetic waves are waves that do not require a material medium for propagation.

Examples are light waves, radio waves, X-rays and gamma-rays.

The Ripple Tank



The ripple tank is a container that when filled with water permits the study of water waves. A concentrated light source positioned above the tank forms images of the waves on a screen beneath the tank. Wave crests and troughs project light and dark lines in the screen.



The ripple tank is a container that when filled with water permits the study of water waves. A concentrated light source positioned above the tank forms images of the waves on a screen beneath the tank. Wave crests and troughs project light and dark lines in the screen.

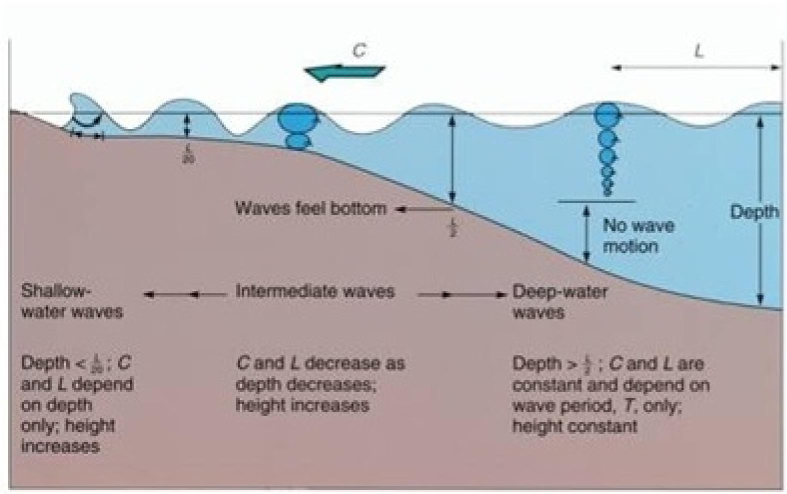
The crests act as converging lenses that focus light, producing the bright lines..The troughs act as diverging lenses that scatter light, producing the dark lines.
The depth at which the dipper is placed affects the amplitude of the waves, while the frequency of waves is determined by frequency of vibration of the dipper.

Refraction of waves and the depth of ripple tank

Refraction of waves involve a change in the direction of waves as they pass from one medium to another. Refraction is the bending of the path of the waves. It is accompanied by a change in speed and wavelength of the waves. It was mentioned that the speed of a wave is dependent upon the properties of the medium through which the waves travel. So if the medium (and its properties) are changed, the speed of the waves are changed.

The most significant property of water which would affect the speed of waves traveling on its surface is the depth of the water.

This boundary behavior of water waves can be observed in a ripple tank if the tank is partitioned into a deep and a shallow section. If a pane of glass is placed in the bottom of the tank, one part of the tank will be deep and the other part of the tank will be shallow. Waves traveling from the deep end to the shallow end can be seen to refract (i.e., bend), decrease wavelength (the wave fronts get closer together), and slow down (they take a longer time to travel the same distance). When traveling from deep water to shallow water, the waves are seen to bend in such a manner that they seem to be traveling more perpendicular to the surface. If traveling from shallow water to deep water, the waves bend in the opposite direction.



Water waves travel fastest when the medium is the deepest. Thus, if water waves are passing from deep water into shallow water, they will slow down and also the wavelength of the plane waves shorten. The frequency remains the same as it is determined by the dipper. Using the equation, v:f x L, the speed of the waves is therefore slower at the shallow water.

There are three types of waves

Three types of waves

Mechanical waves require a material medium to travel (air, water, ropes). These waves are divided into three different types.

Transverse waves cause the medium to move perpendicular to the direction of the wave. For example, a string wave propagates horizontally through space while the string itself (the wave's medium) moves up and down. Transverse waves are characterized by their frequency (number of wave crests per second), amplitude (height of a wave crest) and wavelength (distance between two crests). Seismic waves are also transverse waves.

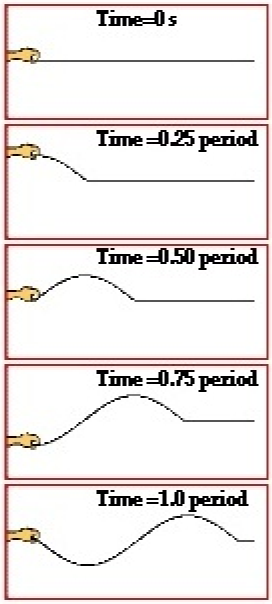
Longitudinal waves cause the medium to move parallel to the direction of the wave. A sound wave is a classic example of such a wave. When you sound a tuning fork, for example, the vibration of its prongs causes nearby molecules in the air to vibrate back and forth horizontally. This displaces nearby particles, causing a domino-effect that propagates the wave through space. You can make a visible longitudinal wave by holding a slinky between your hands and moving one hand side to side, causing the slinky to expand and contract horizontally.

Surface waves are both transverse waves and longitudinal waves mixed in one medium.

Electromagnetic waves do not require a medium to travel (light, radio). Electromagnetic waves, on the other hand, can travel through the vacuum of space. Light, for example, travels 93 million miles from the Sun to Earth without requiring a vibrating medium in between. Matter waves are produced by electrons and particles.

General Wave Equation

a wave is produced when a vibrating source periodically disturbs the first particle of a medium. This creates a wave pattern that begins to travel along the medium from particle to particle. The frequency at which each individual particle vibrates is equal to the frequency at which the source vibrates. Similarly, the period of vibration of each individual particle in the medium is equal to the period of vibration of the source. In one period, the source is able to displace the first particle upwards from rest, back to rest, downwards from rest, and finally back to rest. This complete back-and-forth movement constitutes one complete wave cycle.



The diagrams show several “snapshots” of the production of a wave within a rope. The motion of the disturbance along the medium after every one-fourth of a period is depicted. Observe that in the time it takes from the first to the last snapshot, the hand has made one complete back-and-forth motion. A period has elapsed. Observe that during this same amount of time, the leading edge of the disturbance has moved a distance equal to one complete wavelength. So in a time of one period, the wave has moved a distance of one wavelength. Combining this information with the equation for speed (speed = distance/time), it can be said that the speed of a wave is also the wavelength/period.

Speed = Wavelength/Period

Since the period is the reciprocal of the frequency, the expression 1/f can be substituted into the above equation for period. Rearranging the equation yields a new equation of the form:

Speed = Wavelength x Frequency

$V = f \times \lambda$

As a test of your understanding of the wave equation and its mathematical use in analyzing wave motion, consider the following three-part question:

Questions

Stan and Anna are conducting a slinky experiment. They are studying the possible effect of several variables upon the speed of a wave in a slinky. Their data table is shown below. Fill in the blanks in the table, analyze the data, and answer the following questions.

1. Medium	Wavelength	Frequency
Zinc	1.75 m	2.0 Hz

A. 3.5 m/s B. 4.5 m/s C. 6.5 m/s D. 8 m/s

2. Medium	Wavelength	Frequency
Copper	1.19 m	2.1 Hz

A. 4.5 m/s B. 2.9 m/s C. 2.5 m/s D. 6.5 m/s

3. As the wavelength of a wave in a uniform medium increases, its frequency will ………………………………

A. decrease B. increase C. remain the same D. be zero

4. The speed of a wave depends upon (i.e., is causally affected by) …

A. the properties of the medium through which the wave travels B. the wavelength of the wave C. the frequency of the wave D. both the wavelength and the frequency of the wave

5. Dawn and Aram have stretched a slinky between them and begin experimenting with waves. As the frequency of the waves is doubled,

A. the wavelength is halved and the speed remains constant B. the wavelength remains constant and the speed is double C. both the wavelength and the speed are halved D. both the wavelength and the speed remain constant.

Answers

1. A 2. C 3. C 4. A 5. A

WEEK 9

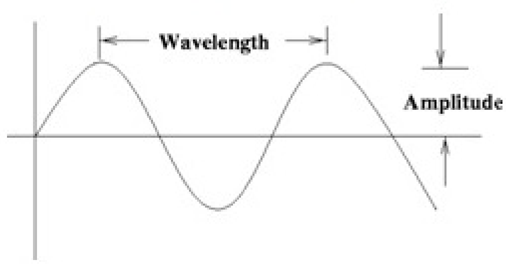
Topic: PROPERTIES OF WAVES

INTRODUCTION

A wave is a transfer of energy from one point to another without the transfer of material between the two points.

It is important to realize that a wave is quite a different object than a particle. A baseball thrown through a window transfers energy from one point to another, but this involves the movement of a material object between two points. A common example of a wave is a wave on the ocean – we know they carry energy, as they cause erosion on the shore, but material (i. e. , water) is not continuously being transferred onto the shore. Another example of a wave is a sound wave, which is vibrations of air molecules which propagate from one place to another. These also carry energy, but do not involve the mass movement of air from one place to another.

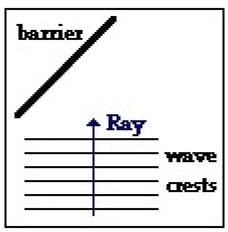
A simple type of wave is illustrated below.

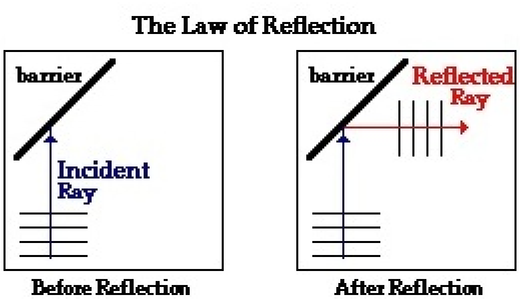


Reflection of Waves

If a linear object attached to an oscillator bobs back and forth within the water, it becomes a source of *straight waves*. These straight waves have alternating crests and troughs. As viewed on the sheet of paper below the tank, the crests are the dark lines stretching across the paper and the troughs are the bright lines.

These waves will travel through the water until they encounter an obstacle – such as the wall of the tank or an object placed within the water. The diagram at the right depicts a series of straight waves approaching a long barrier extending at an angle across the tank of water. The direction that these wavefronts (straight-line crests) are traveling through the water is represented by the blue arrow. The blue arrow is called a ray and is drawn perpendicular to the wavefronts. Upon reaching the barrier placed within the water, these waves bounce off the water and head in a different direction. The diagram below shows the reflected wavefronts and the reflected ray. Regardless of the angle at which the wavefronts approach the barrier, one general law of reflection holds true: the waves will always reflect in such a way that the angle at which they approach the barrier equals the angle at which they reflect off the barrier. This is known as the law of reflection.



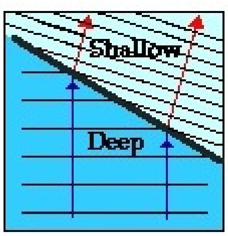


The discussion above pertains to the reflection of waves off of straight surfaces. But what if the surface is curved, perhaps in the shape of a parabola? What generalizations can be made for the reflection of water waves off parabolic surfaces? Suppose that a rubber tube having the shape of a parabola is placed within the water. The diagram at the right depicts such a parabolic barrier in the ripple tank. Several wavefronts are approaching the barrier; the ray is drawn for these wavefronts. Upon reflection off the parabolic barrier, the water waves will change direction and head towards a point. This is depicted in the diagram below.

It is as though all the energy being carried by the water waves is converged at a single point – the point is known as the focal point. After passing through the focal point, the waves spread out through the water.

Refraction of Waves

Reflection involves a change in direction of waves when they bounce off a barrier. Refraction of waves involves a change in the direction of waves as they pass from one medium to another. Refraction, or the bending of the path of the waves, is accompanied by a change in speed and wavelength of the waves. In Lesson 2, it was mentioned that the speed of a wave is dependent upon the properties of the medium through which the waves travel. So if the medium (and its properties) is changed, the speed of the waves is changed. The most significant property of water that would affect the speed of waves traveling on its surface is the depth of the water. Water waves travel fastest when the medium is the deepest. Thus, if water waves are passing from deep water into shallow water, they will slow down, this decrease in speed will also be accompanied by a decrease in wavelength. So as water waves are transmitted from deep water into shallow water, the speed decreases, the wavelength decreases, and the direction changes.

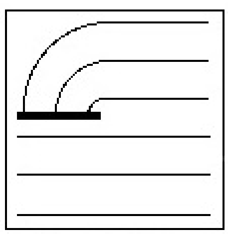


This boundary behavior of water waves can be observed in a ripple tank if the tank is partitioned into a deep and a shallow section. If a pane of glass is placed in the bottom of the tank, one part of the tank will be deep and the other part of the tank will be shallow. Waves traveling from the deep end to the shallow end can be seen to refract (i.e., bend), decrease wavelength (the wavefronts get closer together), and slow down (they take a longer time to travel the same distance). When traveling from deep water to shallow water, the waves are seen to bend in such a manner that they seem to be traveling more perpendicular to the surface.

If traveling from shallow water to deep water, the waves bend in the opposite direction.

Diffraction of Waves

Reflection involves a change in direction of waves when they bounce off a barrier; refraction of waves involves a change in the direction of waves as they pass from one medium to another; and diffraction involves a change in direction of waves as they pass through an opening or around a barrier in their path. Water waves have the ability to travel around corners, around obstacles and through openings.



Diffraction of Waves

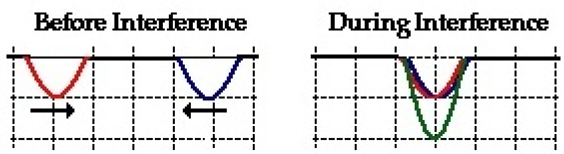
This ability is most obvious for water waves with longer wavelengths. Diffraction can be demonstrated by placing small barriers and obstacles in a ripple tank and observing the path of the water waves as they encounter the obstacles. The waves are seen to pass around the barrier into the regions behind it; subsequently the water behind the barrier is disturbed. The amount of diffraction (the sharpness of the bending) increases with increasing wavelength and decreases with decreasing wavelength. In fact, when the wavelength of the waves is smaller than the obstacle, no noticeable diffraction occurs.

Diffraction of water waves is observed in a harbor as waves bend around small boats and are found to disturb the water behind them. The same waves however are unable to diffract around larger boats since their wavelength is smaller than the boat. Diffraction of sound waves is commonly observed; we notice sound diffracting around corners, allowing us to hear others who are speaking to us from adjacent rooms. Many forest-dwelling birds take advantage of the diffractive ability of long-wavelength sound waves. Owls for instance are able to communicate across long distances due to the fact that their long-wavelength *hoots* are able to diffract around forest trees and carry farther than the short-wavelength *tweets* of songbirds. Diffraction is observed of light waves but only when the waves encounter obstacles with extremely small wavelengths (such as particles suspended in our atmosphere).

Reflection, refraction and diffraction are all boundary behaviors of waves associated with the bending of the path of a wave. The bending of the path is an observable behavior when the medium is a two- or three-dimensional medium. Reflection occurs when there is a bouncing off of a barrier. Reflection of waves off straight barriers follows the law of reflection. Reflection of waves off parabolic barriers results in the convergence of the waves at a focal point. Refraction is the change in direction of waves which occurs when waves travel from one medium to another. Refraction is always accompanied by a wavelength and speed change. Diffraction is the bending of waves around obstacles and openings. The amount of diffraction increases with increasing wavelength.

Interference

Wave interference is the phenomenon that occurs when two waves meet while traveling along the same medium. The interference of waves causes the medium to take on a shape that results from the net effect of the two individual waves upon the particles of the medium. To begin our exploration of wave interference, consider two pulses of the same amplitude traveling in different directions along the same medium. Let's suppose that each displaced upward 1 unit at its crest and has the shape of a sine wave. As the sine pulses move towards each other, there will eventually be a moment in time when they are completely overlapped. At that moment, the resulting shape of the medium would be an upward displaced sine pulse with an amplitude of 2 units. The diagrams below depict the before and during interference snapshots of the medium for two such pulses. The individual sine pulses are drawn in red and blue and the resulting displacement of the medium is drawn in green.



Polarization is a property of waves that can oscillate with more than one orientation. Electromagnetic waves, such as light, and gravitational waves exhibit polarization whereas this is not a concern with sound waves in a gas or liquid which have only one possible polarization, namely the direction in which the wave is travelling.

In an electromagnetic wave such as light, both the electric field and magnetic field are oscillating but in different directions; by convention the "polarization" of light refers to the polarization of the electric field. Light which can be approximated as a plane wave in free space or in an isotropic medium propagates as a transverse wave—both the electric and magnetic fields are perpendicular to the wave's direction of travel. The oscillation of these fields may be in a single direction (linear polarization), or the field may rotate at the optical frequency (circular or elliptical polarization). In that case the direction of the fields' rotation, and thus the specified polarization, may be either clockwise or counter clockwise; this is referred to as the wave's chirality or *handedness.*

The most common optical materials (such as glass) are isotropic and simply preserve the polarization of a wave but do not differentiate between polarization states. However there are important classes of materials classified as birefringent or optically active in which this is not the case and a wave's polarization will generally be modified or will affect propagation through it.
A polarizer is an optical filter that transmits only one polarization.

ASSESSMENT

1. Which of following is not a longitudinal wave?
   (a) Ultrasonic wave
   (b) Infrasonic wave

(c) Infrared wave
(d) Seismic wave

2. If wavelength of a wave moving on a slinky spring with a frequency of 5 Hz is equal to 0.5 m then speed of wave is equal to
   (a) 0.1 m s-1
   (b) 2.5 m s-1
   (c) 10 m s-1
   (d) None of above

3. For a constant frequency, wavelength of an electromagnetic wave is
   (a) directly proportional to its velocity
   (b) inversely proportional to its velocity
   (c) independent of its velocity
   (d) None of above

4. All waves can be classified into two categories which are
   (a) Sound waves and electromagnetic waves
   (b) Transverse waves and electromagnetic waves
   (c) Longitudinal waves and electromagnetic waves
   (d) Transverse waves and longitudinal waves

5. If amplitude of a wave is denoted as 'A', then vertical displacement between a crest and a trough of a wave in terms of 'A' would be
   (a) 1 ⁄ 2 of A
   (b) A
   (c) 2A
   (d) None of above

ANSWERS

1. c
2. b
3. a
4. d

5. c

WEEK 10

Topic: LIGHT WAVES

Sources

Light is a form of energy, called luminous energy. This energy causes a sensation of vision, enabling us to see. There are various sources of light, for example the sun and the stars are natural sources of light. Artificial sources of light are the candle, electric torch and electric lamp, incandescent and arc lights and fluorescent light.

Self luminous or luminous sources of light are those that generate and emit light by themselves. Examples are the sun, star, fire-flies and some deep sea fishes and the artificial light sources to illuminate them. They are seen only when they illuminate light from their luminous body. For example, light from a car headlamp falling on a road sign in the night, causes the sign to throw back part of this light into the eyes of the car-driver thereby enabling the road sign to be seen. The road sign is a non-luminous body, the headlamp is a luminous body, an artificial luminous body. Examples of non-luminous bodies are a page of a book, a person's face, a brick and the moon. The sun's rays illuminate the moon and make it to appear luminous in the night.

Transmission of Light

Light is an electromagnetic wave. It can pass through a vacuum and through a material medium. If light shines on a body, part of the light is transmitted through the body, the rest is reflected. The amount of light passing through a body is depends on the nature of the body. If a light percentage of light falling on a body passes through it, the body is said to be transparent. Examples of transparent bodies are glass and water. Because light is easily transmitted through these transparent bodies, we can see objects through them easily. Some objects like frosted glass and tissue paper allow some small amount to pass through them. Such objects are called translucent objects. Because the amount of light passing through translucent bodies is small, objects cannot be seen clearly through them.

Some other bodies do not allow any light to pass through them. These are called opaque objects. Examples of opaque objects are wood, bricks, walls and metal sheets.

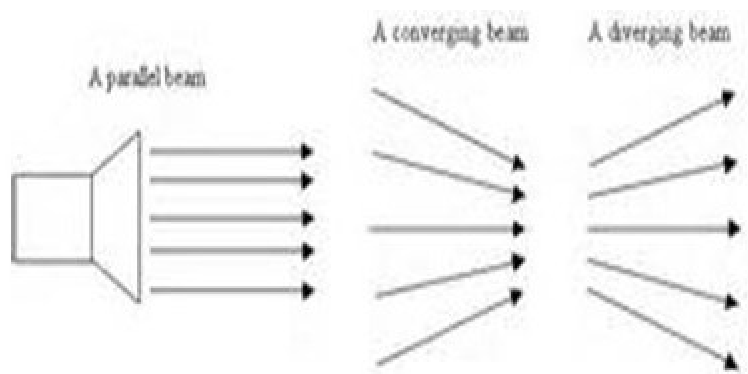
Rays and Beams of Light

A light ray is the direction or path along which light energy flows. Such rays are indicated in diagrams by thin lines in arrow head which indicate the direction of travel of the light. A collection of rays is called a beam. There are three types of beams.

(i) A parallel is one in which the light rays are parallel to one another. Search-lights give off parallel beams of light.

(ii) A convergent beam is one which the rays converge or meet at a point. A hand lens can be used to produce such a beam.

(iii) A divergent beam is one in which the light rays all come from a point and spread out or diverge from the source. Lamps produce a divergent beam of light.



The Ray Box

Rays of light are produced in the laboratory by means of a ray box. A simple laboratory ray box consists of a box made of wood or cardboard inside which is a source of light, e.g., a candle or an electric lamp

Reflection in Plane and Curved Mirrors

Mirrors are the contrivances that reflect light waves. They are broadly classified as plane mirrors and curved mirrors. Curved mirrors, as the name suggests, have curved surfaces that reflect the light rays. Basically these curved surfaces are parts of spherical surfaces and hence they are also called as spherical mirrors. The reflecting surface may be bulged towards the object or concave right to the object. Curved mirrors have extensive uses in various applications.

Convex Mirror

A mirror with a spherical surface and reflecting from the exterior the curvature is called a convex mirror. A convex mirror is also known as Diverging Mirror as it diverges the incident rays after reflection.

The **mirror** is defined as an optical device which has the capacity to reflect beam of light and form a clear identical image. Some beams are filtered through mirrors while some are reflected from it. But they preserve only colour or diffused light. Mirrors are used for decoration, to see our clear image, for scientific purpose, in apparatus like cameras, telescope, machines etc. generally mirrors are made up for visible light. Some common types of mirrors are flat surface mirrors and curved surface mirrors.

The plane mirrors are flat surface mirrors while the curved surface mirrors are produced a clear image with focusing of light. The spherical mirrors are of two types that are **concave** and **convex mirrors**. These are used because of their one of the main advantage that they form an image without chromatic aberration. Here we are discussing about the convex spherical mirrors, their image formation process, and some different types of convex mirrors.

Concave Mirror

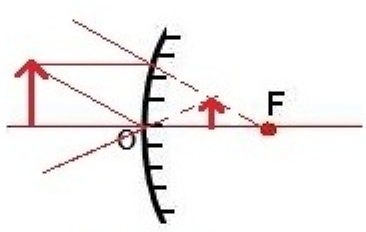
A mirror with a spherical surface and reflecting from the interior of the curvature is called a concave mirror. A concave mirror is also known as Converging Mirror as it converges the incident rays after reflection.

As mentioned, the normal to a spherical surface is always towards the center. Hence in cases where the inner surface of curved mirror is reflecting, the angle of reflection falls towards the object. Therefore, the rays which fall on the surface of a mirror concave opposite to the object are converged.

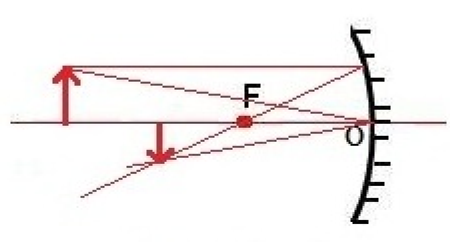
For understanding the concept of the mirror, we should know about **the law of reflection** which states that when a beam of light is passed through a surface then it is deflected at some angle. This angle is the angle of reflection while the incoming angle is the angle of incidence. Both are equal. A beam of light which passes through the space is invisible. It can be seen only when it hits something through which it is scattered. Light is not scattered by mirrors.

Curved mirrors can reflect the light due to their curved surface while the plane mirrors cannot. The flat mirror makes virtual image while the curved mirror forms real images. The curved mirrors are classified in two types that are concave and convex. The **convex** reflects at an angle at edges and also forms a smaller distorted image than actual size while the **concave** are converging mirror which are similar to spoon shape. These types of mirrors form image when light is bounced by their curve up to a specific area. Here we are discussing about the concave mirror, its equation and properties, mirror images at various points, mirror ray diagram, and its uses.

As mentioned earlier, the curved mirrors are partial spherical surfaces. The line of symmetry of the curved mirror is called as the **principal axis of the mirror**. The radius of the sphere is called the **radius of curvature** and half radius of curvature of the mirror is called the **focal length of the mirror**. The focal length is also defined as the distance from the mirror along the principal axis to the point called '**focus**' of the mirror.



Convex mirror



Concave mirror

Look at the above diagram. The mirror on the left has a bulging towards left, that is, towards the object. The focus in this case is on the other side of the mirror. On the other hand the mirror on the right is concave to the right and hence the focus of the mirror is at the same side as that of the object. The mirror on the left reflects out the ray, outward or diverges the incident ray. Hence this mirror is called as ‘diverging mirror’ or ‘convex mirror’. The image formed by a diverging mirror is virtual because the reflected rays only ‘appear’ to intersect behind the mirror. The mirror on the right side reflects out the ray, inward or converges the incident ray. Hence this mirror is called as ‘converging mirror’ or ‘concave mirror’. The image formed by a converging mirror is real because the reflected rays actually intersect before the mirror. However, if an object is placed within the focal length of a concave mirror, the mirror can produce only a virtual image but it is magnified.

Uses of Convex Mirror

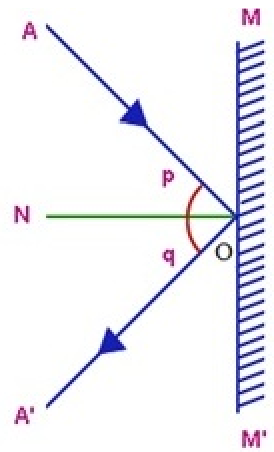
If an object is placed within the focal length of a concave mirror, the mirror can produce a magnified virtual image. This property helps to use concave mirrors as magnifying reflectors. For example, you can study a wound on your face more clearly by keeping your face close to a concave mirror and the image will look much bigger compared to a plane mirror.

The light rays from a source placed on the focus of a concave mirror are reflected in such a ways that the reflected rays is parallel. This concept is used in hand torches operated by electric batteries, in the head lights of automobiles etc. Concave mirrors are also used in telescopes.

Uses of Concave Mirror

The convex mirrors diverge the light rays. As a result, the images produced are virtual and smaller in size. In addition, the images appear closer unlike in case of plane mirrors where the images are at the same distance as that of the object. The property that the images of a convex mirror are smaller in size helps to view more objects. This concept used in ‘search mirrors’ placed in big stores or community halls. The property that image of a convex mirror appear closer helps to concentrate on objects which are following us. This is the concept of rear view mirrors that are used in all automobiles.

Plane Mirror



A plane mirror is the simplest form of mirrors and the most commonly used. We look ourselves in front of a mirror at least a few times a day. In addition to the cosmetic purposes, plane mirrors have also important applications in medical, industrial and scientific fields.

As the name suggests the shape of a plane mirror is a plane area. It is made from a clear plane glass sheet, usually thin and pasted with suitable reflecting abrasive (for example, mercury) on one side. Once this pasting is done, then the glass becomes opaque but due to the reflecting property of the abrasive, the plane glass sheet becomes a plane glass reflector or a plane glass mirror.

Plane Mirror Reflection

Consider the above figure. MM’ is a plane mirror. The hatched surface shows the abrasive and hence the other surface is used as a reflecting surface. Consider a ray AO strikes the plane mirror at an angle AON with the normal ON to the surface at O. This angle is called as the **Angle of Incidence**. The ray is reflected by the plane mirror as ray OA’ and it is called **Reflected Ray**. The angle made by the reflected ray with the normal is called as angle of reflection. As per the fundamental law of reflection, the angle of incidence and the angle of reflection are always congruent.

ASSESSMENT

1. Light interacts with matter as
   (a) wave
   (b) particle
   (c) both A and B
   (d) rays
2. Our eyes detect light in
   (a) RGB form, Red Blue Green form
   (b) ROYGBIV, rainbow color form
   (c) The simple form of a particular color
   (d) none of these ways
3. Symbol to represent speed of light in vacuum or air is
   (a) v
   (b) c
   (c) a
   (d) l
4. Mid-point between lens surface and principle axis is termed as
   (a) midway center
   (b) focal center
   (c) focal point
   (d) optical center
5. Light can travel in
   (a) air only
   (b) vacuum only
   (c) both air and vacuum
   (d) none of mediums

ANSWERS

1. b
2. b
3. b
4. d
5. c

THIRD TERM NOTES ON ON PHYSICS

TABLE OF CONTENTS

THIRD TERM

WEEK 1

Topic: REFRACTION OF LIGHT

INTRODUCTION

When a ray travels from one transparent medium to another of different density, its direction is abruptly changed at the surface separating the two media. This is known as the refraction of the light ray. Thus a light ray appears to bend as it crosses the boundary of two different media. Refraction is due to the difference in the speed of light in the different media.

Refraction is the bending of a light ray as it crosses the boundary between two media of different densities, thus causes a change in direction.

The phenomenon of refraction is responsible for the following common observations: (i) The bottom of a clear river or pond appears shallower than it really is. (ii) A rod or spoon appears bent or broken when it is partially immersed in water or any liquid. (iii) Letters in prints seem to be nearer when we place a thick block of glass over them.

Laws of Refraction

Two laws are associated with refraction. The first law of refraction states that, the incidence, and the refracted ray all lie in the same plane.

The second law states that, the ratio of sine of the angle of incidence to the sine of the angle of refraction is constant for all rays passing from one medium to another.

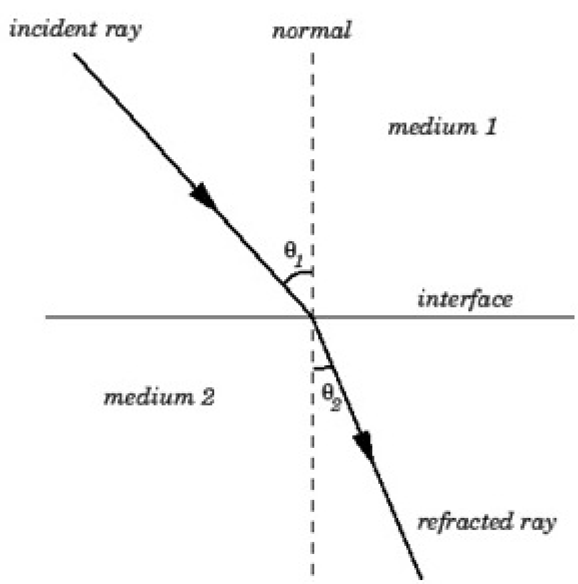
The two lays of refraction were postulated by a physicsist called Snell. Snell's first law of refraction is given as, Sin *I*/Sin r = n, a constant, for a given pair of media.

The law of refraction, which is generally known as *Snell's law*, governs the behaviour of light-rays as they propagate across a sharp interface between two transparent dielectric media.

Consider a light-ray incident on a plane interface between two transparent dielectric media, labelled 1 and 2, as shown in the Fig below. The law of refraction states that the incident ray, the refracted ray, and the normal to the interface, all lie in the *same plane*. Furthermore,

$n_1 \sin \theta_1 = n_2 \sin \theta_2$,

where θ_1 is the angle subtended between the incident ray and the normal to the interface, and θ_2 is the angle subtended between the refracted ray and the normal to the interface. The quantities n_1 and n_2 are termed the *refractive indices* of media 1 and 2, respectively. Thus, the law of refraction predicts that a light-ray always deviates more towards the normal in the optically denser medium: *i.e.*, the medium with the higher refractive index. Note that $n_1 > n_2$ in the figure. The law of refraction also holds for non-planar interfaces, provided that the normal to the interface at any given point is understood to be the normal to the local tangent plane of the interface at that point.



By definition, the refractive index of a dielectric medium of dielectric constant is given by

$n = \sqrt{K}$.

Table below shows the refractive indices of some common materials (for yellow light of wavelength $\lambda = 589nm$).

Refractive Indices of some common materials at λ = 589nm.

Material	n
Air (STP)	1.00029
Water	1.33
Ice	1.31
Glass:	
Light Flint	1.58
Heavy Flint	1.68
Heaviest Flint	1.89
Diamond	2.42

The law of refraction follows directly from the fact that the speed v with which light propagates through a dielectric medium is *inversely proportional* to the refractive index of the medium, $v = c/n$, where c is the speed of light in a vacuum. Consider two parallel light-rays, a and b, incident at an angle θ_1 with respect to the normal to the interface between two dielectric media, 1 and 2. Let the refractive indices of the two media be n_1 and n_2 respectively, with $n_2 > n_1$. It is clear from the figure below that ray b must move from point B to point Q, in medium 1, in the same time interval, Δt, in which ray *a*moves between points A and P, in medium 2. Now, the speed of light in medium 1 is $v_1 = c/n_1$, whereas the speed of light in medium 2 is $v_2 = c/n_2$. It follows that the length BQ is given by $v_1 \Delta t$, whereas the length AP is given by $v_2 \Delta t$. By trigonometry,

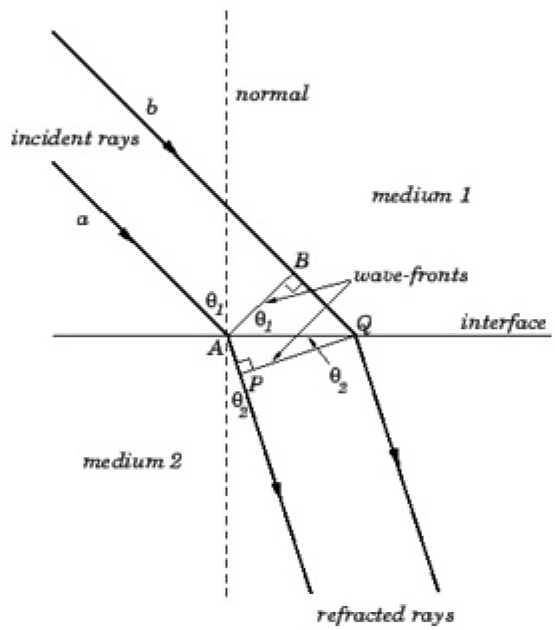
$\sin \theta_1$ BQ/AQ = $v_1\Delta t$/AQ,

and

$\sin \theta_2$ AP/AQ = $v_2\Delta t$/AQ

Hence $\sin \theta_1 / \sin \theta_2 = v_1/v_2 = n_2/n_1$

which can be rearranged to give Snell's law. Note that the lines AB and PQ represent wave-fronts in media 1 and 2, respectively, and, therefore, cross rays and at right-angles.



Derivation of Snell's law

When light passes from one dielectric medium to another its velocity changes, but its frequency *f* remains *unchanged*. Since, $v = f\lambda$ for all waves, where λ is the wavelength, it follows that the wavelength of light must also change as it crosses an interface between two different media. Suppose that light propagates from medium 1 to medium 2. Let n_1 and n_2 be the refractive indices of the two media, respectively. The ratio of the wave-lengths in the two media is given by

$\lambda_2/\lambda_1 = v_2/f \,/\, v_1/f = v_2/v_1 = n_2/n_1$

Thus, as light moves from air to glass its wavelength *decreases.*

Again, the constant n, is known as the refractive index of the second medium with respect to the first medium. It is a number which gives a measure of refraction or bending of light as it travels from one medium to another. If light is travelling from air to glass, the refractive index of glass is given by

${}_an_g$ = sine of angle of incidence in air/sine of angle of refraction in glass

If light travels from glass to air then the refractive index $_gn_a$ = sine of angle of incidence in glass/sine of angle of refraction in air

From the principle of the reversibility of light we have:

$_an_g = 1 / _gn_a$

Since refraction is due to the change in the speed of light as it travels from one medium to another, the refractive index is also given by

$_an_g$ = speed of light in air (vacuum)/speed of light in glass

Terms Associated with Refraction

(i) The incident ray: This is the direction of rays of the light from the source to the first medium.

(ii) The refracted ray: This is the direction to which the light travels from the point of incidence to the second medium which is always denser than the first medium.

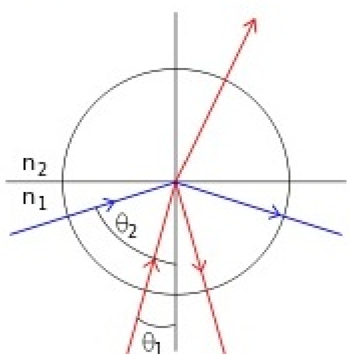
(iii) The angle of incidence: Thus is the angle at which the incident ray mixes with the normal in the first medium.

(iv) The angle of refraction: This is the angle at which the refracted ray mixes with the normal in the second medium.

Total Internal Reflection

Total internal reflection is a phenomenon that happens when a propagating wave strikes a medium boundary at an angle larger than a particular critical angle with respect to the normal to the surface. If the refractive index is lower on the other side of the boundary and the incident angle is greater than the critical angle, the wave cannot pass through and is entirely reflected. The **critical angle** is the angle of incidence above which the total internal reflectance occurs. This is particularly common as an optical phenomenon, where light waves are involved, but it occurs with many types of waves, such as electromagnetic waves in general or sound waves.

When a wave crosses a boundary between materials with different kinds of refractive indices, the wave will be partially refracted at the boundary surface, and partially reflected. However, if the angle of incidence is greater (i.e. the direction of propagation or ray is closer to being parallel to the boundary) than the critical angle – the angle of incidence at which light is refracted such that it travels along the boundary – then the wave will not cross the boundary and instead be totally reflected back internally. This can only occur when the wave in a medium with a higher refractive index (n_1) hits its surface that's in contact with a medium of lower refractive index (n_2). For example, it will occur with light hitting air from glass, but not when hitting glass from air.



The larger the angle to the normal, the smaller is the fraction of light transmitted rather than reflected, until the angle at which total internal reflection occurs. (The color of the rays is to help distinguish the rays, and is not meant to indicate any color dependence).

The critical angle is the angle of incidence *above* which total internal reflection occurs. The angle of incidence is measured with respect to the normal at the refractive boundary (see diagram illustrating Snell's law). Consider a light ray passing from glass into air. The light emanating from the interface is bent towards the glass. When the incident angle is increased sufficiently, the transmitted angle (in air) reaches 90 degrees. It is at this point no light is transmitted into air. The critical angle θ_c is given by Snell's law,

$n_1 \sin \theta_i = n_2 \sin \theta_t$.

Rearranging Snell's Law, we get incidence

$\sin \theta_i = n_2/n_1 \sin \theta_t$

To find the critical angle, we find the value for θ_i when $\theta_t = 90°$ and thus $\sin \theta_t = 1$. The resulting value of θ_i is equal to the critical angle θ_c.

Now, we can solve for θ_i, and we get the equation for the critical angle:

$\theta_c = \theta_i = \arcsin (n_2/n_1)$,

If the incident ray is precisely at the critical angle, the refracted ray is tangent to the boundary at the point of incidence. If for example, visible light were traveling through acrylic glass (with an index of refraction of approximately 1.50) into air (with an index of refraction of 1.00), the calculation would give the critical angle for light from acrylic into air, which is

$\theta_c = \arcsin (1.00/1.50) = 41.8^o$

Light incident on the border with an angle less than 41.8° would be partially transmitted, while light incident on the border at larger angles with respect to normal would be totally internally reflected.

If the fraction n_2/n_1 is greater than 1, then arcsine is not defined—meaning that total internal reflection does not occur even at very shallow or grazing incident angles.

So the critical angle is only defined when n_2/n_1 is less than 1.

Refraction of light at the interface between two media, including total internal reflection.

A special name is given to the angle of incidence that produces an angle of refraction of 90˚. It is called the critical angle.

ASSESSMENT

1. When a ray of light enters a glass, and moves out of it. ray before it entered and ray after it left glass are
   (a) perpendicular
   (b) at a certain angle
   (c) parallel
   (d) at critical angle

2. If light enters glass, it slows down further to
   (a) 200,000 km/s
   (b) 150,000 km/s
   (c) 100,000 km/s
   (d) 50,000 km/s
3. Name given to change in speed of light is known as
   (a) Reflection
   (b) Critical change
   (c) Refraction
   (d) Rarefaction
4. Ray of light is always refracted in
   (a) an indefinite direction
   (b) a definite direction
   (c) acute angle
   (d) obtuse angle
5. Refraction of light is proved by
   (a) Law of Einstein
   (b) Law of light
   (c) Law of Refraction
   (d) Law of Thomas

ANSWERS

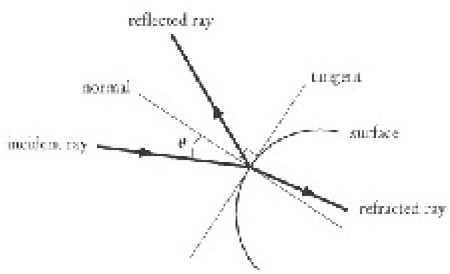
1. c
2. b
3. c
4. b
5. c

Week 2

Topic: LENSES

INTRODUCTION

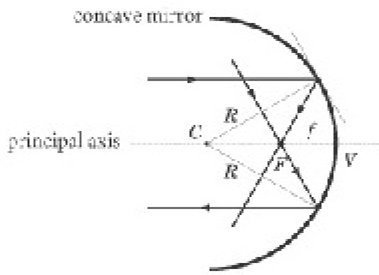
The reflection and refraction we have dealt with so far have focused only on light interacting with flat surfaces. Lenses and curved mirrors are optical instruments designed to focus light in predictable ways. While light striking a curved surface is more complicated than the flat surfaces we have looked at already, the principle is the same. Any given light ray only strikes an infinitesimally small portion of the lens or mirror, and this small portion taken by itself is roughly flat. As a result, we can still think of the normal as the line perpendicular to the tangent plane.



The four basic kinds of optical instruments—the only instruments are concave mirrors, convex mirrors, convex (or converging) lenses, and concave (or diverging) lenses. If you have trouble remembering the difference between concave and convex, remember that, like caves, concave mirrors and lenses curve inward. Convex lenses and mirrors bulge outward.

General Features of Mirrors and Lenses

Much of the vocabulary we deal with is the same for all four kinds of optical instruments. Before we look at the peculiarities of each, let's look at some of the features they all share in common.



The diagram above shows a “ray tracing” image of a concave mirror, showing how a sample ray of light bounces off it. Though we will take this image as an example, the same principles and vocabulary apply to convex mirrors and to lenses as well.

The **principal axis** of a mirror or lens is a normal that typically runs through the center of the mirror or lens. The **vertex**, represented by *V* in the diagram, is the point where the principal axis intersects the mirror or lens.

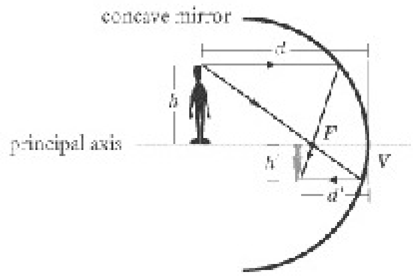
Spherical mirrors have a **center of curvature**, represented by *C* in the diagram, which is the center of the sphere of which they are a slice. The radius of that sphere is called the **radius of curvature**, *R*.

All rays of light that run parallel to the principal axis will be reflected—or refracted in the case of lenses—through the same point, called the **focal point**, and denoted by *F* on the diagram. Conversely, a ray of light that passes through the focal point will be reflected parallel to the principal axis. The **focal length**, *f*,is defined as the distance between the vertex and the focal point. For spherical mirrors, the focal length is half the radius of curvature, $f = R/2$.

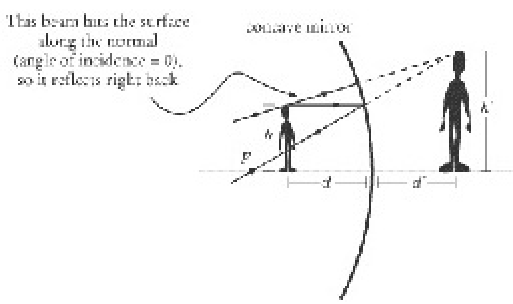
Concave Mirrors

Suppose a boy of height *h* stands at a distance *d* in front of a concave mirror. By tracing the light rays that come from the top of his head, we can see that his reflection would be at a distance d' from the mirror and it would have a height h'. As anyone who has looked into a spoon will have guessed, the image appears upside down.

The image at d' is a **real image**, as we can see from the ray diagram; the image is formed by actual rays of light. It means that, if you were to hold up a screen at position d’, the image of the boy would be projected onto it. You may have noticed the way that the concave side of a spoon can cast light as you turn it at certain angles. That’s because concave mirrors project real images.



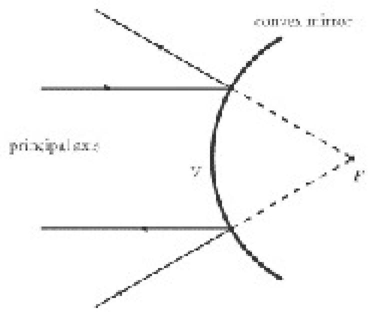
You’ll notice, though, that we were able to create a real image only by placing the boy behind the focal point of the mirror. What happens if he stands in front of the focal point?



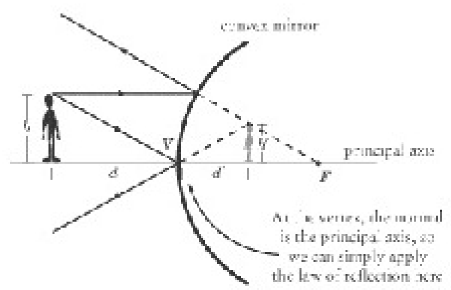
The lines of the ray diagram do not converge at any point in front of the mirror, which means that no real image is formed: a concave mirror can only project real images of objects that are behind its focal point. However, we can trace the diverging lines back behind the mirror to determine the position and size of a **virtual image**. Like an ordinary flat mirror, the image appears to be standing behind the mirror, but no light is focused on that point behind the mirror. With mirrors generally, an image is real if it is in front of the mirror and virtual if it is behind the mirror. The virtual image is right side up, at a distance d’ from the vertex, and stands at a height h’.

You can test all this yourself with the right kind of spoon. As you hold it at a distance from your face, you see your reflection upside down. As you slowly bring it closer, the upside-down reflection becomes blurred and a much larger reflection of yourself emerges, this time right side up. The image changes from upside down to right side up as your face crosses the spoon’s focal point.

Convex Mirrors



The focal point of a convex mirror is behind the mirror, so light parallel to the principal axis is reflected away from the focal point. Similarly, light moving toward the focal point is reflected parallel to the principal axis. The result is a virtual, upright image, between the mirror and the focal point.



You have experienced the virtual image projected by a convex mirror if you've ever looked into a polished doorknob. Put your face close to the knob and the image is grotesquely enlarged, but as you draw your face away, the size of the image diminishes rapidly.

The Two Equations for Mirrors and Lenses

So far we have talked about whether images are real or virtual, upright or upside down. We've also talked about images in terms of a focal length *f*, distances *d* and d', and heights *h* and h'. There are two formulas that relate these variables to one another, and that, when used properly, can tell whether an image is real or virtual, upright or upside down, without our having to draw any ray diagrams.

These two formulas are all the math you'll need to know for problems dealing with mirrors and lenses.

First Equation: Focal Length

The first equation relates focal length, distance of an object, and distance of an image:

$1/d + 1/d' = 1/f$

Values of *d*, d', and *f* are positive if they are in front of the mirror and negative if they are behind the mirror. An object can't be reflected unless it's in front of a mirror, so *d* will always be positive. However, as we've seen, *f* is negative with convex mirrors, and d' is negative with convex mirrors and with concave mirrors where the object is closer to the mirror than the focal point. A negative value of d' signifies a virtual image, while a positive value of d' signifies a real image.

Note that a normal, flat mirror is effectively a convex mirror whose focal point is an infinite distance from the mirror, since the light rays never converge. Setting $1/f = 0$, we get the expected result that the virtual image is the same distance behind the mirror as the real image is in front.

Second Equation: Magnification

The second equation tells us about the **magnification**, *m*, of an image:

$m = h'/h = -d'/d$

Values of h' are positive if the image is upright and negative if the image is upside down. The value of *m* will always be positive because the object itself is always upright.

The magnification tells us how large the image is with respect to the object: if $|m| > 1$, then the image is larger; if $|m| < 1$, the image is smaller; and if $m = 1$, as is the case in an ordinary flat mirror, the image is the same size as the object.

Because rays move in straight lines, the closer an image is to the mirror, the larger that image will appear. Note that d'/d will have a positive value with virtual images and a negative value with real images. Accordingly, the image appears upright with virtual images where *m* is positive, and the image appears upside down with real images where *m* is negative.

Example

A woman stands 40cm from a concave mirror with a focal length of 30cm. How far from the mirror should she set up a screen in order for her image to be projected onto it? If the woman is 1.5cm tall, how tall will her image be on the screen?

How far from the mirror should she set up a screen in order for her image to be projected onto it?

The question tells us that d = 40 cm and f = 30 cm. We can simply plug these numbers into the first of the two equations and solve for d', the distance of the image from the mirror:

$$1/40\text{cm} + 1/d' = 1/30\text{cm}$$

$$1/d' = 1/120\text{cm}$$

$$d' = 120\text{cm}$$

Because d' is a positive number, we know that the image will be real. Of course, we could also have inferred this from the fact that the woman sets up a screen onto which to project the image.

How tall will her image be on the screen?

We know that d = 40 cm, and we now know that d' = 120 cm, so we can plug these two values into the magnification equation and solve for m:

$$m = -d'/d$$

$$= -120\text{cm}/40\text{cm}$$

$$= -3$$

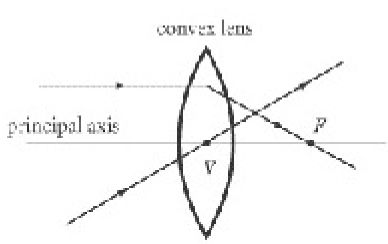
The image will be three times the height of the woman, or 1.5 x 3 = 4.5m tall. Because the value of *m* is negative, we know that the image will be real, and projected upside down.

Convex Lenses

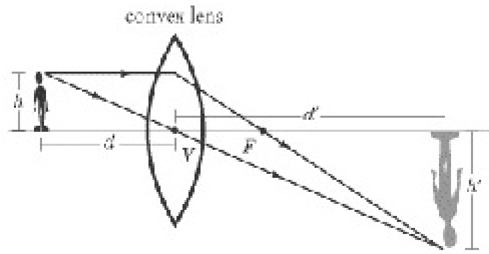
Lenses behave much like mirrors, except they use the principle of refraction, not reflection, to manipulate light. You can still apply the two equations above, but this difference between mirrors and lenses means that the values of d' and *f* for lenses are positive for distances behind the lens and negative for distances in front of the lens. As you might expect, *d* is still always positive.

Because lenses, both concave and convex, rely on refraction to focus light, the principle of dispersion tells us that there is a natural limit to how accurately the lens can focus light. For example, if you design the curvature of a convex lens so that red light is focused perfectly into the focal point, then violet light won't be as accurately focused, since it refracts differently.

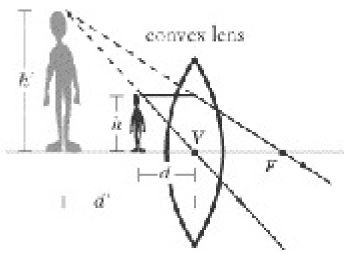
A **convex lens** is typically made of transparent material with a bulge in the center. Convex lenses are designed to focus light into the focal point. Because they focus light into a single point, they are sometimes called "converging" lenses. All the terminology regarding lenses is the same as the terminology we discussed with regard to mirrors—the lens has a vertex, a principal axis, a focal point, and so on.



Convex lenses differ from concave mirrors in that their focal point lies on the opposite side of the lens from the object. However, for a lens, this means that $f > 0$, so the two equations discussed earlier apply to both mirrors and lenses. Note also that a ray of light that passes through the vertex of a lens passes straight through without being refracted at an angle.

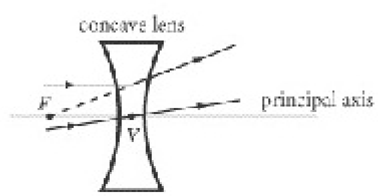


In this diagram, the boy is standing far enough from the lens that *d* > *f*. As we can see, the image is real and on the opposite side of the lens, meaning that d' is positive. Consequently, the image appears upside down, so h' and *m* are negative. If the boy were now to step forward so that *d* < *f*, the image would change dramatically:

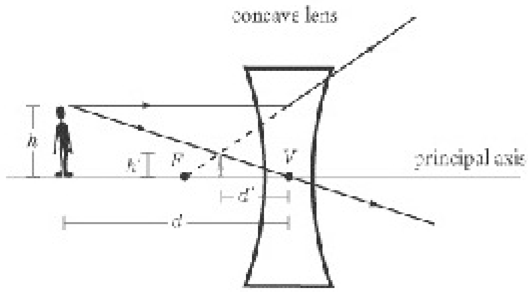


Now the image is virtual and behind the boy on the same side of the lens, meaning that d' is negative. Consequently, the image appears upright, so h' and *m* are positive.

Concave Lenses



A **concave lens** is designed to divert light away from the focal point, as in the diagram. For this reason, it is often called a "diverging" lens. As with the convex lens, light passing through the vertex does not bend. Note that since the focal point *F* is on the same side of the lens as the object, we say the focal length *f* is negative.



As the diagram shows us, and as the two equations for lenses and mirrors will confirm, the image is virtual, appears on the same side of the lens as the boy does, and stands upright. This means that d' is negative and that h' and *m* are positive. Note that *h* >h', so *m* < 1.

Summary

ASSESSMENT

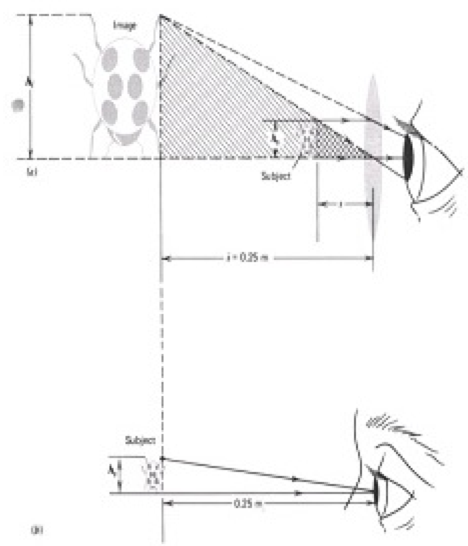
1. What are lenses?
2. What are the four basic kinds of optical instrument?
3. What are the features of mirrors and lenses?
4. What are the two equations of mirrors and lenses?
5. A woman stands 60cm from a convex mirror with a focal length of 15cm. How far from the mirror should she set up a screen in order for her image to be projected onto it? If the woman is 3cm tall, how tall will her image be on the screen

WEEK 3

Topic: OPTICAL INSTRUMENTS

Magnifiers

Perhaps the simplest optical instrument is the lens magnifier. Without optical aid, we cannot "see" things close up. The eye will simply not focus closer than about 0.25 m (unless you are nearsighted!). But an object places just inside the focal point of a converging lens will produce a large virtual image that can be viewed more easily. Let's look at our Convex Lens again.



Her we can see that the ratio of the heights of the subject and image, the magnification *M* is

$M = h_i/h_s = i/s$

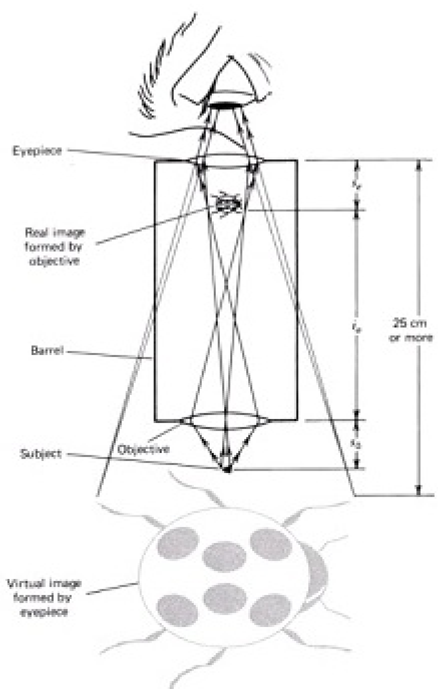
Usually we are able to get good magnification and place the image near 0.25 m if the object is close to the focal point on the object side of the lens. Using $i \sim 0.25$ m and $s \sim f$, we get

$M \sim 0.25/f$

as long as *f* is measured in meters. (For *f* in cm, the constant in the numerator is 0.25 x 100 = 25).

Microscopes

The standard optical microscope consists of two <u>lenses</u> (each can be a compound lens). By placing the object to be observed very close to the focal point of the first or objective lens, a larger real (but inverted) image will be produced. This real image is then observed with a second lens, the eyepiece, which acts as a magnifier to make the image even larger. If you wear eyeglasses or reading glasses, removing them will allow you to view the microscope properly.



The net magnification of the entire system is the product of the magnifications of the objective and eyepiece. For these we just use the magnifications given for a simple lens and a magnifier:

$M = M_o M_e = (i_o/s_o)(0.25/f_e)$

Because the image is much larger than the object, it usually requires that the object be brightly lit, or it will be too dark to see well.

Another practical limit on an optical microscope comes from the fact that the wavelength of visible light is so “large”. The fineness of detail that can be observed, measured in radians, is given by Rayleigh’s criterion:

$\theta_R = 1.22\lambda/d$

where *d* is the diameter of the opening through which the light passes (such as the objective), and l is the wavelength of light used. This limitation comes from the wave properties of light. Light passing through a narrow opening undergoes diffraction, which spreads the beam out. Diffraction is basically just the interference pattern of a light wave with other portions within the same opening instead of a different opening.

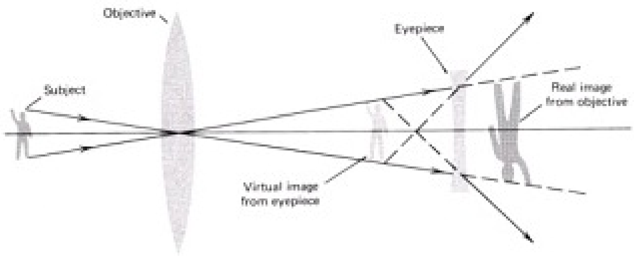
Better resolution can be obtained using UV light, but that only helps a little.

Electrons have much smaller wavelengths than visible light, and so can be used to see smaller details. This is the basis of the electron microscope, which uses magnetic fields to focus the electrons. However, this is getting off the subject of light & color….

Refracting Telescopes

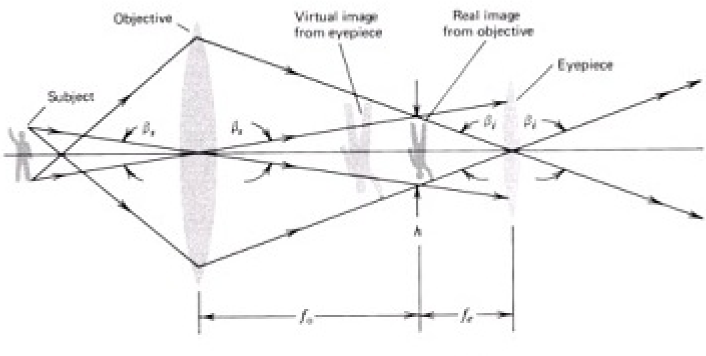
Telescopes come in many different designs. Those that use a lens as the objective to gather and focus the light are refracting telescopes, while those that do this with mirrors are reflecting telescopes.

The first telescopes were refractors that used a convex lens to form an inverted image of a distant object, and used a concave lens to invert this image to an upright orientation as well as provide some additional magnification. Because this was the sort of device Galileo used to make the first important telescopic discoveries in astronomy, it is usually referred to as a *Galilean telescope*.



Galilean Telescope

However, Kepler found that greater magnification could be obtained using an eyepiece that was a convex lens, at the expense of keeping the inverted orientation of the image formed by the objective.



Keplerian Telescope

Refracting telescopes used in astronomy are of the Keplerian type, while the upright image of the Galilean design is usually preferred for terrestrial observing.

The critical optical parameters for an astronomical telescope are its light-gathering power, angular resolution, magnification, and image brightness.

Light-Gathering Power

The greater the diameter of the objective, the greater the surface that will intercept the light from an object. If one is dealing with faint sources, this is usually the single most important criterion. For this reason, astronomers "label" telescope sizes by the diameter of their objectives (lens or mirror) and try to make it as large as possible. If the diameter of the telescope is *D* meters, then the surface area intercepting the light is

$A_{objective} = \pi/4\ D^2\ m^2$

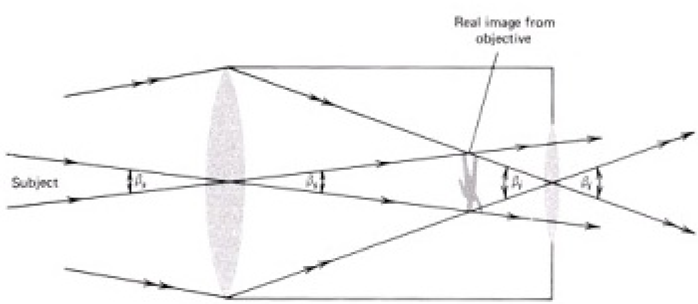
The largest optical telescopes today have diameters of 8-10 m. By contrast, the inner diameter of the iris in the human eye, after dark adaptation, is about 1/2 cm.

Resolution

Although the diameter *D* is generally much larger than the wavelength of light, it is not infinitely bigger, and Rayleigh's criterion still applies. Larger diameter objectives and smaller light wavelengths improve the situation. (As a practical matter, atmospheric turbulence will dominate over diffraction in degrading the image for telescopes larger than about 10 cm. Compensating for this phenomenon using adaptive optics or placing the telescope above the atmosphere improve the situation).

Angular Magnification

Because the actual image distance and size are often unknown (in astronomy *usually* unknown), we will deal with *angular magnification* instead.



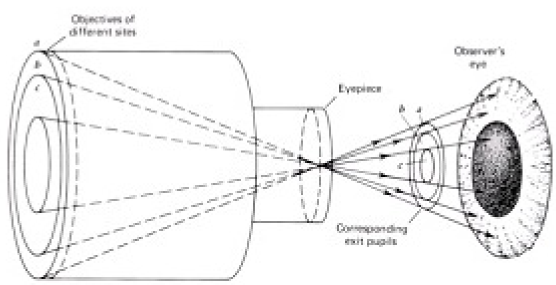
The angular magnification is simple the ratio of the focal lengths of the objective & eyepiece:

$M_{ang} = f_{objective}/f_{eyepiece}$

So with a telescope of some fixed objective, higher magnification is just a matter of using small focal length eyepieces. The magnification is usually described as magnifying “power”, often just designated with an “X”. Thus a telescope with a magnification of 100 would be described as “100 power” or “100 X”.

Image Brightness

When using the human eye to observe with a telescope, care must be paid to how the beam of light enters the eye. The so-called *exit pupil* should roughly match that of the eye. Making it too big directs light outside the pupil of the eye, so it is wasted. Making it smaller is done at the cost of a smaller effective objective opening, and the image is fainter (the light-gathering power of the eye is wasted).



Up to a limit then, the larger “cone” the brighter the source. The number often used to describe this is the f-ratio defined as

$F^{i} = f_{objective}/D_{objective}$

If the focal length is 5 times the diameter, the lens is said to be an f/5 lens. In both astronomical photography and terrestrial photography, the eye is replaced by a camera (which may or may not have a lens in it). The smaller the f-number, the brighter the image formed on the detector (film, plate, CCD chip, etc). Getting small f/ requires highly curved lenses, and this requires the use of multiple lenses of differing shapes & materials in order to minimize chromatic (and other) aberration. Every surface that is required costs money to make…..

The light convergence is done by using a curved surface for the mirror. If that were all that were use, however, the eyepiece and the observer’s head would have to be placed in front of the telescope, blocking the light! So Newton used a flat secondary mirror to redirect the light to the side. This design is still called a *Newtonian telescope*.

A spherical mirror will produce noticeable spherical aberration unless the f-ratio is large. Spherical aberration is eliminated by using a parabolic mirror, at the cost of introducing coma. Another way to produce a better image is to use a curved *secondary mirror* designed to remove some of the aberrations of the objective or *primary mirror*. The *Cassegrain telescope* is one example.

The Projector

A **projector** or **image projector** is an optical device that projects an image (or moving images) onto a surface, commonly a projection screen.

Most projectors create an image by shining a light through a small transparent lens, but some newer types of projectors can project the image directly, by using lasers. A virtual retinal display, or retinal projector, is a projector that projects an image directly on the retina instead of using an external projection screen.

The most common type of projector used today is called a video projector. Video projectors are digital replacements for earlier types of projectors such as slide projectors and overhead projectors. These earlier types of projectors were mostly replaced with digital video projectors throughout the 1990s and early 2000s (decade), but old analog projectors are still used some places. The newest types of projectors are handheld projectors that use lasers or LEDs to project images. Their projections are hard to see if there is too much ambient light.

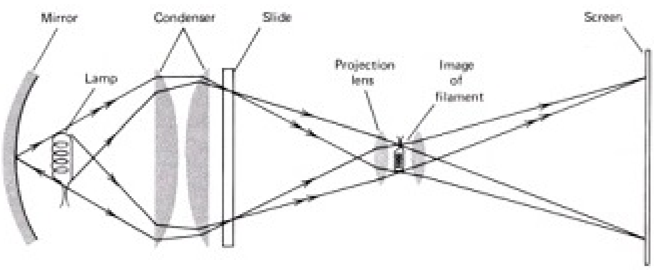
Movie theaters use a type of projector called a movie projector. Another type of projector is the enlarger, a device used to produce photographic prints from negatives.

Projection Systems

Film and slide projectors consist of 4 basic components:

1. a lamp (often with a rear reflective mirror to add more light

2. a condenser lens to direct as much light through the film/slide as possible and form an image of the filament of the lamp where it won't be visible
3. the film/slide
4. the projection lens



The projection lens forms an image of the film/slide on a screen. The image of the filament, formed inside the projection lens is so out of focus as not to be visible.

The design of projection screens is a science of its own. Screens can be made to reflect the light back in a number of ways. (There is more to reflective surfaces than Lambertian and specular reflection!).

The standard "overhead projector" used in classrooms uses a Fresnel lens as the condenser.

A similar design I used for some automobile headlights, but the "grooved" surface is inside. If it were on the outside, it would collect dirt more easily and be a nightmare to clean!

ASSESSMENT

1. List 3 types of optical instruments
2. Define angular projection
3. What is a projector?
4. What are the basic components of a projection system?

Week 4

Topic: Optical Instruments

INTRODUCTION

Optical instruments processes light waves to enhance an image for viewing or analyze light waves to determine number of characteristic properties. The very first optical instruments were telescopes and microscopes used for magnifications of images. Mirrors and lenses find their applications in very many walks of life. Since the days of Galileo, these optical instruments have been greatly improved and extended into other portions of the electromagnetic spectrum. These instruments employ calculations of positions of objects and images from ray diagrams that we have discussed in Spherical Mirrors and Lenses.

Some optical instruments that we see in everyday lives are:

The human eye – convex lens.

Corrections of defects of vision – combinations of concave and convex lenses.

Compound microscope – double convex lens.

Telescope – convex lenses.

Holography – combination of convex lens and mirrors.

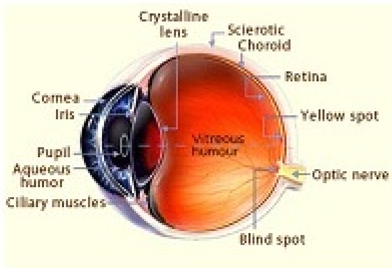
Three dimensional viewing – combination of convex lenses.

Binoculars – Prisms, convex lenses and mirrors.

Camera – combination of convex lenses.

Periscope – Plane mirrors or prisms.

Human Eye



Light is the only thing we see with the most remarkable optical instrument known – the eye. Light enters the eye through the transparent cover called the cornea, which does about 70% of the necessary bending of the light before the light passes through the pupil (which is an aperture in the iris). The light then passes through the lens, which is used only to provide the extra bending power needed to focus images of nearby objects on the layer at the back of the eye, the retina.

The lens is held by ciliary muscles, which stretch and relax to change the focal length of the lens. The distance of the image that a lens produces on the retina depends on the object distance and the focal length of the lens. In the case of the eye lens, however, the image is always produced on the retina no matter where the object is. In other words, for the eye lens, the image distance is fixed. Therefore the focal length of the eye lens must change in accordance with the object distance. This is the function of ciliary muscles.

The Defects of Human Eyes

Myopia (Short sightedness): Human eye can see clearly the objects lying at short distances from it. but not the far off objects

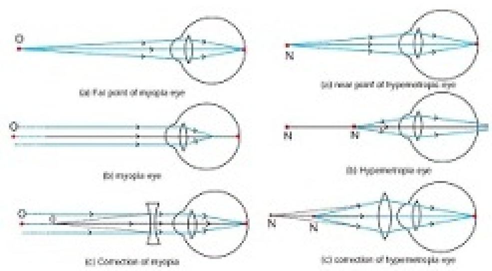
Causes of Myopia:

1. Increase in the length of the eye ball as if distance of the retina from the eye has increased.

2. Decrease in focal length of eye lens when the eye is fully relaxed.

Remedy: To correct a myopic eye, the person has to wear spectacle with a concave lens of suitable focal length. (i.e.) the focal length of concave lens is equal to the distance of the far point of the myopic eye.

Hypermetropia (Long sightedness): It is that defect of a human eye by virtue of which it can see clearly the objects lying at large distances from it but the nearby objects cannot be seen clearly.



Causes of Hypermetropia:

(1) Decrease in length of eye ball as if distance of retina from the eye lens has decreased

(2) Increase in the focal length of the eye lens when the eye is fully relaxed.

Remedy: To correct a hypermetropic eye, the person has to wear spectacle with a convex lens of suitable focal length.

The focal length of the convex lens is given by f=(x d) / (x-d)

where x is the distance of near point of defective eye, d is the distance of near point of normal eye (25 cm)

Presbyopia: In this defect old person cannot read and write comfortably.

Remedy: An old person has to use spectacles with a convex lens of suitable focal length

When a person suffers from both myopia and hypermetropia his spectacles have bi-focal lenses (i.e) both concave and convex lenses.

Astigmatism

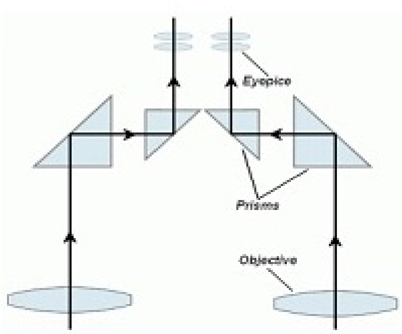
The defect, by which the person is notable to differentiate horizontal and vertical position, is called astigmatism. It can be rectified by using cylindrical lenses.

Binoculars

Binoculars are like a pair of telescopes fixed together so there is one for each eye. The distance between them is adjustable for different people and they can be focused on whatever you are looking at. They are vital for bird watching, watching horse racing and in the military.

To understand the working principle of binoculars, first you need to know a little about telescopes. In fact, this is exactly what binoculars are, two identical telescopes placed next to each other.

At the front of each telescope is a lens, called the objective. Its role is to gather light from whatever it is you're looking at and bring it to a focus in the eyepiece, where the light is formed into a visible image and magnified to take up a large portion of the retina. The magnification depends on the focal length of the eyepiece, and for binoculars it is usually between 5x and 10x.



The image produced by this telescope will be upside down and backwards, but for astronomical viewing this is not a major inconvenient. In space there is no up and down or left and right. However, for watching birds or following the action at a baseball game a right- side-up picture is essential. This is why binoculars use corrective elements between the objective and the eyepiece, called prisms.

Prisms used in binoculars are blocks of glass that function as mirrors, but without a mirror's reflective backing. They come in two models and use different types of glass, and we will

discuss about this later in the article. For now let's just mention their role, that is to bring the light beams from the objective closer together by means of internal reflection, and also turn the image right-side up and orient the view properly left to right.

To better understand the working principles take a look at the image above. It shows the path of the light as it enters the objectives, passes through a set of prisms that turn the image right side up, and finally leaves the eyepieces to enter the observer's eyes. This applies to all binoculars, no matter what model or size.

All binoculars are described by using a pair of numbers, such as 7×50 or 8×30. The first number, including the x, represents magnification or "power". This tells the degree to which the object observed is enlarged. For example, a 7x binocular makes an object appear seven times closer than when viewed by the naked eye.

There are some models of binoculars that offer variable magnification, usually in the range of 5x to 8x. They are called zoom binoculars, and in most cases are not very suited for astronomical observations because of the inferior optical quality and fragile mechanics. The best thing to do is to avoid them and stick with the usual fixed-power binoculars.

Magnification is not that important, and in most cases comes within 7x to 12x. If the magnification exceeds these figures, most likely you won't be able to hold the binoculars steady enough and the images will be blurry and in constant movement. This is especially frustrating when observing faint objects like galaxies and nebulae. A tripod mount or image-stabilized binoculars will get you rid of this problem, but we will talk about this later in the article.

ASSESSMENT

1. What are optical instruments?
2. List some examples of optical instruments.

3. What is the function of the Ciliary muscles?
4. What are the causes of myopia?
5. What are the causes of hypermetropia?
6. How can astigmatism be corrected?

WEEK 5

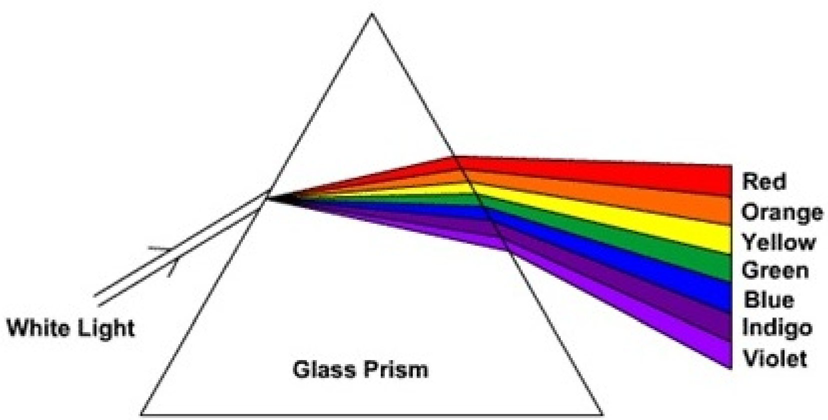
Topic: DISPERSION OF WHITE LIGHT

INTRODUCTION

Dispersion is the splitting up of white light into seven colors on passing through a transparent medium like a glass prism. When a white light beam is passed through a prism, a band of seven colors are formed is known as spectrum of white light. The seven colors in the spectrum are red, orange, yellow, green, blue, indigo and violet respectively.

Dispersion of Light through Prism

The formation of spectrum of seven colors shows that white light is a mixture of seven colors (or seven colored light). The effect of transparent medium (like glass prism) is only to separate the seven colors of white light.



White light is a mixture of lights of seven colors: red, orange, yellow, green, blue, indigo and violet. The dispersion of light occurs because the angle of refraction (or the angle of bending) of lights of different colors is different when passing through the transparent medium (glass prism)

Pure Spectrum

Spectrum produced so far is impure because the rays overlap and the position of the spectrum also changes as the colour is not separated. A pure spectrum can be produced using a triangular prism-two converging lenses and a narrow slit of white light. The narrow slit is used to produce series of narrow coloured images, which minimizes the chances of overlapping colours, when incident rays are incidented on the converging lens which retracts the rays into a parallel beam and focus it on angle 60 triangular prism. The emergent rays are then focused on another converging lens to produce parallel of different colours on the screen at its focus. This produces a spectrum which does not overlap.

For the production of a pure spectrum, we require the following conditions:

(i) A narrow slit as a source of light; this produces series of narrow, coloured images, which minimizes the chances of overlapping colour.

(ii) A converging lens is placed with the slit at its focus, so that a beam of parallel light is produced.

(iii) A 60^o prism for dispersion of the parallel beam.

(iv) A second lens for collecting the parallel beams of different colours, but this is not essential.

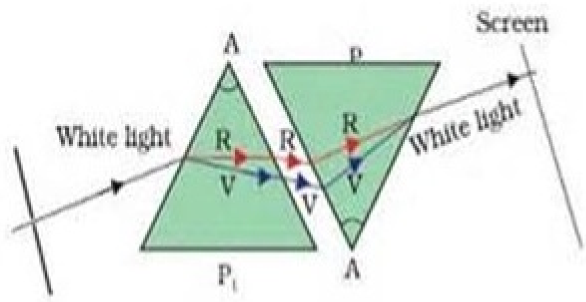
(v) A screen at the focus of the second lens on which the pure spectrum can be projected.

Impure Spectrum

Impure spectrum can be produced if only one converging lens is available. The image produced on the screen will not be pure, since there is absence of final converging lens to produce a parallel beam as that of pure spectrum. The converging lens focuses the refracted beam parallel to the prism which in turn is refracted and dispersed by focusing them on a screen. The prism must be placed at minimum deviation position to obtain a fairly impure spectrum.

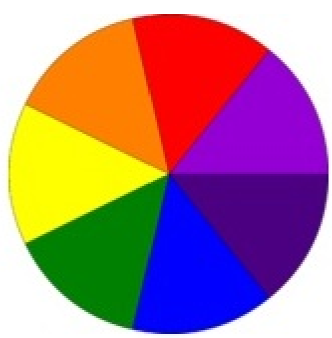
Recombination of Spectrum

The spectrum of colours can be reversed to its original light [colour]. This follows a simple procedure: The emergent rays from the prism which serve as incident ray for the second prism B, the rays are refracted and combined before coming out as a single ray of light which can be focused on the screen as a wavelength.



Newton's Colour Disc

A **Newton disc** is a disc with segments in rainbow colours. When the disc is rotated, the colors fade to white; In this way Isaac Newton demonstrated that white light is a combination of the seven different colours found in a rainbow. A Newton Disc can be created by painting a disc with the seven different colours. A combination of red, green and blue in the circular disc will yield the same result. This is due to the phenomenon called persistence of vision. It can easily be board piece. It was an important discovery as it proves that light is not colourless, but has colour in it which together converge to give a faded white colour which we consider colourless. It was made by Isaac Newton. This property is based on the principles of dispersion of light.



Dispersion Power

The refractive index of the material of a prism is given by:

$\mu = \sin (A + D/2)/\sin (A/2)$

Where A is the acute angle of the prism, D is the minimum deviation for small angle prism.

$D = [\mu - 1] A$

for small prism $A = \alpha$ acute angle

$D = d =$ minimum deviation

Then, $d = [\mu - 1]\alpha$

$d = [\mu - 1]\alpha$

The dispersion power (w) of the material of a small angle prism for blue and red rays is defined as the angular dispersive difference blue and red to its minimum deviation.

w = angular dispersive difference between red and blue

$w = n_b - n_r/\mu - 1$

ASSESSMENT

1. What is dispersion?
2. What are the conditions required for the production of a pure spectrum?
3. White light is a combination of which colours?
4. What is a Newton colour disc?

WEEK 6

Topic: Dispersion of White Light: Colours and Paints

Forms of Colours

1. Primary colours: There are three forms of colours or spectrum which cannot be produced by mixing any colour together. The primary colours are red, green and blue. They occur naturally from the spectrum and they can form other colours when mixed in the same proportion.

2. Secondary colours: There are colours formed from primary colours. They are colours obtained by mixing two of the primary colours together in the same proportion, e.g. when light mixes with blue light, they produce magenta colour, also when blue is mixed with green light, they produce cyan and when a green light is mixed with red light they produce a yellow light.

Red + Green → Yellow

Green + Blue → Cyan

Blue + Red → Cyan

3. Complementary colours: There are two colours which give a white colour when mixed together. Complementary colours are obtained when a secondary colour is mixed with a colour that is not in its component. Complementary colours can be obtained by.

(i) mixing a primary colour with a secondary colour.

(i) mixing two secondary colours.

(iii) mixing the primary colours.

Colour Triangles and Circles

The colour trianges and circles are obtained from the additive colour mixing of primary colours with other colours which are secondary and tertiary colours [complementary]. The colour obtained can be summarized as,

R + B → magenta

R + G → yellow

B + G → cyan

Complementary

R + B + G → white

B + Y → white

R + cyan → white

G + magenta → white

These colours of bodies can be represented on

WEEK 7

Topic: SOUND WAVES

SOUND WAVES

We know that waves are the produced disturbance which are formed by vibration and travel through a medium. There are different types of waves like transverse, longitudinal waves, etc. even whatever we hear that sound also comes in the form of a wave. So, we can say that sound comes towards us in the form of a wave.

The sound waves are mechanical waves which are created from vibrations between the particles of the medium. When it is moved through the medium of air then the air particles are displaced by the moving energy of sound waves and wave is travelled. But it can also be a longitudinal wave like in vibrating tuning fork which creates waves from vibrations.

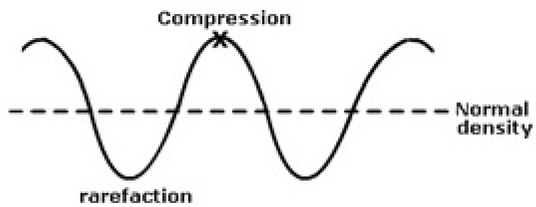
But what type of wave is sound? How it is travelled from one medium to another medium? Is it **mechanical wave** or **longitudinal wave** or **pressure wave**? Here we are given a complete explanation of these questions. Let's discuss a detailed description on the sound waves.

Consider an excited tuning fork or a plucked guitar string, produces sound. On close observation, the prongs of the tuning fork or the string is found to have a hazy and blurred outline on account of rapid vibrations. If they are gently touched with the fingers, a series of impulses will be felt. These sensations are nothing but the Sound waves.

The source of a sound wave is vibrating object. Thus, the Sound waves are the traveling waves in which oscillation of pressure is transmitted from one point to another in different mediums.

Sound wave is defined as: A traveling wave which is an oscillation of pressure transmitted through a solid, liquid, or gas, composed of frequencies within the range of hearing.

The sound wave can be represented as follows:



In constructing sound, there must be a source for a sound.

The speed of sound

Sound travels at different velocities in different media. In air at 20 ºC, sound travels at 344 $m.s^{-1}$ (the so-called *SPEED OF SOUND*). This figures varies with temperature and pressure. In water at 20 ºC, sound travels at 1498 $m.s^{-1}$. In general, the more incompressible a medium is, the faster sound will travel in that medium. If an object travels faster than the speed of sound in a particular location, that object is said to travel at supersonic speed.

Remember that the relationship between the velocity, **v** of a wave, its frequency **f**, and its wavelength, **λ** is given by $\mathbf{f = v/\lambda}$.

A sound wave is a pressure disturbance that travels through a medium by means of particle-to-particle interaction. As one particle becomes disturbed, it exerts a force on the next adjacent particle, thus disturbing that particle from rest and transporting the energy through the medium. Like any wave, the speed of a sound wave refers to how fast the disturbance is passed from particle to particle. While frequency refers to the number of vibrations that an individual particle makes per unit of time, speed refers to the distance that the disturbance travels per unit of time. Always be cautious to distinguish between the two often-confused quantities of speed (*how fast…*) and frequency (*how often…*).

Since the speed of a wave is defined as the distance that a point on a wave (such as a compression or a rarefaction) travels per unit of time, it is often expressed in units of meters/second (abbreviated m/s). In equation form, this is

Speed = distance/time

The faster a sound wave travels, the more distance it will cover in the same period of time. If a sound wave were observed to travel a distance of 700 meters in 2 seconds, then the speed of the wave would be 350 m/s. A slower wave would cover less distance – perhaps 660 meters – in the same time period of 2 seconds and thus have a speed of 330 m/s. Faster waves cover more distance in the same period of time.

The Speed of Sound in Air

The speed of a sound wave in air depends upon the properties of the air, mostly the temperature, and to a lesser degree, the humidity. Humidity is the result of water vapor being present in air. Like any liquid, water has a tendency to evaporate. As it does, particles of gaseous water become mixed in the air. This additional matter will affect the mass density of the air (an inertial property). The temperature will affect the strength of the particle interactions (an elastic property). At normal atmospheric pressure, the temperature dependence of the speed of a sound wave through *dry air* is approximated by the following equation:

$v = 331 \text{ m/s} + (0.6 \text{ m/s/C}) \cdot T$

where T is the temperature of the air in degrees Celsius. Using this equation to determine the speed of a sound wave in air at a temperature of 20 degrees Celsius yields the following solution.

$v = 331 \text{ m/s} + (0.6 \text{ m/s/C}) \cdot T$

$v = 331 \text{ m/s} + (0.6 \text{ m/s/C} \cdot (20 \text{ C})$

v = 331 m/s + 12 m/s

v = 343 m/s

(The above equation relating the speed of a sound wave in air to the temperature provides reasonably accurate speed values for temperatures between 0 and 100 Celsius. The equation itself does not have any theoretical basis; it is simply the result of inspecting temperature-speed data for this temperature range. Other equations do exist that are based upon theoretical reasoning and provide accurate data for all temperatures.

Example:

A tuning fork, labelled “A”, has a frequency of 440 Hz.

What is the period of the wave that it produces?

Answer:

The period, T, is the reciprocal of the frequency, **f**. Thus, T = 1/440 (s^{-1}) = 2.27×10^{-3} s.

The wave travels in air at a speed, v, of 330 $m\cdot s^{-1}$. What is the wavelength of that sound wave?

Answer:

The wavelength, **λ = v/f**.
Hence **λ** = 330/440 = 0.75 $m\cdot s^{-1}$

How many complete vibrations will this tuning fork make in 5 seconds?

Answer:

The period, **T**, is the time taken for ONE complete vibration. Therefore, the number of complete vibrations, N, in any time, **t**, will be given by **t/T = tf**. In this case, it is 10 x 440 = 4400.

Noise, Sound and Music

Noise is an unpleasant sound produced at different frequencies. It disturbs the hearing system of human beings. It is a mixture of different sounds with different frequencies at different levels.

Thus, noise is regarded as a sound or combination of sounds of constantly varying pitch. On the other hand, music is a pleasant sound produced at the same frequency. It is a sound of the same frequency at the same level. It is good for hearing.

Sound: Sound is the transfer of energy through an elastic medium from a source to the listener. Thus, a sound of regular frequency is called a tone or musical note and music is a combination of such sounds.

Difference between Sound Wave and Light Wave

Sound Wave	Light Wave
Sound cannot travel in a vacuum	Light waves can travel in a vacuum
Sound is the transfer of kinetic energy	Light is the transfer of electromagnetic energy
Sound waves are longitudinal waves	Light waves are transverse waves
The speed of sound increases as the waves move from a lighter to a denser medium	The speed of light decreases as the waves move from a lighter to a denser medium

Questions

1. A destroyer's sonar receives an echo from a submarine 11.2 seconds after sending a pulse. The speed of sound in seawater is 1560 $m \cdot s^{-1}$. How far is the submarine away from the destroyer?

A. 8736 m B. 9210 m C. 10205 m D. 17470 m

2. The “noon gun”, fired every day at precisely 12h00 from Signal Hill in Cape Town, is heard 15.0 seconds later from the top of Devil’s Peak. Given that the speed of sound is 333 $m \cdot s^{-1}$, how far has the sound travelled?

A. 3.5 km B. 4.5 km C. 5.0 km D. 6.0 km

The diagrams above demonstrate a sound wave travelling through a compressible medium. Each successive diagram involves a time interval of 0.15 ms measured from the previous one.

3. What is the wavelength of the wave?

A. 0.15m B. 0.30m C. 0.45m D. 0.60m

4. What is the period of the wave?

A. 0.15m B. 0.30m C. 0.45m D. 0.60m

5. What wave category does sound belongs?

A. Longitudinal wave B. Mechanical wave C. Pressure wave D. Transverse wave

Answer

1. A 2. C 3. A 4. C 5. B

WEEK 8

Topic: SOUND WAVES

Effect of Temperature and Pressure on Velocity of Sound

Velocity of Sound Waves

Since there are three states of matter, it means there must be three velocities for the three states, because experimentally three states are not the same. The velocity varies from medium to medium.

The velocity of sound in air, for dry air at 0^0C is approximately 330m/s, but at room temperature, it is about 340m/s, approximately used in calculation as 330m/s.

The velocity of sound in water, i.e, liquid state is about 1,500m/s, approximately about 4 times the velocity of sound in air. For example, steel is in a solid state. The velocity of sound in steel is 5000m/s, i.e, velocity of solids in metal (solids) is approximately about fifteen times as the velocity of sound in air.

Velocity of sound decreases in this order: solids, liquids and air (gases).

Note: The velocity of sound in air increases by 0.6m/s for every 1^oC rise in temperature.

Factors that affect the velocity of sound in air (gases) are: (i) temperature (ii) humidity; but these do not depend on pressure, pitch and loudness.

The velocity of sound in air can be measured using the following methods: (i) echo method (ii) resonance tube method (iii) stationary wave method.

Temperature and the Speed of Sound

Temperature is also a condition that affects the speed of sound. Heat, like sound, is a form of kinetic energy. Molecules at higher temperatures have more energy, thus they can vibrate faster. Since the molecules vibrate faster, sound waves can travel more quickly. The speed of sound in room temperature air is 346 meters per second. This is faster than 331 meters per second, which is the speed of sound in air at freezing temperatures.

The formula to find the speed of sound in air is as follows:

$v = 331m/s + 0.6m/s/C . T$

v is the speed of sound and T is the temperature of the air. One thing to keep in mind is that this formula finds the average speed of sound for any given temperature. The speed of sound is also affected by other factors such as humidity and air pressure.

Pressure on Velocity of Sound

The speed of sound is a term used to describe the speed of sound waves passing through an elastic medium.

The speed varies with the medium employed (for example, sound waves move faster through water than through air), as well as with the properties of the medium, especially temperature.

The term is commonly used to refer specifically to the speed of sound in air.

At sea level, at a temperature of 21 degrees Celsius (70 degrees Fahrenheit) and under normal atmospheric conditions, the speed of sound is 344 m/s (1238 km/h or 770 mph).

The speed varies depending on atmospheric conditions; the most important factor is the temperature.

Humidity has little effect on the speed of sound, nor does air pressure by itself. Air pressure has no effect at all in an ideal gas approximation.

This is because pressure and density both contribute to sound velocity equally, and in an ideal gas the two effects cancel out, leaving only the effect of temperature.

Sound usually travels more slowly with greater altitude, due to reduced temperature.

Noise and Music

Both music and noise are sounds, but how can we tell the difference? Some sounds, like construction work, are unpleasant. While others, such as your favorite band, are enjoyable to listen to. If this was the only way to tell the difference between noise and music, everyone's opinion would be different. The sound of rain might be pleasant music to you, while the sound of your little brother practicing piano might be an unpleasant noise. To help classify sounds, there are three properties which a sound must have to be musical.

A **sound** must have an identifiable pitch, a good or pleasing quality of tone, and repeating pattern or rhythm to be music. **Noise** on the other hand has no identifiable pitch, no pleasing tone, and no steady rhythm.

Functions on Hearing Aids

Hearing is the sense concerned with the perception of sound. We hear with the ear and see with the Eye. As with the eye, the ear may also have some defects or impairments. (For the structure of the ear, the students should consult any good biology textbook).

Just as we need specialists or eye-glasses to improve or enhance ability to see very clearly, we also do need hearing aids to hear more loudly and distinctly.

Hearing aid is a device used by a person with impaired or effective hearing ability to improve his or her ability to hear properly. The device increases the loudness of sound in the ear of the wearer. This sense of hearing depends on the ability of the listener to detect the pressure of sound waves in the air around him or her. The hearing aid helps the listener through acting as an amplifier. It does so by increasing the pressure of sound waves and delivering it into the air at a point within the ear canal.

Types of hearing-aids

There are two principal types of hearing aids. These are

(i) air-conduction aids and

(ii) bone-conduction aids

An air-conduction air amplifies sounds and brings it directly into the ear. This is the hearing aid most people wear. The bone conduction aids are for these people in whom sound cannot be transmitted through the outer or middle ear. This type of aid therefore brings sound waves to the bony parts of the head behind the ear. The bone transmits the air vibrations to the auditory nerves of the cochlea. Hearing becomes possible when these nerves are stimulated.

Other Features of Hearing Aids

More research and technology advances have led the development of better hearing aids. Hearing aids available nowadays have many more features which make our lives a lot easier. Listed below are some of the common features.

Directional microphones – help you listen more clearly in noisy places. Sound that comes from front is greatly amplified compared to the sound that comes from other directions. Face-to-face conversations are easier to handle with this.

T-coil – makes it easier to use telephone with hearing aids. Eliminates whistling that is often encountered with older hearing aids.

Audio input – some hearing aids allow you to connect directly to your TV and other electronic devices. Results in high quality sound for you.

Feedback suppression mechanism – computer chips within hearing aids closely monitor and analyze sounds it receives. These chips learn when there is extra noise or whistling present, and take steps to eliminate them. This led to the production of good quality sound.

ASSESSMENT

1. Arrange the states of matter according to their decreasing velocity of sound.
2. What are the two types of hearing aid?

3. What is the difference between sound and noise?
4. What are the functions of hearing aids?
5. How does temperature affect the speed of sound?

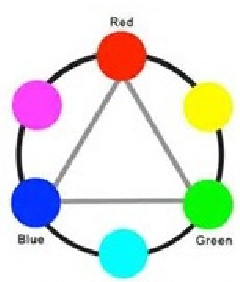
WEEK 9

Subtractive Color Mixing

INTRODUCTION

The mixture of blue and yellow pigments (paints) produces a green colour. This is due to subtractive process.

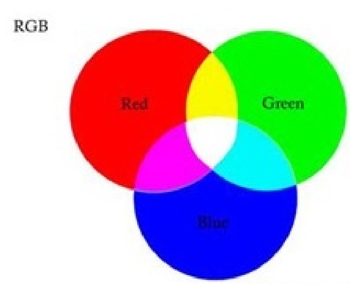
A blue paint absorbs all light except blue and green. Yellow paint absorbs all light except yellow, orange and green. The only light reflected by both yellow and blue pigments is green.



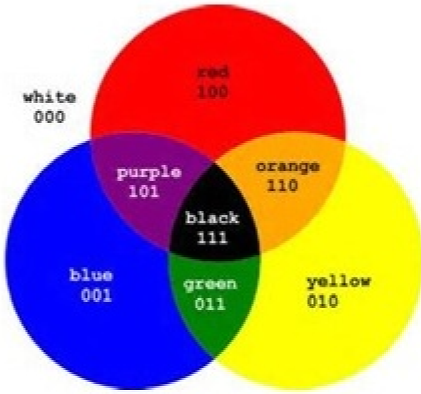
Additive (RGB) Color System

M – magenta, C – cyan, Y – yellow, W – white.

They are sometimes represented by their first alphabet to avoid appearing clumsy. They can also be represented in circles, as a set of venn diagrams, using the principle of set to resolve it.



Additive Color Mixing



Colour of Objects

The apparent colour of an object depends on the quality of the light by which it is seen. This is because they absorb other colours and reflect the light of that colour only, or the combination of reflected light. For instance, a red skirt looks red under ordinary daylight because other colours have been absorbed. But the same red shirt, seen under red light appears pale and whitish because it reflects nearly all the light falling on it. But under green light , it looks black, because it is not able to reflect much of the incoming light . Object appears to be in an uncertain colour because they reflect light of that colour only. The result and reflected and absorbed rays when white light is incidented on an object are shown below in the table.

Colour of object on which light is incident	Reflected ray which one sees	Absorbed rays
Red	Red	Green, blue
Blue	Blue	Red, green
Green	Green	Red, blue
Cyan	Green, blue	Red

Magenta	Red, blue	Green
Yellow	Red, green	Blue

ASSESSMENT

1. What are the three forms of colour?
2. What are complementary colours?
3. What does the apparent colour of an object depend on?
4. What colour does R + B give?

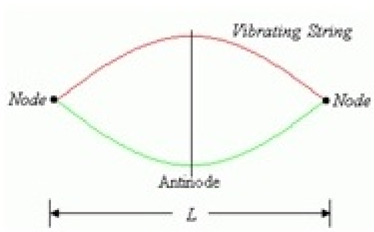
WEEK 10

Topic: RESONANCE

Vibrations in Strings

Fundamental Mode (First Harmonic)

Fundamental Mode – when a string is plucked, it will vibrate in one segment with two nodes at either end.



This is the lowest possible mode of vibration

In a guitar string, for example, it will vibrate between the fret and the tuning key. The bridge transfers the vibration to the "box" (or sound box) through the saddle.

At the fundamental frequency (f_0) we have 1 loop and 2 nodes.

Note: # of nodes = # of loops +1

Also: L = ½ λ (L – length of the string, λ – wavelength)

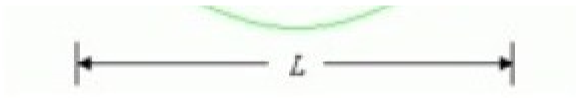
Overtones – when strings vibrate in more than one segment.

Harmonies – frequencies which are multiples of the fundamental.

i.e. $2f_0$, $3f_0$ …

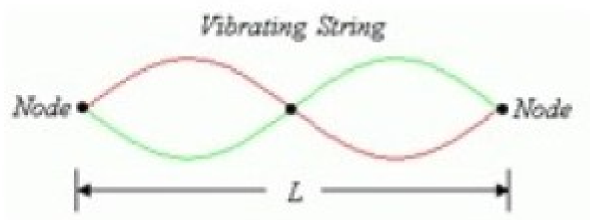
The fundamental frequency (f_0) is known as the First Harmonic.

Modes of Vibrations in Strings



2 nodes, 1 loop

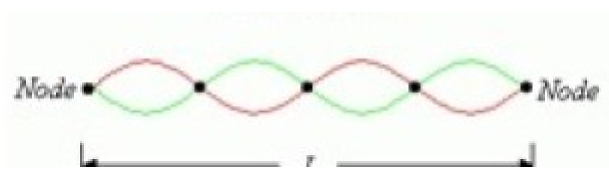
2) Second Harmonic - $L = \lambda$



3 nodes, 2 loops

3) Third Harmonic – $L = 3\lambda/2$

4)Fourth Harmonic –



5 nodes, 4 loops

In general $L = n/2\ \lambda$

where n is the # of loops in the vibrating string.

Example:

What is the fundamental frequency of a violin string (45 cm long) if the speed of the wave in the string is 280 m/s?

Solution:

Given: Required:

L = 0.45 m f_2 = ?

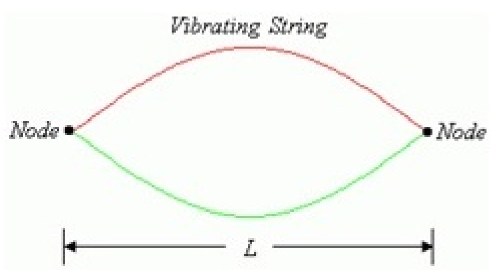
V = 480 Hz

L = n/2 λ λ = 2 L/n = 2 x 0.45m/1 loop = 0.9 m

v = fλ f = v/λ = 280m/s / 0.9m = 311Hz

∴ The frequency is 311 Hz

Modes of vibrating strings follow the same pattern and mathematic rules as STANDING WAVES.



Therefore, distance between nodes = distance between antinodes = λ/2

Example:

What are the wavelengths of the 4 longest waves that can stand in a 60 cm string?

Solution:

[Diagrams can be used to illustrate each case; for diagrams please refer to the lesson above]

Mode 1 (f_0)

$L = \lambda/2$

$\therefore \lambda_0 = 2L = 2.60$ cm = 120 cm

Mode 2: $\lambda_1 = L = 60$ cm

Mode 3: $\lambda_2 = 2/3L = 40$ cm

Mode 4 $\lambda_1 = 2/4\ L = 30$ com

Modes of Vibration in Columns of Air

There are two possible types of resonant air columns (pipes):

1) open at both ends

2) open at one end only (OR closed at one end)

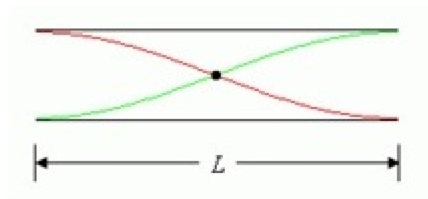
NOTE: Although here sound waves look like transverse waves, remember that sound waves are actually longitudinal (consisting of alternating compression and rarefaction zones), where each compression represents a crest, and a rarefaction represents a trough!

Pipes Open at Both Ends

In order for an air column (pipe) open at both ends to produce a sound, antinodes must be formed at its both ends – there CANNOT be nodes formed at the ends of the pipe.

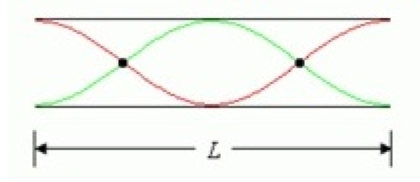
Examples of musical instruments: trumpet, trombone, organ, etc.

Mode 1 1 node First harmonic (fundamental (f_0))



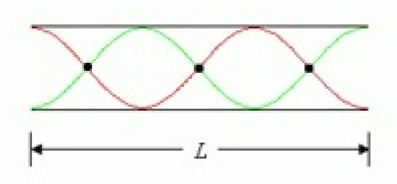
L = ½ λ

Mode 2 2 nodes Second harmonic (f_1)



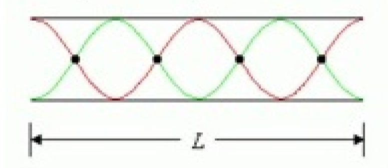
L = λ

Mode 3 3 nodes Third harmonic (f_2)



L = 3λ/2

Mode 4 4 nodes Fourth harmonic (f_3)

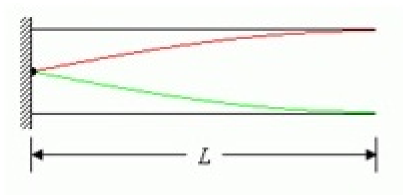


L = 2λ

Pipes Open at One End Only (Closed at One End)

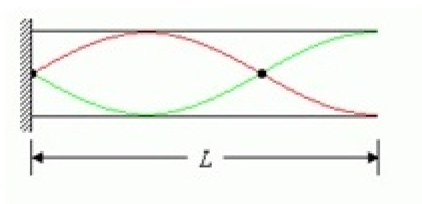
Examples of musical instruments: clarinet, reed, human voice, etc.

Mode 1 1 node First harmonic (fundamental (f_0))



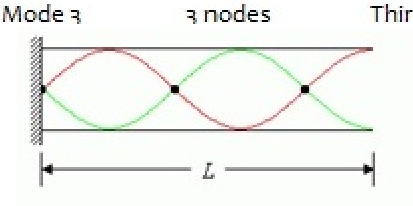
L = ¼ λ

Mode 2 2 nodes Second harmonic (f_1)



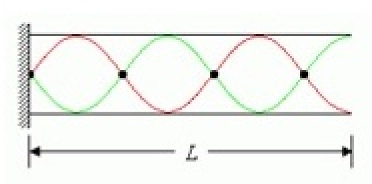
L = 3/2 λ

Mode 3 3 nodes Third harmonic (f_2)



L = 5/4 λ

Mode 4 4 nodes Fourth harmonic (f_3)



L = 7/4 λ

General Rule

For open-ended pipes: $f_n = n \cdot f_0$

For pipes closed at one end: $f_n = f_0 (2n - 1)$

Where **n** is the desired harmonic number.

Example:

At a temperature of 15 °C, what are the three possible lowest frequencies produced by an open organ pipe that is 0.40 m long?

Solution:

Given: T=15 °C, L=0.4 m, Required: f_0 , f_1 , f_2 ?

$v_{sound} = 332 + 0.6T = 332 + 0.6(15) = 341 m/s$

$v = f\lambda$ – Universal Wave Equation

f_0) $L = ½ \lambda$ $\lambda = 2L = 0.8m$, $f = v/\lambda = 341m/s / 0.8m = 426.3$ Hz

f_1) $L = \lambda$ $\lambda = L = 0.4m$, $f = v/\lambda = 341m/s / 0.4 m = 852.5$ Hz

f_2) $L = 3/2\lambda$ $\lambda = 2/3L = 0.27m$, $f = v/\lambda = 341m/s / 0.27m = 1263$ Hz

∴ Three lowest possible frequencies are 426.3 Hz, 852.5 Hz, 1263 Hz.

Frequency of Air Column

Resonance Mode	Open at Both Ends	Open at One End Only

First harmonic (fundamental)	f_0	f_0
Second harmonic	**2**f_0	$3f_0$
Third harmonic	**3**f_0	$5f_0$
Fourth harmonic	**4**f_0	$7f_0$
Fifth harmonic	**5**f_0	$9f_0$
nth harmonic	$f_n = n \cdot f_0$	$fn = f_0 (2_n - 1)$

ASSESSMENT

1. What is the lowest possible mode of vibration?
2. What are the two possible types of resonant air columns?
3. At a temperature of 35 °C, what are the three possible lowest frequencies produced by an open organ pipe that is 1.20 m long?