Contents

Upthrust

We all know that a substance that continually deforms (flows) under an applied shear stress, no matter how small, is known as Fluid. So the term Fluid denotes a subset of the phases of matter. Fluids include liquids, gases, plasmas and, to some extent, plastic solids.

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When we immerse an object in a fluid, two forces act on it. One is the weight of the object that acts downwards. Another is the up thrust of the Fluid that works upwards. The upthrust explains why a block of wood, held just below the surface of water immediately rises to the surface. Similarly, we need fewer efforts to lift a large boulder off the bottom of the river so long it is under water.

All fluids (Liquids and gases) exert upthrust.

The Archimedes principle says that when a body is wholly or partially immersed in a fluid, it experiences an upthrust that is equal to the weight of the fluid displaced.

The values of the weight and upthrust determine whether a body should sink in the fluid or float. If the weight of the displaced fluid is less than the weight of the body, the body will float, otherwise sink. However, if the weight of the body and the displaced fluid are equal, the body shall remain at any level in the fluid.

The same can be explained on the basis of density too. An object would sink in a liquid if its density is more than the liquid.

The Law of floatation says that a *Floating body displaces its own weight of the fluid in which it remains.* This explains why a ship made of iron floats but a nail sinks. The hollow ship, has a density less than the density of the water.

If we look at the floating piece of iceberg on the sea, approximately what fraction of it is visible above the seawater level?
(A)1/8th
(B)1/6th
(C)1/10th
(D)1/5th

Answer: Approximately 1/8 (12.5 %) of the ice is visible above water and 7/8 (87.5 %) of the ice is submerged below the surface. This is because ice and snow are less dense than water. Here we must note that if the iceberg is made up of only compact ice, its visible part may be even 1/10th part because the compact part is relatively denser. But the top of the iceberg is usually made up of snow which is not that much compact and that is why the correct answer of this question is 1/8th.

When a balloon is filled with a light gas such as Hydrogen or helium, it rises because of the lower density of the system (baloon+gas) in comparison to the atmosphere. As the density of the air decreases with altitude, the balloon will become stable at one altitude and thus can not rise indefinitely.

What are fundamentals behind buoyancy of Submarines?

The density of pure water is 1000 kg/m3. The density of the Ocean water is a bit more. The average density of seawater at the ocean surface is 1.025 g/ml. Seawater is denser than both fresh water and pure water. The submarines use the Variable Ballast Tanks to take on or off water to meet the environment. Temperature, Salinity and Depth are the three things which affect how much water can support to keep a submarine buoyant. When the Variable Ballast Tanks are filled with water, the average density of the submarine becomes more than water and it dives. When the submarine is needed to emerge at surface, Compressed Air is forced into the Variable Ballast Tanks so force the water out and make the density lower.

Diffusion

Diffusion is the spread of particles through random motion from regions of *higher concentration to regions of lower concentration.* The time dependence of the statistical distribution in space is given by the diffusion equation.

So, the mixing up of molecules of different gases, liquid and solids is called diffusion. The common example is of a perfume bottle which when kept opened in one corner of a house will mix with the molecule of air and spread all over room.

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Surface Tension

The most basic constituents of the matter are its molecules. Among the molecules, the intermolecular forces exist. The attractive or cohesive forces operating among these molecules are larger for the solids and that is why the solids have definite shape and size. In liquids the molecular forces are very small or negligible. The forces that are operative between the molecules of two different solids are called Adhesive forces. Due the adhesive forces, water can wet the surfaces. When we write on blackboard with Chalk or whiteboard with marker, it is the adhesive force which enables us to read what has been written.

Why Mercury does not wet glass?

For a solid-liquid pair of substances, if the cohesive forces among the liquid molecules is greater than the adhesive forces between the liquid and solid, the liquid does not wet the solid.

Mercury in a glass flask is a good example of the effects of the ratio between cohesive and adhesive forces. Because of its high cohesion and low adhesion to the glass, mercury does not spread out to cover the bottom of the flask, and if enough is placed in the flask to cover the bottom, it exhibits a strongly convex meniscus, where the meniscus of water is concave . Mercury will not wet the glass, unlike water and many other liquids, and if the glass is tipped, it will 'roll' around inside.

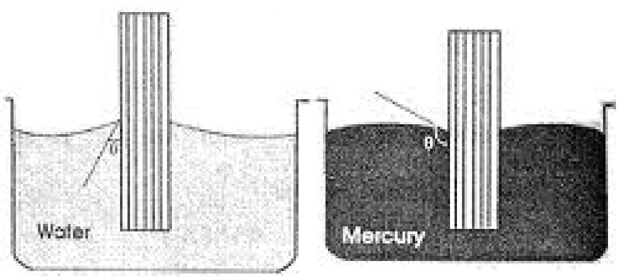
The cohesive forces exist in all liquids. The free surface of all liquids behaves to some extent like a streteched elastic membrane that has the natural tendency to contract and occupy the minimum possible surface area as permitted by the circumstances of the liquid mass. In the bulk of the liquid, each molecule is pulled equally in every direction by neighboring liquid molecules, resulting in a net force of zero. The molecules at the surface do not have other molecules on all sides of them and therefore are pulled inwards. This creates some internal pressure and forces liquid surfaces to contract to the minimal area.

Surface tension is a property of the surface of a liquid that allows it to resist an external force. At the surface of the liquid, the liquid molecules are attracted to each other and exert a net force pulling them together. High values of the surface tension means the molecules have a high cohesive force. Lower values mean the molecules do not interact as strongly and they have lower cohesive forces.

The effect of surface tension permits insects to walk on water and for drops of water to bead up. Surface Tension is measured in **newton per meter (N/m)** and is often represented by σ or γ.

- The surface tension of all the liquids decreases linearly with temperature over the small temperature range.
- The value of the surface tension becomes zero at critical temperature. Critical temperature or critical point specifies the conditions (temperature, pressure and sometimes composition) at which a phase boundary ceases to exist.

The above description makes it clear that surface of a liquid behaves like a strained body and possesses potential energy. This energy is equal to the work done in creating the surface. The energy per unit area of the surface is called Surface energy. The surface energy of the liquid is numerically equal to the surface tension. The unit of surface energy is Joule/ meter^2.



When we immerse a solid plate or tube in a liquid, the surface of the liquid near sold is generally curved. It can be either convex or concave. The angle between the tangents to the liquid surface and the solid surface at

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the point of contact is called angle of contact for that particular pair of liquid and solid.

- If the liquid is very strongly attracted to the solid surface (strongly hydrophilic solid) the droplet will completely spread out on the solid surface and the contact angle will be close to 0°.
- Less strongly hydrophilic solids such as glass will have a contact angle up to 90°.
- On many highly hydrophilic surfaces, water droplets will exhibit contact angles of 0° to 30°.
- If the solid surface is hydrophobic, the contact angle will be larger than 90°.
- On highly hydrophobic surfaces the surfaces have water contact angles as high as ~120° on low energy materials e.g. fluorinated surfaces.
- However, some materials with highly rough surfaces may have a water contact angle greater than 150°. These are called superhydrophobic surfaces. Sometimes the contact angle is measured through the gas instead of through the liquid, which reverses 0 and 180 in the above explanation.

Why does rain come in drops, why not in continuous stream?

Rain consists of drops of water that fall from a cloud. They have a typically diameter of at least 0.5 mm and the size of the drop rarely exceeds about 5 mm. Larger drops do not survive as the process of surface tension which holds the drop together is exceeded by the frictional drag of air and therefore larger drops break apart into smaller ones. A raindrop starts falling and then picks up speed due to gravity. When one drop starts falling a wake follows in the cloud akin to the clearance that is normally found behind a speeding boat.This clearance causes another drop to follow and not exactly in the same path but close to it. Drops that pick up speed are slowed down by the drag of the surrounding air. The smallest drops may not fall at all, being suspended or perhaps forced upward by ascending currents of air until they grow large enough to fall. As larger droplets descent, they produce an airstream around them.

The raindrops falling on a vertical windowpane not always run on straight line. Why?

There are three forces acting on a rain drop on a windowpane.

1. The water drop on a vertical windowpane is pulled down by gravity. It should run down straight if there is no other force.
2. There are adhesive forces between the glass and water that keep a small drop stuck to the glass surface.
3. There is also the surface tension acting at the free surface between the drop and air.

Due to surface tension the free surface behaves like a stretched membrane and this gives shape to the drop. Similar surface energies are present between the windowpane and water and also between windowpane and air. These three surface energies fix the contact angle of the drop surface at the contact line. Thus, the contact angle, surface tension and gravity decide the shape of the drop. When this drop rolls down, there is a hairpin shaped contact line on the windowpane. Most of the water is concentrated at the head with a tail of thin film between the two boundaries of the contact line. When the drop rolls down further there is an increase in the surface area. Creation of this more surface area would need more work. However, if there is already a water film, this additional work may not required and thus water will take this path of least resistance. If such a film downstream does not exist, the irregular shape of the drop's head affects the direction of progress. This direction need not always be straight. The direction is also modified by the dust particles, impurities of air and wind.

Please note that the water has a high value of surface tension because it has a **high degree of hydrogen bonding**. Organic molecules with polar groups such as iodide and hydroxyl have a slightly lower surface energy than water. Pure hydrocarbons are even lower, while **fluorinated compounds are very low because the fluorine atom won't share electrons very well so only dispersion interactions occur.**

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How water striders are able to walk on water surface?

The water striders, water bugs or the Pond Skaters are able to walk on top of water due to a combination of several factors including the Surface Tension. The water striders are at advantage through their highly adapted legs and distributed weight. The legs of a water strider are long and slender, providing the weight of the water strider body to be distributed over a much larger surface area. The legs are strong, but have flexibility that allows the water striders to keep their weight evenly distributed and flow with the water movement. Hydrophobic hairs line the body surface of the water strider. There are several thousand hairs per square millimeter, providing the water strider with a hydrophobic body that prevents wetting from waves, rain, or spray, which could inhibit their ability to keep their entire body above the water surface if the water stuck and weighed down the body.

We should note here that the pressure inside a soap bubble or a liquid drop must be in excess of the pressure outside the bubble or drop so that it can be in a stable equilibrium. Due to surface tension, the bubble or drop have a tendency to contract and disappear together. To balance the tendency to contract, there is always an excess of pressure inside the bubble.

This excess pressure inside the soap bubble is denoted by

$$\text{Excess Pressure} = \frac{4T}{R}$$

However, the Excess Pressure inside a drop is expressed by

$$\text{Excess Pressure} = \frac{2T}{R}$$

Where T is surface tension and R is the Radius of the Bubble or Drop.

Here we should note that for the soap bubble, the two surfaces are taken into account on which surface tension works i.e. inside and outside.

Question:

When two soap bubbles of different sized, brought together in contact, which among the following will happen?

(A)The two bubbles will merge with each other and a larger bubble will be formed

(B)The two bubbles will join each other with the common wall bulging in the larger bubble

(C)The two bubbles will join each other with the common wall bulging in the smaller bubble

(D)The two bubbles will join each other with the common wall remaining flat

Answer:

The two bubbles will join each other with the common wall bulging in the larger bubble. A very simple physical principle applies here. We should know that **the pressure in the smaller bubble is always greater than the pressure (internal pressure) in the larger bubble,** and this pressure differences in bubbles of different radii has been predicted by the Young–Laplace equation. So, when the small bubble joins the big bubble, there will be a common wall bulging in the "Larger Bubble"

Capillary Action

Capillary action is the ,ability of a liquid to flow against gravity where liquid spontaneously rises in a narrow space such as a thin tube, or in porous materials due to surface tension.

When we dip a long glass tube of very fine bore (a capillary) into a liquid, the liquid rises or depressed into the tube. The small holes in the bloating paper work as capillary and that is why it is able to suck the ink. The oil in the wicks rises due to capillary action. The Capillary action plays important role in the rise of water in the plants.

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Why do newspapers absorb water quickly as compared to Glossy paper?

Glossy paper is made up of fibrous plant cellulose tissues which are bonded by pulp of finer fibres and bonding material. Surface of the glazed / glossy paper is glazed by this finer pulp so that we have the smooth writing comfort. This renders such paper more expensive as compared to the news print paper devoid of the glazing layer. The aggregated web of the fibrous particles leaves large number of fine gaps or pores between them which support absorption of liquids like water by capillarity action.

Capillarity action is a result of surface tension of the liquid in contacts with the solid surface. As per this principle, finer the gaps, more will they be filled by the absorbed liquid. In news print paper the fine capillary pores come in contact with the water which gets 'sucked' or absorbed. And, in the other variety of (or glazed) paper, the pores are not open for the water to enter.

Please note that that Capillary action depends upon the **5 factors** as follows:

1. **Surface Tension**
2. **Contact angle**
3. **Density of liquid (mass/volume)**
4. **Gravity**
5. **Radius of tube**

So, if δ is the liquid-air surface tension, if θ is the contact angle, ρ is the density of liquid , g is gravity and r is radius of tube, then the height of the meniscus will be:

$$H= \frac{2\delta cos\theta}{\rho g r}$$

From the above formula, we derive the following facts:

- The height of the meniscus is directly proportional to cos θ. If the contact angle is acute means less than 90°, then the liquid will rise in the capillary and if the contact is obtuse i.e. more than 90°, then the liquid is depressed. In simple words, the liquid which wets the solid (glass in this case) will rise and the liquid which does not wet will depress.
- The height of the meniscus is inversely proportional to the density of the liquid. So, if a capillary is immersed in two liquids of different density, the liquid of low density will rise more.
- The height of the meniscus is inversely proportional to gravity. This is very important. In the artificial satellites or in zero gravity condition, if a capillary tube is dipped into water than the water would rise up to full height of the capillary, whatever may be the length of the capillary.
- The height of the meniscus is inversely proportional to the radius. This means that the finer is the tube, higher is the meniscus.

Why they split the nib of a fountain pen?

A fountain pen is a nib pen which contains an internal reservoir of water-based liquid ink. From the reservoir, the ink is drawn through a feed to the nib and then to the paper via a combination of gravity and capillary action. As a result, the typical fountain pen requires little or no pressure to write. The nib is split starting from a breather hole till the tip to form two tines (branches). The split carries the ink to the tip and paper. The channel allows an occasional flow of air in the opposite direction into the reservoir so that pressure there does not decrease too much due to emptying of the ink. The nib tip has a special shape consisting of two hemispherical ends at the bottom of the tines. Ink forms a meniscus between these two rounded parts and spreads on paper as soon as a contact is established. The capillary force maintains a continuous ink flow and also helps to support ink from dripping due to gravity while not writing.

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Why Fountain Pens don't work in space?

Fountain Pens as well as Ball Pens don't work in space. The reason is twofold. First the capillary action depends upon gravity, so in space, the pen will not work due to zero gravity. Second, the pressure in the bulb of the fountain pen is 1 atmosphere as it is loaded with ink on the surface of earth. In space the pressure drops, so ink flows out. Pencils work finely in space, but the flammable wood material and dangers of graphite dust don't make it very useful.

The Space Pen developed by Fisher claims that it can work in space, in zero gravity, upside down, underwater, over wet and greasy paper, at any angle, and in extreme temperature ranges. The reason is a property of material called **Thixotropy.**

What is Thixotropy?

Thixotropy is the property of certain fluids that are thick (viscous) under normal conditions, but flow (become thin, less viscous) when shaken, agitated, or otherwise stressed. So, the ink of the Space Pen is normally dense and viscous like chewing gum, but when the Pen comes under use, the nitrogen gas inside the ink cartridge pushes the ink down to the tungsten carbide ball at tip. When the ball rotates, the ink becomes liquid.

Please note that the Capillary action describes the attraction of the water molecules to soil particles. It is the Capillary action which is responsible for moving the groundwater from wet areas to dry areas. Just after the heavy rain falls, the farmers plough their agriculture lands so that the capillaries in the dry soil which just became wet are broken and the soil is able to retain the water for longer time.

Why we can create sand sculptures from the damp soils, why not dry soils?

There are two fundamentals of this question viz. surface tension and friction. The sand consists of lots of small, hard grains of rock that can slide over each other. If the forces pushing the sand grains together are small, then the grains slide easily over each other. When the sand is damp, each grain is coated with a thin film of water. The droplets of water adhere to the sand grains, the tension is applied to each grain, and this effectively pulls each grain against its neighbor, providing quite a strong force between them even if there is no weight of sand above. This force is enough to provide plenty of friction so that sculpture stays together. This force is stronger than gravity and prevents walls of sandcastle from falling down. These bridges work through the water's surface tension. The surface of the liquid bridges is concave, and so generates a `capillary action' which helps to hold the grains of sand firmly together.

Viscosity

Viscosity refers to the "thickness" or "internal friction" of the fluids. Thus, water is "thin", having a lower viscosity, while honey is "thick", having a higher viscosity. Viscosity describes a fluid's internal resistance to flow and may be thought of as a measure of fluid friction. All real fluids (except superfluid) have some resistance to stress and therefore are viscous, but a fluid which has no resistance to shear stress is known as an ideal fluid or inviscid fluid. The branch of science that studies Viscosity is **rheology.**

Viscosity is measures in terms of coefficient of viscosity. Its unit is **Pascal-second or Pas.** The poise is the unit of dynamic viscosity in the **centimeter gram second** system of units. 1 Pas is equal to 10 Poise.

- The Coefficient of viscosity is higher for liquids in comparison to gases.
- Viscosity falls with temperature. This is why most oil become less sticky when warmed.
- Except water, the viscosity of fluids increases with pressure. For water, the viscosity will decrease.

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What is Rheopecty?

We have just now studied that Thixotropy is the property of certain fluids that are thick (viscous) under normal conditions, but flow (become thin, less viscous) when shaken, agitated, or otherwise stressed. This funda has been used to divide the space pen. The opposite of this phenomenon is called **Rheopecty**. Rheopecty is the rare property of some fluids to show a time-dependent change in viscosity; **when the fluid undergoes shearing force, the higher its viscosity**. Examples are some lubricants which thicken or solidify when shaken, gypsum pastes and printers inks.

The Rheopectic substances are of great use and that is why a lot of research going on over them. The property which makes them highly viscous under pressure (shock absorption) is useful for making Body armor and combat vehicle armor in arms industry, Sports Industry and transportations.

The role of Viscosity in fluids is same as that of Friction in solids. This viscous force F that is acting on an object falling through the fluid with coefficient of viscosity φ is as follows:

$$F=6\pi\varphi rv$$

Where:

- R is the size of the object, if it's a ball, its radius.
- V is velocity.
- The above principle is known as **Stokes Law.**

We derive from this formula that bigger is the size of the ball, bigger is the viscous force. When an object falls in a fluid, its speed increases due to the gravitational acceleration. But at the same time, The viscous force becomes equal to the gravitational force and the net acceleration of the body becomes zero. The object will stop accelerating at this point and the body attains a constant velocity. This velocity is called terminal velocity. Since, the viscous force depends upon size of the body; the terminal velocity is higher for larger bodies. This is the principle that works behind skydiving. The skydivers are able to make different patterns in air because they are able to alter their terminal velocities by changing positions in air.

Types of Flow

Flow can be laminar, turbulent or a mixture of both. They have

Laminar flow:

In laminar flow, all the particles in the fluid follow the same line of flow. These lines of flow can be visualised as "sheets" and are known as streamlines. In the case of a tube these streamlines are a set of concentric tubes, the velocity of which increases the closer to the centre one measures.

Turbulent flow:

In contrast to laminar flow, the particles in this case are moving in different directions to each other, hence the description turbulent. A good example of this is smoke rising from a cigarette.

Bernoulli's Theorem

The **Bernoulli's Theorem** is another important concept related to the motion of fluids. It says that when a *fluid flows from one place to another with no friction, its total energy viz. kinetic+potential+pressure remains constant.* In other words, *an increase in the speed of the fluid occurs simultaneously with a decrease in pressure or a decrease in the fluid's potential energy.*

Mathematically represented by

$$P + \frac{1}{2}\rho\ v2 + \rho gh = constant$$

Where

- P = Pressure

- g = Acceleration due to gravity (m/s2)
- h = Height of the tube
- ρ= Density of liquid
- v = Velocity of fluid
- This theorem is applicable to a perfect system so all the energy is conserved as either pressure energy, potential (or stored) energy, and the energy existing as flow. We assume no loss of energy through heat caused by friction within the fluid or caused by drag on the tube's walls.
- This means that if we alter the **energy of one portion of the system**, it has an effect on the rest of the system. So if the **kinetic energy rises, the potential energy and pressure must fall**.

When we apply the Bernoulli principle in our practice we can ignore the portion due to gravity to make life a little simpler. The above equations use a linear relationship between flow speed squared and pressure. At higher flow speeds in gases, or for sound waves in liquid, the changes in mass density become significant so that the assumption of constant density is invalid.

What is importance of Bernoulli's theorem in carburetor of Engines?

The carburetor used in many reciprocating engines contains a *venture* to create a region of low pressure to draw fuel into the carburetor and mix it thoroughly with the incoming air. We have just now read that as per Bernoulli's theorem, the material in a funnel flows faster as the funnel narrows. Because this speeds up the flow of the fuel, it creates a pressure difference, which continually draws more fuel into the carburetor. Air traveling through a funnel passes above a tank of fuel, and the funnel's diameter narrows when it passes above the fuel. The fast-moving air has a lower pressure than the air in the fuel tank, so the fuel in the tank is sucked up into the funnel.

What is Physics behind spin and Swing bowling?

As the ball travels through the air towards the person facing it, one side of the imaginary seam is also spinning towards the viewer, and the other side is moving away, and the ball demonstrably swerves as though it was being 'pulled ahead' on its left side and 'pushed back' on its right - i.e. to the right. The slower the ball is moving through the air, and the harder it is spun, the more pronounced this effect appears to be to the viewer. Thus we can say that difference in flow velocity is achieved by means of spinning the ball, as the wind velocity is increased on one side and decreased on another. The ball is then "sucked" from the region of high static pressure towards the region of low static pressure. Layer of fluid, in this case air, will have a greater velocity when moving over another layer of fluid than a solid, in this case the surface of the ball, and the greater the velocity of the fluid, the lower its static pressure. When the ball is new the seam is used to create a layer of turbulent air on one side of the ball - by angling it to one side and spinning the ball along the seam. This changes the separation points of the air with the ball, this turbulent air creates a greater coverage of air; providing lift. The next layer of air will have a greater velocity over the side with the turbulent air due to the greater air coverage and as there is a difference in air velocity, the static pressure of both sides of the ball are different and the ball is both 'lifted' and 'sucked' towards the turbulent airflow side of the ball.

Heat

Internal Energy & temperature

The total kinetic and potential energy of the molecules in a matter is called the Internal Energy of that substance. The greater is the internal energy, hotter it is.

This explains why the water at the bottom of the waterfall is slightly warmer that at the top. The potential energy of the water at the top is converted into kinetic energy at the bottom and part of this kinetic energy is transformed into the internal energy of water.

The physical property of matter that quantitatively expresses the common notions of hot and cold with respect to some standard body is called temperature. The heat is the internal energy which is transferred

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from one body to another body due to the difference in temperatures. Once heat is transferred to a body, it becomes its internal energy.
The temperature is measured by the thermometer.
Most commonly used temperature scale is the Celsius scale (°C). It has the same incremental scaling as the Kelvin scale used by scientists, but fixes its null point, at 0°C = 273.15K, the freezing point of water. A few countries such as United States, use the Fahrenheit scale for common purposes, a historical scale on which water freezes at 32 °F and boils at 212 °F.
The Celsius scale and Fahrenheit scale are converted as follows in each other:

$$C=\frac{5}{9}(F-32)$$

$$C=$$

For practical purposes of scientific temperature measurement, the International System of Units (SI) defines a scale and unit for the thermodynamic temperature by using the easily reproducible temperature of the triple point of water as a second reference point. For historical reasons, the triple point is fixed at 273.16 units of the measurement increment, which has been named the Kelvin in honor of the Scottish physicist who first defined the scale. The unit symbol of the Kelvin is K. Absolute zero is defined as a temperature of precisely 0 Kelvin, which is equal to −273.15 °C or −459.68 °F.
The 0 Kelvin is known as **Absolute Zero.** Absolute zero is the theoretical temperature at which entropy reaches its minimum value. As per the laws of Thermodynamics, absolute zero cannot be reached using only thermodynamic means. Please note that when a system is at absolute zero, *it still possesses quantum mechanical zero-point energy, the energy of its ground state. The kinetic energy of the ground state cannot be removed.*
Generally, the solids and liquids expand when heated and contract when cooled.

- ✓ They leave the gaps between the railway tracks so that expansion of these tracks is allowed.
- ✓ The iron and steel tyres are tightly fitted on the cartwheels by heating them first and slipping them into the cartwheel while hot.
- ✓ Metal hot water heating pipes should not be used in long straight lengths
- ✓ One of the reasons for the poor performance of cold car engines is that parts have inefficiently large spacing until the normal operating temperature is achieved.
- ✓ A gridiron pendulum uses an arrangement of different metals to maintain a more temperature stable pendulum length.
- ✓ A power line on a hot day is droopy, but on a cold day it is tight. This is because the metals expand under heat.

When we heat a 1 meter long iron rod through 1°C, its length increases by 0.000012 meters. This is called **linear expansivity** which is expressed in /°C.

Why Pyrex Glass is used in making lab Glassware and lenses?

Pyrex Glass is made by borosilicate glass. Borosilicate Pyrex is composed of: 14% boron, 51% oxygen, .3% sodium, 1% aluminum, 38% silicon, and less than 1% potassium. Pyrex glass can also be made of tempered soda lime glass. There are two properties of Pyrex Glass associated with its use in the specific applications. First, it has very high thermal resistance. Second it has very low Linear Expansivity. The Linear expansivity of the ordinary glass is 0.00009, while the same of Pyrex Glass is 0.00003.
Pyrex borosilicate glass has a high thermal resistance, so it is used in the manufacture of laboratory ware. It has low

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expansion characteristics, so is often the material of choice for reflective optics in astronomy applications.

Mercury Thermometers

Mercury thermometer is used to measure temperatures above zero degree Celsius. Mercury expands upon heating and is a good thermal conductor. It is also a bright liquid and thus convenient for temperature measurement. However, mercury cannot be used because it freezes and stops flowing at minus 38.87 degrees Celsius. Measurement of subzero temperatures are necessary in many areas.

What are resistance thermometers?

Temperatures below zero degree Celsius (that is, the minus scale) can be measured by resistance thermometers. They work on the premise that the resistance of materials changes with temperature. Resistance decreases as the temperature is reduced in the case of metals (positive temperature coefficient), while the resistance increases with decrease of temperature in the case of semiconductors (negative temperature coefficient).

Platinum resistance thermometers are used down to minus 170 degree Celsius. For measurement of even lower temperatures, Germanium and Silicon diode (semiconductor) thermometers are used. Thermocouples can also be used for measuring temperatures below zero degrees C.

What are thermocouples?

Temperatures below zero degree C can be measured using thermocouples. In fact, thermocouples are now used for measuring any range of temperatures (-250 to even -1400 degrees Celsius).

Thermocouples are based on the principle of thermo-electric effect which states that when two dissimilar metals (or their alloys) are joined to each other at their two ends and given a difference of temperatures at these two junctions, then a thermo-electric current starts flowing through the loop.

So, if one of the metal wires is cut and a voltmeter connected in the gap, then a voltage (emf) is developed which is almost proportional to the temperature difference between the two junctions. The emf is read out and converted to the corresponding temperature.

Uses of Bimetallic Strips

One of the important applications of the Linear Expansion is in making the use of Bimetallic Strips. The Bimetallic Strips are basically used to convert a temperature change into mechanical displacement. For example, a brass strip and a invar strip riveted together to make a bimetallic strip. When the temperature rises, the brass expands more than the invar and result is that strip bends with its convex on brass side. This differential expansion can be used to make the thermostats which are used in controlling the heating and cooling. Some thermostats use a mercury switch connected to both electrical leads. The angle of the entire mechanism is adjustable to control the set point of the thermostat. The same property is used to make miniature circuit breakers to protect circuits from excess current.

The bimetallic strips are also used in the mechanical clocks. A bimetallic strip is used to compensate the change / error in the mechanic clocks. Most common method is to use a bimetallic construction for the circular rim of the balance wheel. As the spring controlling the balance becomes weaker with increasing temperature, so the balance becomes smaller in diameter to keep the period of oscillation (and hence timekeeping) constant.

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What will happen when an egg with shell is kept in Microwave Oven?

When we keep our food in microwave, the energy of the microwaves is converted into heat and makes the water molecules vibrate faster. This is the fundamental principle, how microwave oven works. We can say that when egg is kept in microwave oven, it will also tend to be cooked as it has water. But, when placed in microwave, different components in an egg expand at different rates. White of egg contains a high proportion of water and yolk contains a high proportion of fat. Microwaved eggs can reach temperatures much higher than if they were simply boiled in water at 100 degrees Celsius. At these elevated temperatures, water inside the egg, mostly in the white albumen, vaporizes — even as the albumen solidifies. If the pressure inside the egg exceeds the breaking strength of the shell, the egg will explode. Thus, if we keep an egg in the microwave oven and wait for it to get boiled, we may be surprised as it explodes. So, a wooden pick or tip of a knife is generally used to break the yolk membrane of an unbeaten egg before cooking to allow the steam to escape and prevent the explosion.

Anomalous expansions

Please note that a number of materials contract on heating within certain temperature ranges. When these materials contract with rising temperature, it should be called negative thermal expansion. For example, the coefficient of thermal expansion of water drops to zero as it is cooled to roughly 4 °C and then becomes negative below this temperature; this means that water has a maximum density at this temperature, and this leads to bodies of water maintaining this temperature at their lower depths during extended periods of sub-zero weather. Also, fairly pure silicon has a negative coefficient of thermal expansion for temperatures between about 18 Kelvin and 120 Kelvin.

Transmission of Heat

Heat can be transmitted by three modes viz. conduction, convection and radiation.

Conduction

Conduction means the transfer of thermal energy between regions of matter due to a temperature gradient or temperature difference. Its worth note that heat automatically flows from a region of higher temperature to a region of lower temperature thus, approaching thermal equilibrium over a period of time. But please note that the conduction refers to the heat flow through the region of matter itself, as opposed to requiring bulk motion of the matter as in convection. Conduction takes place in all forms of matter, viz. solids, liquids, gases and plasmas, but does not require any bulk motion of matter. In solids, it is due to the combination of vibrations of the molecules in a lattice or phonons with the energy transported by free electrons. In gases and liquids, conduction is due to the collisions and diffusion of the molecules during their random motion.

The conduction occurs as rapidly moving or vibrating atoms and molecules interact with neighboring particles, transferring some of their kinetic energy. Heat is transferred by conduction when adjacent atoms vibrate against one another, or as electrons move from one atom to another. Conduction is the most significant means of heat transfer within a solid or between solid objects in thermal contact. Conduction is greater in solids because the network of relatively fixed spatial relationships between atoms helps to transfer energy between them by vibration. Air is a very bad conductor of heat. This is what behind the use of woolen cloths, shawls etc. The two walls of geysers, two walls of refrigerators have air between them. Similarly, Ice is also a very poor conductor of heat.

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What is the Physics behind the Frozen Lakes?

Water has a maximum density at 4°C. So, the Ice floats. besides, Ice is a good insulator; it does not conduct heat well. A layer of ice on the surface of a river or lake reduces the rate at which heat is lost to the cold clear sky above and the ice layer grows thicker very slowly as a result. Most substances are denser in the solid state than they are in the liquid state: a given volume of the solid substance weighs more than the same volume of the substance in liquid form. But the reverse is true of water.
If it were not so the ice would sink to the bottom as it formed and entire lakes might freeze solid, exterminating their inhabitants.

The poor conductivity of Ice is the reason that we use defrosting in Refrigerators. A refrigerator has to be switched off for defrosting because ice deposits on the outside and inside of the freezer. This poor conductor of heat affects the cooling of the freezer.

Convection

Convection is the transfer of heat from one place to another by the movement of fluids. While conduction is usually the dominant form of heat transfer in solids, convection is usually the dominant form of heat transfer in liquids and gases. But convective heat transfer actually describes the combined effects of conduction (heat diffusion), plus heat transfer by bulk fluid flow, a process is so correctly called "heat advection."
When we heat a liquid in vessel from below, the liquid at the bottom heats up and rises. This will give rise to the convection currents. The whole liquid gets heated to a uniform temperature due to these currents only. This is one reason why the heating filaments / elements in geysers are fitted at the bottom. Similarly, the Freezer of the Refrigerator is fitted at the top inside the Refrigerator so that it cools the entire enclosed area.
Convection explains the sea and land breezes. Water is maximum specific heat, so it cools slowly and warms slowly. During day time, land warms up faster than seas and that is why the air over the land warms up and cooler air from water takes its place thus resulting in sea breeze. In night, the land cools faster than the sea, thus resulting in the land breeze.

Radiation

Thermal radiation is electromagnetic radiation generated by the thermal motion of charged particles in matter.

- All matter with a temperature greater than absolute zero emits thermal radiation.
- While both conduction and convection need material medium for conveying the heat from one part to another, Radiation does not need a medium.
- **All bodies keep emitting and absorbing the thermal radiation.**
- If the body receives more than it emits, its temperature rises or vice versa.
- The rate at which a body emits or absorbs the radiant energy depends upon its temperature, nature, area of surface. A rough surface is a better absorber.
- Good absorber materials are good emitters and poor absorbers are poor emitters.

Black Body

A black body is an idealized physical body that absorbs all incident electromagnetic radiation. Since it is perfect for absorbing all the wavelengths, it is also the best possible emitter of thermal radiation. The object appears dark because **it does not emit and visible light**. A black body has an **emissivity of e = 1.0**. In practice, common applications define **all sources of infrared radiation as a black body** when the object approaches that emissivity and is **greater than approximately 0.99**. A source with lower emissivity is often referred to as a gray body.
In 2009, Japanese scientists created a material very close to an ideal black body, based on vertically aligned single-walled carbon nanotubes.

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Newton's Law of cooling

Newton's law states that *the rate of heat loss of a body is proportional to the difference in temperatures between the body and its surroundings temperature.*
The example is that, if the hot water and fresh water at room temperature are placed in a refrigerator, the rate of cooling of hot water would be higher than that of water at room temperature.

Greenhouse Effect

A Greenhouse **inhibits transfer of heat by convection** and works like a radiation trap. The heat radiation from the sun can pass through the glass and keeps the plants and air inside hot, but glass does not let the hot air escape back.
In the Green House Effect, the thermal radiation from a planetary surface is absorbed by atmospheric greenhouse gases, and is re-radiated in all directions. The result is that the temperature is higher than it would be if direct heating by solar radiation were the only warming mechanism.

- ✓ Names of three scientists are associated with the Green House Effect.
- ✓ Joseph Fourier discovered it in 1824. John Tyndall in 1858 carried out some reliable experiments and Svante Arrhenius in 1896 reported quantitatively on the impacts.

Process:

We all know that Earth receives the energy from Sun in the form of Ultraviolet, Visible and Near Infra Red radiation. Except most of the UV radiation, almost all of them pass through the atmosphere without being absorbed. Out of this 50% is absorbed by the surface of the Earth. When it becomes warm, its surface radiates the far Infrared thermal radiation, which has longer wavelengths than that of the radiation absorbed. This thermal radiation is absorbed by the atmosphere, and the atmosphere reradiates it both upwards and downwards. The radiation that is sent downward again raises the temperature of the Earth.

- ✓ Thus the long wave radiation is trapped and the equilibrium temperature of earth is higher than if there was no atmosphere. This is known as Green House Effect.
- ✓ The Incoming sun light is mostly in the form of visible light and nearby wavelengths, in the range 0.2–4 μm.
- ✓ Out of this half is visible light.
- ✓ The loss of the Radiation is almost nothing at the surface level but maximum at higher in the atmosphere because of the decreasing concentration of water vapor, an important greenhouse gas.
- ✓ While the major atmospheric components (Nitrogen and Oxygen) absorb little or no radiation, some of the minor components are effective absorbers.
- ✓ Particularly effective is water vapor and CO_2 which absorb effectively in the IR wavelength range.
- ✓ These absorbing gases and their surrounding air warm up, emitting radiation downward, towards the Earth's surface, as well as upward, towards space.
- ✓ This effectively traps part of the IR radiation between ground and the lower 10 km of the atmosphere. This reduction in the efficiency of the Earth to lose heat causes the surface temperature to rise above the effective temperature until finally, enough heat is able to escape to space to balance the incoming solar radiation.
- ✓ The effect is analogous to that of a blanket that traps the body heat preventing it from escaping into the room and thus keeps us warm on cold nights.

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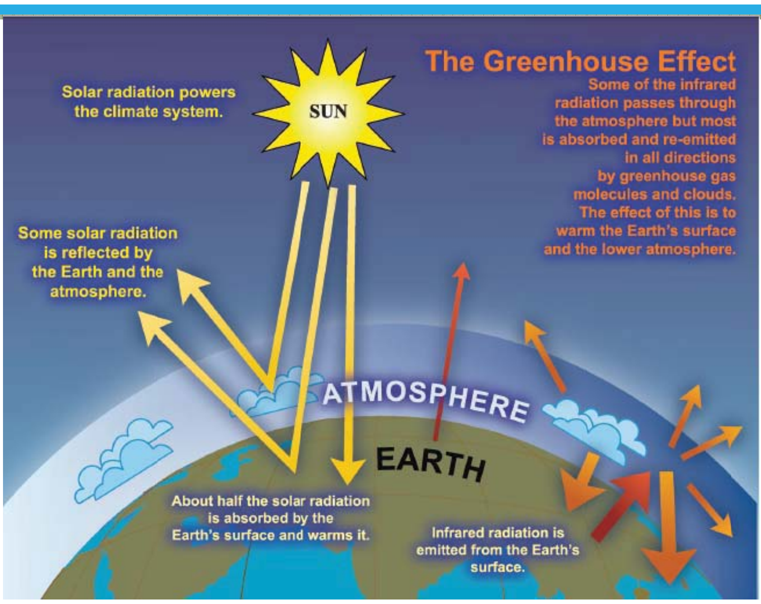

✍ If Earth was an ideal black body which absorbs all the radiation from the Sun and emit the radiation due to this heating, its temperature would have been 5.3 °C.

✍ The Earth and other planets are not perfect black bodies, as they do not absorb all the incoming solar radiation but reflected part of it back to space.

✍ The ratio between the reflected and the incoming energies is termed the planetary albedo.

✍ Earth reflects 36-37% of this incoming light and it corresponds to the Earth Albedo 0.367.

✍ So, Earth's mean temperature is 14 °C. If there were no atmosphere and no radiation was lost due to reflection, its mean temperature would have been −18 or −19 °C. This difference is due to the Green House Effect.

Anti-greenhouse effect

Many planetary bodies show the Green House Effect.

✍ In our solar System**, Mars and Venus** show the Green House Effect, but **Titan, the largest planet of Saturn and Pluto, shows the opposite phenomena** which is called Anti-Green House Effect.

Greenhouse effect occurs because the atmosphere transparent to solar radiation, but largely opaque to infrared and far infrared emitted by the planet / body.

But in anti-greenhouse effect, the atmosphere is opaque to solar but lets out infrared.

The effect is that the body is cooler than the actual temperature would have been. In case of Titan, both Green House Effect and Anti Green House Effect have been proved. Due to Green House Effect, the temperature goes up by 21K while, due to Anti-Green House effect, the temperature goes down by 9K. The result is that surface temperature is 12 K warmer than without atmosphere.

✍ At Pluto, there is different mechanism. Here, the sunlight causes the Nitrogen ice to sublimate which cools the body.

Working of a solar cooker

A solar cooker uses the Greenhouse effect to entrap the energy of solar rays. So, a good insulation is key to its efficiency. The greenhouse effect is produced by the combination of two essential effects : the selectivity and the transparency of the materials. Selectivity refers to the phenomenon that will allow the materials the

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oven is made of to transform the wavelength of the ray whose energy we want to trap. Selectivity is the ratio between the absorption factor of a wavelength, or of the field of a wavelength, and the emission factor of another wavelength, or of the field of a wavelength, of a given material.

The transparency of a material is its ability to stop the radiations according to the wavelength or to let them in. Typically, in a solar oven we'll use materials that are transparent to radiations < 3μm and opaque to radiations > 3μm. Glass and Plexiglas are good examples of such materials. First the source light goes through the material that is transparent to its wavelength. Then the wavelength of the light source is transformed by the selectivity of another material into another wavelength to which the first material is opaque. Thus the radiation is trapped between the two materials that are opaque to it, and this is how we get the greenhouse effect.

Working of Thermos Flask

A vacuum Flask provides thermal insulation by interposing a partial vacuum between the contents and the ambient environment. it has hollow walls; the narrow region between the inner and outer wall is evacuated of air. thus it is simply like a two thin-walled bottles nested one inside the other and sealed together at their necks. Using vacuum as an insulator avoids heat transfer by conduction or convection. Radiative heat loss can be minimized by applying a reflective coating such as silver to surfaces. The contents of the flask reach thermal equilibrium with the inner wall; the wall is thin, with low thermal capacity, so it exchanges little heat with the contents and hence has little effect on their temperatures.
A vacuum cannot be maintained at the opening; so, a stopper made of insulating material is used.

Wave motion

Our world is full of waves. The two main types of waves are mechanical waves and electromagnetic waves.

Mechanical Waves

The sound waves, water waves are mechanical waves. In each case, some physical medium is being disturbed such as air molecules, water molecules. Electromagnetic waves do not require a medium to propagate; some examples of electromagnetic waves are visible light, radio waves, television signals, and x-rays.
When we observe what we call a water wave, what we see is a rearrangement of the water's surface. Without the water, there would be no wave. A wave traveling on a string would not exist without the string. Sound waves could not travel through air if there were no air molecules. With mechanical waves, what we interpret as a wave corresponds to the propagation of a disturbance through a medium.

Wehn we float on a raft in a large lake, we slowly bob up and down as waves move past us. When we look from the ground, we see the individual waves approaching. In these waves, the point at which the displacement of the water from its normal level is highest is called the crest of the wave. The distance from one crest to the next is called the wavelength λ. When we measure the time between the arrivals of two adjacent waves, we measure the period T of the waves. The period is the time required for two identical points (such as the crests) of adjacent waves to pass by a point. Waves travel with a specific speed, and this speed depends on the properties of the medium being disturbed. For instance, sound waves travel through room temperature air with a speed of about 343 m/s (781 mi/h), whereas they travel through most solids with a speed greater than 343 m/s.

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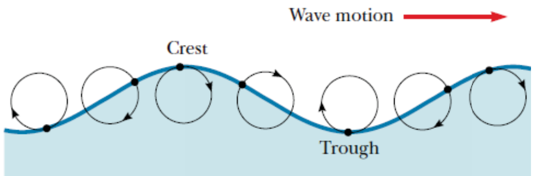
A traveling wave that causes the particles of the disturbed medium to move perpendicular to the wave motion is called a transverse wave.

A traveling wave that causes the particles of the medium to move parallel to the direction of wave motion is called a longitudinal wave.

Sound waves are another example of longitudinal waves. The disturbance in a sound wave is a series of high-pressure and low-pressure regions that travel through air or any other material medium.

Some waves in nature exhibit a combination of transverse and longitudinal displacements. **Surface water waves** are a good example. When a water wave travels on the surface of deep water, water molecules at the surface move in nearly circular paths, as shown in the following figure:



In the above figure, the transverse displacement is seen as the variations in vertical position of the water molecules. The **longitudinal displacement** can be explained as follows:

As the wave passes over the water's surface, water molecules at the crests move in the direction of propagation of the wave, whereas molecules at the troughs move in the direction opposite the propagation. Because the molecule at the labeled crest in Figure will be at a trough after half a period, its movement in the direction of the propagation of the wave will be canceled by its movement in the opposite direction. This holds for every other water molecule disturbed by the wave. Thus, **there is no net displacement of any water molecule during one complete cycle**. Although the molecules experience no net displacement, the wave propagates along the surface of the water.

P & S Waves

There are some three-dimensional waves that travel out from the point under the Earth's surface at which an earthquake occurs are of both types—transverse and longitudinal. The longitudinal waves are the faster of the two, traveling at speeds in the range of 7 to 8 km/s near the surface. These are called P waves, with "P" standing for primary because they travel faster than the transverse waves and arrive at a seismograph first. The slower transverse waves, called S waves (with "S" standing for secondary), travel through the Earth at 4 to 5 km/s near the surface. By recording the time interval between the arrival of these two sets of waves at a seismograph, the distance from the seismograph to the point of origin of the waves can be determined.

A single such measurement establishes an imaginary sphere centered on the seismograph, with the radius of the sphere determined by the difference in arrival times of the P and S waves. The origin of the waves is located somewhere on that sphere. The imaginary spheres from three or more monitoring stations located far apart from each other intersect at one region of the Earth, and this region is where the earthquake occurred.

Superposition of waves

If two or more traveling waves are moving through a medium, the resultant wave function at any point is the algebraic sum of the wave functions of the individual waves. This is shown in the following graphics:

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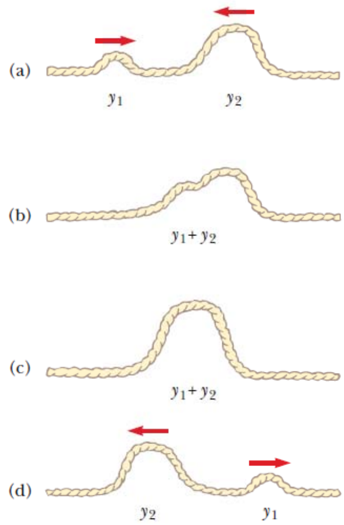

- Waves that obey this principle are called linear waves and are generally characterized by small amplitudes.
- Waves that violate the superposition principle are called nonlinear waves and are often characterized by large amplitudes.

Two wave pulses traveling on a stretched string in opposite directions pass through each other. When the pulses overlap, the net displacement of the string equals the sum of the displacements produced by each pulse. Because each pulse displaces the string in the positive direction, we refer to the superposition of the two pulses as constructive interference.

Sound waves

Sound waves are the longitudinal mechanical waves which are generated by the transmission of the disturbances in the form of compressions and rarefactions. This train of contractions and rarefactions on reaching the listener's ears produces variations of the pressure on his ear membranes. These pressure variations stimulate the auditory nerves which carry the message to the hearing centre of the brain 9 (primarily in the temporal lobe).

Sound is transmitted through gases, plasma, and liquids as longitudinal waves and in this case it is called the **compression waves**. Through solids, however, it can be transmitted as both **longitudinal waves and transverse waves. Longitudinal sound waves are waves of alternating pressure deviations** from the equilibrium pressure, causing local regions of compression and rarefaction, while transverse waves (in solids) are waves of alternating shear stress at right angle to the direction of propagation.

We can listen to the sounds which range between 20Hz to 20000 Hz normally. This is called audibility limit and based upon this, the sound waves have been classified as :

- Infrasound i.e. less than 20 Hz
- Audible Waves i.e. 20-20000 Hz.
- Ultrasound i.e. 20,000 Hz and more.

Infrasound

Infrasound is sound that is lower in frequency than 20 Hz, the "normal" lower limit of human hearing. The study of such sound waves is called infrasonics, covering sounds beneath 20 Hz down to 0.001 Hz. These sounds are typically produced inside earth when earthquakes occur. This frequency range is utilized for monitoring earthquakes, charting rock and petroleum formations below the earth, and also in

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ballistocardiography and *seismocardiography* to study the **mechanics of the heart**. This is because; these **sounds are produced in the hearts during heart beats**.

Infrasound is characterized by an **ability to cover long distances** and get around obstacles with little dissipation.

Infrasound and animals

Whales, elephants, hippopotamuses, rhinoceros, giraffes, okapi, and alligators are known to use infrasound to communicate over distances. Whales are able to communicate up to hundreds of miles using infrasounds. Migrating birds use naturally generated infrasound such as these generated by mountains. Elephants produce infrasound waves that travel through solid ground and are sensed by other herds using their feet, despite being separated by hundreds of kilometers. These waves are called **"Rayleigh waves"**.

Rayleigh waves

Rayleigh waves are a type of surface acoustic wave that travels on solids. They are produced on the Earth by earthquakes, in which case they are also known as "ground roll". The waves are called so because Lord Rayleigh predicted their existence in 1885. These vibrations move through the ground like waves move on the surface of the ocean. They travel at 10 times the speed of sound. In the 2004 Tsunami, the waves would have reached the land areas hours before the water hit. The Mammals, birds, insects, and spiders can detect Rayleigh waves. Most can feel the movement in their bodies, although some, like snakes and salamanders, put their ears to the ground in order to perceive it. It was said that the causalities in animals such as wildlife of National Parks of Sri Lanka was negligible in comparison to the Human causalities. This might be possible that the animals detected these waves and ran for higher grounds.

Do Humans perceive Infrasound?

Please note that under certain conditions, we humans do perceive the Infrasound i.e. some 12 Hz. They cause pressure on ear drums and are known to cause feelings of awe or fear. They are not perceived consciously and it can make people feel vaguely that supernatural events are taking place.

What is wind-turbine syndrome?

Wind Turbines are known to produce the infrasound and low-frequency noise. These may cause headaches, dizziness, nausea and are called wind-turbine syndrome.

Audible Sound

The generally accepted range of audible frequencies is 20 to 20,000 Hz, though the range depends upon environmental factors.

Frequencies below 20 Hz are **generally felt rather than heard**, assuming the amplitude of the vibration is great enough. Frequencies above 20,000 Hz can sometimes be **sensed by young people**. High frequencies are the **first to be affected** by hearing loss due to age and/or prolonged exposure to very loud noises. The maximum intensity of sound which a man can hear is approx 85 decibels.

- There are numerous applications of the audible sounds including speech, music, training etc. etc. If a person is unable to perceive sound, it is deafness.
- Noise pollution is excessive, displeasing human, animal or machine-created environmental noise that disrupts the activity or balance of human or animal life.
- **Acoustic holography** is used to estimate the sound field near a source by measuring acoustic parameters away from the source via an array of pressure and/or particle velocity transducers. It is

used in transportation, vehicle and aircraft design. The near-field acoustic holography (NAH) and statistically optimal near-field acoustic holography (**SONAH**) are some of its variations.

- The mechanical force of sound is measured by **Phonometer**. Phonometer was devised by Thomas Edison and it converted sound energy or sound power into rotary motion which could drive a machine such as a small saw or drill. The telephone and telegraph were based upon this instrument.

Ultrasound

As far as Physical properties are concerned, there is no differenece between audible sound and ultrasound, the only fact is that humans cannot hear it. Its range is 20,000 hertz and above. Please note that our middle ear, works as a low-pass filter. If we pass feed the ultrasound directly into the skull bone and reaches the cochlea through bone conduction without passing through the middle ear, a person can hear the ultrasound. The upper limit of human audible range decreases with age, the infants can sense ultrasound to some extent. Dogs, cats, dolphins, bats, and mice all can hear ultrasound.

How Dog Whistles work?

Human audible range is from 12-16 Hz (normally 20 Hz) to 20000 Hz. In Dogs, it is within the range of approximately 40 Hz to 60,000 Hz. The Dog whistles are blown at around 22-25000 Hz, which seem silent to us but can bring a dog in action, thus used in their training.

Bats use the concept of echolocation and their frequency range is between 20 Hz and 120,000 Hz.

Dolphins range anything between 0.25 to 150 kHz.

Ultrasonography

Ultrasound is used in ultrasonography or Medical sonography, which is a diagnostic medical imaging technique used to visualize muscles, tendons, and many internal organs, to capture their size, structure and any pathological lesions with real time tomographic images. This technique is relatively inexpensive and portable in comparison to MRI & CT Scan.

✍ Please note that Ultrasound is considered to be the safe test because **it does not use mutagenic ionizing radiation**, which can pose hazards such as chromosome breakage and cancer development.

The wrong effects of ultrasound are limited to

1. Enhancement of inflammatory response
2. Heating of soft tissue.

This is because; Ultrasound **produces a mechanical pressure wave** through soft tissue, which may cause microscopic bubbles in living tissues and distortion of the cell membrane, influencing ion fluxes and intracellular activity.

When ultrasound enters the body, it **causes molecular friction** and **heats the tissues** slightly. The applications of medical ultrasound are as follows:

- ✓ Date the pregnancy
- ✓ Confirm fetal viability
- ✓ Location of fetus, intrauterine vs ectopic
- ✓ Number of foetoses
- ✓ Physical abnormalities.
- ✓ Determine the sex of the baby

Use in Adults

- ✓ Detection of pelvic / rectal abnormalities (in adults)

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- ✓ Cleaning teeth in dental hygiene.
- ✓ phacoemulsification for cataract treatment.
- ✓ Ultrasound-guided sclerotherapy and endovenous laser treatment for the non-surgical treatment of varicose veins.
- ✓ Liposuction can also be assisted by ultrasound.

Lithotripsy

- ✓ The lithotripsy is the medical treatment that involves Ultrasound in **breaking the kidney stones** and gallstones into small fragments so that they can be passed from the body without undue difficulty.

HIFU and MRgFUS

- ✓ High Intensity Focused Ultrasound (HIFU): High Intensity Focused Ultrasound (HIFU) or focused ultrasound surgery (FUS) uses the low frequency but of high intensity and focus Ultrasound waves to ablate tumors or other tissue non-invasively. This process is used under the guidance of Magnetic Resonance Imaging (MRI) and when done so, the combination of MRI and HIFU is called Magnetic resonance-guided focused ultrasound (MRgFUS).

ATDD

- ✓ ATDD refers to acoustic targeted drug delivery. It is the process of delivering chemotherapy to brain cancer cells and various drugs to other tissues. The funda is to focus the acoustic energy on the tissue of interest to agitate its matrix and make it more permeable for therapeutic drugs. Thus, Ultrasound helps in Cancer treatment too.

Other applications of Ultrasound

- ✓ An ultrasonic cleaner works mostly by energy released from the collapse of millions of microscopic cavitations near the dirty surface. The bubbles made by cavitation collapse forming tiny jets directed at the surface.
- ✓ Sonication and Sonoporation are some of the techniques that use the ultrasound in killing bacteria in sewage.
- ✓ Ultrasonic humidifier uses vibrating a metal plate at ultrasonic frequencies to nebulize the water, thus cool mist / vapour can be produced without boiling water. Used in aeroponics. Since, water is not boiled, no pathogens are killed and Ultrasonic humidifier can produce illness which is called "Humidifier Fever".
- ✓ Ultrasound Identification (USID) is a Real Time Locating System (RTLS) or Indoor Positioning System (IPS) automatically track and identify the location of objects

SONAR

Sonar, an acronym for Sound Navigation and Ranging, is a detection system based on the reflection of underwater sound waves, just as radar is based on the reflection of radio waves in air. The sonar emits ultrasonic pulses using a submerged radiating device. It listens with a sensitive microphone, or hydrophone, for reflected pulses from potential obstacles or submarines. The sonar is used by airplanes and ships each deploying a different type of sonar. Airplanes use a device called a sonobuoy, consisting of a hydrophone mounted on a floating buoy. Spin-offs from the development of sonar technology include acoustic oceanography, the study of ocean properties using a variety of acoustic means, and an imaging or remote-

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sensing technique using computer analysis to study the data collected when acoustic signals are passed through an object.

Speed of Sound

For the propagation of the sound waves, a medium is needed and that is why the sound waves don't propagate in vacuum. The speed of sound is different from different media. In dry air at 20 °C , the speed of sound is 343.2 meters per second. It comes out to be 1,236 kilometers per hour, or about one kilometer in three seconds or approximately one mile in five seconds.

Newton observed that the speed of sound is dependent on elasticity of Medium E and density of the medium d.

$$V = \sqrt{\frac{E}{d}}$$

If the medium is solid then,

$$V = \sqrt{\frac{\gamma}{d}}$$

Where, γ is the Young's Modulus.

Speed of sound in Solids

The sound waves propagate as two different types in solids. The longitudinal waves are associated with compression and decompression in the direction of travel, which is the same process as all sound waves in gases and liquids. A transverse wave or shear wave, is also due to elastic deformation of the medium perpendicular to the direction of wave travel, known as "polarization" of this type of wave. These different waves (compression waves and the different polarizations of shear waves) may have different speeds at the same frequency. Therefore, they arrive at an observer at different times.

As written above, the speed of sound is variable and depends on the properties of the substance through of which the wave is travelling.

- ✓ *In solids, the speed of longitudinal waves depend on the stiffness to tensile stress , and the density of the medium.*
- ✓ *In fluids, the medium's compressibility and density are the important factors.*
- ✓ *In gases, compressibility and density are related, making other compositional effects and properties important, such as temperature and molecular composition.*
- ✓ *In low molecular weight gases, such as helium, sound propagates faster compared to heavier gases, such as xenon (for monatomic gases the speed of sound is about 75% of the mean speed that molecules move in the gas).*
- ✓ *For a given ideal gas the sound speed depends only on its temperature.*
- ✓ *At a constant temperature, the ideal gas pressure has no effect on the speed of sound, because pressure and density (also proportional to pressure) have equal but opposite effects on the speed of sound, and the two contributions cancel out exactly. In a similar way, compression waves in solids depend both on compressibility and density—just as in liquids—but in gases the density contributes to the compressibility in such a way that some part of each attribute factors out, leaving only a dependence on temperature, molecular weight, and heat capacity (see derivations below). Thus, for a single given gas (where molecular weight does not change) and over a small temperature range (where heat capacity is relatively constant), the speed of sound becomes dependent on only the temperature of the gas. Humidity has a small but measurable effect on sound speed (causing it to increase by about 0.1%-0.6%), because oxygen and nitrogen molecules of the air are replaced by lighter molecules of water. This is a simple mixing effect. (source: wikipedia)*

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Speed of Sound in Various media at 0°C in meters per second

CO2	260
Air	332
Vapour	405
Alcohol	1213
Hydrogen	1269
Mercury	1450
Water	1493
Sea water	1533
Iron	5130
Glass	5640
Aluminum	6420

- ✓ Please note that at the same temperature, the speed of sound does not vary with Pressure in a gas.
- ✓ The speed of sound in all media is directly proportional to the square root of its absolute temperature.
- ✓ For every 1°C rise in temperature, the speed of sound in air increases by 0.61 m/sec.
- ✓ Density of dry air is more than that of the moist air, so speed of sound in moist air is more than that in the dry air.

What will happen if a person speaks with helium filled in his / her throat?

Voice's pitch is determined by speed of sound, along with other factors. In air, sound travels at 330 meters per second (m/s) approximately but in Helium this speed is three times faster -- nearly 900 m/s. So, when somebody talks with helium in his / her lungs, all of the sound waves travel nearly three times faster through throat, mouth and nasal cavities, creating a pitch that's nearly three times higher.

Musical Sound

The musical notes differ from each other in respect to at least one of the following three properties

1. Intensity
2. Pitch
3. Quality

The above three are called characteristics of Musical sound. The difference in any of them helps us to differentiate between the musical notes.

The intensity written above is defined as the rate of flow of energy per unit area of the plane perpendicular to the directions of the wave propagation. So, Intensity is measured in Joule /sec-meter^2

The intensity of a simple harmonic wave is as follows:

$$I=2\pi^2 v^2 a^2 \rho \vartheta$$

Where:

a = amplitude of the wave

ρ= Density of the medium

v= Frequency of the wave

ϑ = speed of the wave

The above formula makes it clear that the intensity of the musical sound is

- ✓ proportional to the square of the amplitude of the wave
- ✓ proportional to the density of the medium
- ✓ proportional to the square of the frequency of wave
- ✓ proportional to the wave velocity

A positive change in any of them would increase the intensity of the Sound. Apart from these, the intensity of the sound is inversely proportional to the square distance of the source. It is directly proportional to elasticity of the medium.

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Intensity is the special feature of the sound by which we can identify the feeble and strong sounds. Its unit is Watt/M², but this unit is obsolete now.

The unit used now is bel. Bel is a logarithmic scale and frequency is used to measure the relative density. The unit bel is named after Graham Bel. 1/10th of bel is called decibel. This is the most important practical unit, as we all know.

Decibel (dB) is a logarithmic unit that indicates the ratio of a intensity relative to a specified or implied reference level.

A ratio in decibels is ten times the logarithm to base 10 of the ratio of two power quantities. A change in power ratio by a factor of 10 is a 10 dB change. A change in power ratio by a factor of two is approximately a 3 dB change.

So, the ratio of a power value P1 to another power value P0 is represented by LdB, that ratio expressed in decibels, which is calculated using the formula:

$$L_{\mathrm{dB}} = 10 \log_{10} \left(\frac{P_1}{P_0} \right)$$

As the decibel is measured on a log scale, **an increase of every 10 dB would indicate a ten-fold change** in the sound intensity. For example, a sound level of 90 dB has intensity 10 times more than the sound level of 80 dB.

Source of Sound	Intensity in Decibels
Whisper	15-20
Ordinary conversation	40-60
Loud Speaker	70-80
Heavy Motor vehicle	90-95
Press	100-105
Siren	190-200
Rocket	160-170
Missile	180-190

Pitch & Timbre of Sound

Pitch is an auditory perceptual property that allows the differentiation of sounds on a frequency-related scale. So, pitch of a musical note is that physical cause, which distinguishes a shrill note from a grave note of "same" intensity, coming from the same instrument. This means that when we play a flute at a particular intensity of the sound, it is the pitch that would help us to recognize the degree of shrillness. The women and kids have shrill sound due to high pitch, while an older male has grave sound, due to low pitch. Pitch is a major auditory attribute of musical tones, along with duration, loudness, and timbre.

- ✓ Quality or timbre is the third feature of a musical note which distinguishes between two notes of same intensity and pitch.
- ✓ If **two different musical instruments are playing notes at the same pitch and loudness, it is the timbre that allows us to differentiate**, such as Flute and saxophone.
- ✓ Tone quality and Tone color are defined by timbre.

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Echo

Echo is the natural phenomenon which describes the reflection of sound. It is simply the repetition of the sound wave produced by reflection from an object / obstacle such as a wall , tower or mountain.

Please note that time difference between the arrival of direct wave and reflected wave should be at least 0.1 second so that a human ear can distinguish between two sounds.

When dealing with audible frequencies, the human ear cannot distinguish an echo from the original sound if the delay is less than 1/10 of a second. Thus, since the velocity of sound is approximately 343 m/s at a normal room temperature of about 20°C, the reflecting object must be more than 17.15 m from the sound source at this temperature for an echo to be heard by a person at the source.

Question:

If the time taken in an echo is 5 seconds, which among the following will be the approximate distance of the object from source of sound? (assume normal room temperature at 20°C)

(A)1715 meters
(B)1256 meters
(C)857 meters
(D)554 meters

Answer:

The time taken by the sound waves in going and coming back is 5 seconds, i.e. 2.5 second to reach and 2.5 seconds to come back. So the object is placed 343 x 2.5= 857 meters

Reverberation of Sound

Whenever the programmes of music, speech, concerts etc, are organized in some halls / cinemas/ auditoriums, then we hear a series of multiple reflections that take place from the walls, roofs and floors. When we off the source of the sound, these echoes sustain the sound for quite some time, which is called reverberation.

Why they put porous screens on walls of cinema halls?

Time of reverberation depends upon the material of the absorber medium such as walls, roofs etc. The fitness of the auditoriums, cinema halls etc. is measured by echo and reverberation. This time of reverberation can be adjusted by increasing and decreasing the area and quality of the absorbing material. This is one reason why the cinema hall walls are covered by porous screens.

Refraction of Sound

When a sound wave moves from one medium to another medium , the wave is refracted. The refracted wave is deviated from the path of the original wave / incident wave. The main reason of the refraction is different speeds of sound in different media.

Vibrations

Vibrations are the mechanical oscillations about an equilibrium point. The oscillations may be periodic or random. They can be wanted or unwanted, useful or useless even harmful.

The study of sound and vibration are closely related. We are able to speak due to the vibrating structures (e.g. vocal cords). The sound waves which are pressure waves can induce the vibration of structures (e.g. ear drum).

- ✓ Vibrations can be Free Vibrations or forced Vibrations.
- ✓ **Free vibration** occurs when a mechanical system is set off with an initial input and then allowed to vibrate freely. Examples of this type of vibration are pulling a child back on a swing and then letting

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go or hitting a tuning fork and letting it ring. The mechanical system will then vibrate at one or more of its "natural frequency" and damp down to zero.

- ✓ **Forced vibration** is when an alternating force or motion is applied to a mechanical system. Examples of this type of vibration include a shaking washing machine due to an imbalance or the vibration of a building during an earthquake. In forced vibration the frequency of the vibration is the frequency of the force or motion applied, with order of magnitude being dependent on the actual mechanical system.

Resonance

In the forced vibrations, when the frequency of the external periodic force becomes equal to the natural frequency of the body of the free vibration, it is called resonance. Resonance is the tendency of a system to *oscillate at a greater amplitude at some frequencies than at others* known as the system's resonant frequencies. At these frequencies, **even small periodic driving forces can produce large amplitude oscillations**, because the system stores vibrational energy. It may cause violent swaying motions and even catastrophic failure in improperly constructed structures including bridges, buildings and airplanes—a phenomenon known as **resonance disaster**.

What is the funda behind quake-resistant technology for multistory buildings?

In 1939, the **Tacoma Bridge** in USA was destroyed due to the mechanical resonance. The reason was that the fast moving air confined to the outer surface of the bridge had the same frequency as that of natural frequency of the bridge.

The seismic waves caused by an earthquake will make buildings sway and oscillate in various ways depending on the frequency and direction of ground motion, and the height and construction of the building. Seismic activity can cause excessive oscillations of the building which may lead to structural failure. To enhance the building's seismic performance, a proper building design is performed engaging various seismic vibration control technologies.

During an earthquake, multistory buildings are set in motion and start oscillating with a certain frequency and a natural period. Earthquake resistant technology tries to see that the **multistory buildings do not oscillate with the same natural period as that of the earthquake in order to avoid resonance.** If both the natural periods coincide, the damage to buildings will be total. **Extensive cross-bracing is done inside the buildings,** tying the floors with the walls and the roofs so that the buildings behave as a single entity.

Why the soldiers are asked to march NOT in tuning while crossing a Bridge?

When the soldiers cross any bridge in troops, the condition of resonance must be avoided. As a precaution for this particular reason, they are asked to walk on bridge in such a way that the feet of the troop's men are not in same tuning.

Why sound changes continuously as a vessel is being filled with water from a tap?

A changing sound is a result of the resonance phenomenon common with vibrating systems. When water enters an empty or partially filled vessel, sound waves of almost all frequencies are produced in the air contained in it. Waves whose frequencies match natural frequencies of vibration give rise to stationary waves in the medium, which can last for relatively long periods of time.

A natural frequency corresponds to that stationary wave whose `nodes' are formed on rigid walls opposite to each other. Or it may correspond to that wave whose `anti-node' is formed somewhere on the narrow open `mouth' of the vessel. A node refers to a point where the amplitude of vibration of the medium is, ideally speaking, zero while anti-node refers to a point where this amplitude is the maximum.

Stationary waves can be formed only when the `node to node' distance is an integral multiple of the half-wavelength of the waves

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produced. Stationary waves are also formed when the `node to anti-node' distance is an odd integral multiple of the quarter-wavelength of the waves.
Generally, the fundamental modes are the dominant modes in the frequency spectrum of vibrations produced by water falling in to the vessel. The pitch of the sound one hears from the vessel is determined collectively by the wavelengths of the dominating modes of vibrations. As the level of water in the vessel rises and the air cavity shrinks in size, the wavelengths of most of these (and also of their harmonics) decrease, particularly of those, which have anti-nodes near the mouth of the vessel. This leads to a gradual rise of the pitch of the sound produced. In other words, one hears a changing sound.

Doppler's Effect

When there is a relative motion between an observer and a source then the pitch of the note emitted by the source appears to be changed to the observer.
This apparent change is due to the relative motion between the observer and the source. When the source of the waves is moving toward the observer, each successive wave crest is emitted from a position closer to the observer than the previous wave. Therefore each wave takes slightly less time to reach the observer than the previous wave. Therefore the time between the arrival of successive wave crests at the observer is reduced, causing an increase in the frequency. While they are traveling, the distance between successive wave fronts is reduced; so the waves "bunch together". Conversely, if the source of waves is moving away from the observer, each wave is emitted from a position farther from the observer than the previous wave, so the arrival time between successive waves is increased, reducing the frequency. The distance between successive wave fronts is increased, so the waves "spread out".

Please note that Austrian physicist Christian Doppler who proposed it in 1842, first saw it in light waves and proposed the Optical Doppler effect. He propounded that the spectral lines of certain starts were shifting towards red or violet end of the spectrum from their normal position by a very small distance. These shifts towards Red and Violet signify the stars that move away and towards earth respectively.
Doppler Effect is the basic characteristic and is found in all kinds of waves.
In case of the sound waves the Apparent pitch or frequency n' is obtained by

$$n' = \frac{v \pm v_0}{v \pm v_s} \times n$$

Where:

- ✓ n' = apparent frequency
- ✓ n= actual frequency
- ✓ v= velocity of the sound
- ✓ v_0= velocity of the observer
- ✓ v_s= velocity of the source

Mach Number

The **Mach number**, in aerodynamics and fluid mechanics, is the ratio of the speed of an object through a fluid (gas or liquid) to the speed of sound in the fluid.

$$\textbf{Mach Number} = \frac{V_{sound}}{V_{object}}$$

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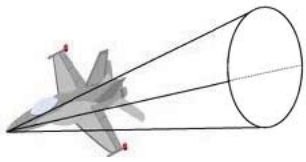
The **Mach number** was named after the Austrian physicist and philosopher **Ernst Mach**. An airplane travelling at less than Mach 1 is travelling at subsonic speeds; at about Mach 1, transonic, or approximately the speed of sound; and greater than Mach 1, at supersonic speeds.

Mach Cone

When a boat travels in water , it creates the bow and stern waves, its a normal observation. Similarly, when an object passes through the air it creates a series of pressure waves in front of it as well as behind it. These waves travel at the speed of sound, and as the speed of the object increases, the waves are forced together, or compressed, because they cannot get out of the way of each other, eventually merging into a single shock wave at the speed of sound. When the speed of the object is equal to the speed of the sound, this critical speed is known as Mach 1 and is approximately 1,225 km/h (761 mph) at sea level and 20 °C (68 °F). In smooth flight, the shock wave starts at the nose of the aircraft and ends at the tail. Because radial directions around the aircraft's direction of travel are equivalent, the shock forms a **Mach cone** with the aircraft at its tip as the following graphic.



The half-angle (between direction of flight and the shock wave) **α** is given by the following equation:

$$\text{Sin}(\alpha)= \frac{V_{sound}}{V_{object}}$$

- ✓ If Mach Number is >1, the velocity of the source such as a Jet Plane (supersonic plane) is called Supersonic
- ✓ If Mach number is >5 , then the velocity is called Hypersonic.

Shockwaves

Shock waves form when the speed of a gas changes by more than the speed of sound. The region where this occurs sound waves traveling against the flow reach a point where they cannot travel any further upstream and the pressure progressively builds in that region, and a high pressure shock wave rapidly form. The shockwaves carry energy and can propagate through a medium (solid, liquid, gas or plasma) or in some cases in the absence of a material medium, through a field such as the electromagnetic field.

- Across a shock there is always an extremely rapid rise in pressure, temperature and density of the flow.
- A shock wave travels through most media at a higher speed than an ordinary wave.
- Energy of a shock wave dissipates relatively quickly with distance.
- When a shock wave passes through matter, the total energy is preserved but the energy which can be extracted as work decreases and entropy increases. This creates additional drag force on aircraft with shocks. This is the fundamental principle behind a waverider.

Waverider

A hypersonic aircraft design that improves its supersonic lift-to-drag ratio by using the shock waves being generated by its own flight as a lifting surface is called the waverider. Only waveriders till date is Mach 3

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supersonic **XB-70 Valkyrie** and **Boeing X-51A** scramjet demonstration aircraft at various stages of development.

Optics

Visible light is electromagnetic radiation that is visible to us. Its wavelength in a range from about 380 nanometers to about 740 nm, with a frequency range of about 405 THz to 790 THz. The direction of the path taken by light is called a ray. Ray is represented by a line with an arrow on it. Number of rays constitutes the beam of light. This beam may be *converging, diverging or parallel.*

Speed of Light

The speed of light in a vacuum is defined to be exactly 299,792,458 m/s. This is fixed because meter itself is defined in terms of the speed of light.

Dual nature of Light

The initial explanations of light said that light consists of tiny particles which they call photons, which travel at a speed of light. When these particles hit something, they get bounced, absorbed or reflected back. When the bounce off from something and enter our eyes, we are able to see something.

The above descriptions could not satisfactorily explain why some photons are absorbed and others are reflected.

The theory of Electromagnetic spectrum tried to solve this dilemma. It is based upon the hypothesis that light is made up of waves. This theory has been used to explain that longest wavelength of the visible light (red) and shortest wavelengths of the visible light (blue) are absorbed by the green leaves (Chlorophyll) and green light is let reflected so that leaves appear green.

However, there are some properties of light which can be explained by particle nature and other by wave nature. This is called the **Dual nature of Light**.

The electromagnetic spectrum incorporates the range of all electromagnetic radiation, and extends from electric power at the long-wavelength end to gamma radiation at the short-wavelength end. In between, we find radio waves, infra-red, visible light, ultra violet and X-rays used in medical diagnostics. The following graphics shows the general properties of all the wavelengths of the electromagnetic spectrum. All of them are commonly known as Electromagnetic waves.

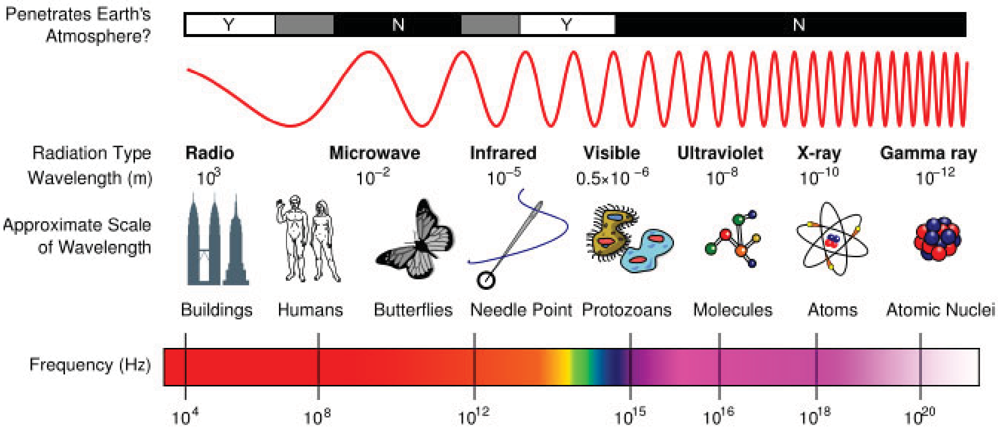

Image: Wikimedia Commons

Electromagnetic waves are defined by their special characteristics, such as frequency, wavelength and amplitude.

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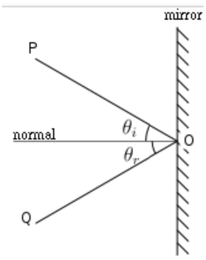
Reflection of Light



Certain surfaces such as mirrors reflect the light. The law of reflection says that

1. The incident ray, the reflected ray and the normal to the reflection surface at the point of the incidence lie in the same plane.
2. The angle which the incident ray makes with the normal is equal to the angle which the reflected ray makes to the same normal.
3. The reflected ray and the incident ray are on the opposite sides of the normal.

Virtual Image and Real Image

When a point source of light is placed in front of a plane mirror, rays of light from the source fall on the mirror and are reflected back. These reflected rays enter the eye, and appear as if they are coming from a point behind the mirror, but the light rays do not actually come from this point. So this image is called virtual image. In other words, if we cannot take an image on screen, it would be called a virtual image. A real image is formed by the actual intersection of rays and can be taken on a screen.

Images from a Plane Mirror

When an image is formed on a plane mirror, the image will be of the same size as the object. It will be far behind the mirror as the object is in front of it. It will be a virtual image and is laterally inverted means that if person is wearing a watch on his left hand, the watch appears to be an right hand of the image. When an object is placed between two inclined mirrors, several images of the object are formed. The number of images are as follows:

Number of images = (360÷angle) - 1

Here please note:

- ✓ If the mirrors are placed at parallel to each other , the images will be infinite in numbers, we can see in hair saloons.
- ✓ If the mirrors are placed at an angle of 90° with each other , 3 images will be produced.
- ✓ The more we decrease the angle between the two mirrors from 90°, the more will be number of images.
- ✓ At 60° the number of images is 5'
- ✓ At 30°, the number of images will be 11.

This concept is the principle of working of the Kaleidoscopes that operate on multiple reflection, several mirrors are attached together. The three mirrors if set at 45° from each other, creates eight duplicate images of the objects, six at 60°, and four at 90°.

Curved Mirrors

There are two types of curved spherical mirrors, concave and convex. Most curved mirrors have surfaces that are shaped like part of a sphere, but other shapes are sometimes used in optical devices. The most common non-spherical type are **parabolic reflectors**, found in optical devices such as reflecting telescopes that need to image distant objects, since spherical mirror systems suffer from spherical aberration.

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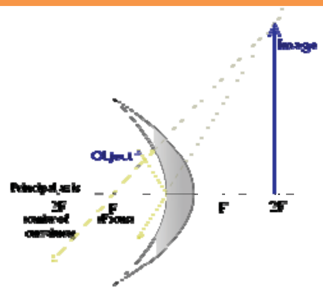
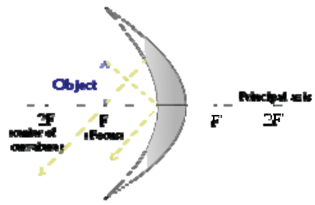
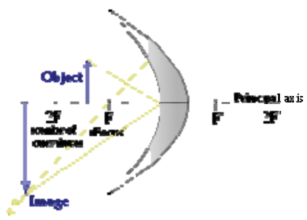
Deposition on the outside of the glass makes a concave (or converging) mirror, while deposition on the inside makes a convex (or diverging) mirror.

Concave Mirrors

When light falls on a concave mirror, it is reflected so as to converge to a point called the focus of mirror. Since a concave mirror can concentrate the sun's radiation falling on it at one point, it can be used as a **converging mirror**. This property makes the concave mirrors usable in the solar cookers.

The image formed by the concave mirrors is shown in the following table sourced from wikipedia.

Object's position (*S*), focal point (*F*)	Image	Diagram
$S < F$ (Object between focal point and mirror)	• Virtual • Upright • Magnified (larger)	
$S = F$ (Object at focal point)	• Reflected rays are parallel and never meet, so no image is formed. • In the limit where S approaches F, the image distance approaches infinity, and the image can be either real or virtual and either upright or inverted depending on whether S approaches F from above or below.	
$F < S < 2F$ (Object between focus and centre of curvature)	• Real • Inverted (vertically) • Magnified (larger)	

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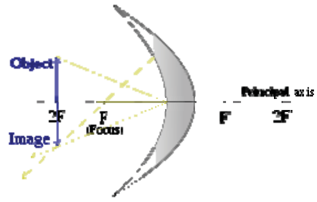
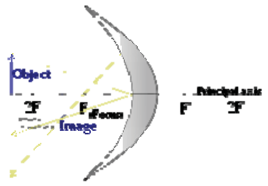
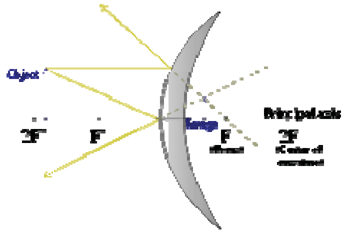
$S = 2F$ (Object at centre of curvature)	• Real • Inverted (vertically) • Same size • Image formed at centre of curvature	
$S > 2F$ (Object beyond centre of curvature)	• Real • Inverted (vertically) • Reduced (diminished/smaller)	

Convex Mirrors

A convex mirror always produces virtual images. These images are erect and smaller than the objects.

Object's position (*S*), focal point (*F*)	Image	Diagram
$S > F,\ S = F,\ S < F$	• Virtual • Upright • Reduced (diminished/smaller)	

Convex mirrors are very convenient for use as rear view mirrors in vehicles because they have the advantage of a wide field of view and a driver can see the entire traffic behind. A plane mirror used for the same purpose would have a narrower field of view.

Why rear view mirrors of two wheelers come with etched phrase "objects in the mirror are closer than they appear'?

Rear view mirrors employed in vehicles are generally convex in nature and so called the diverging mirrors. It diverges the light rays to produce virtual, diminished images. The distance of the virtual image from the mirror is less than the distance of the object from the mirror that is, in a convex mirror, the image distance is always less than the object distance and the image is virtual and diminished irrespective of the position of the object. This nature (virtual) of the image enables us to see the image on the mirror, which otherwise requires a screen to project the image, if it were real.

Refraction

A change in direction of a wave due to a change in its speed is called Refraction. This is most commonly observed when a wave passes from one medium to another at **any angle other than 90° or 0°**.

So, a ray of light bends when it passed obliquely from one medium to another. When a ray passes from one medium to another optically denser medium, e.g. from air to water or glass, it bends towards the normal. A

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ray passing from water or glass into air is bent away from the normal. Light that enters another medium along the normal, however, does not bend.

The explanation for the bending lies in the different speeds of light in media of different densities. The speed of light in vacuum, denoted by c, is nearly 3x10-8m/s. In air the speed of light is slightly (0.03%) less than c. the speed of light in water is nearly 0.75 c and is glass it is nearly 0.66c

The refractive (u) of a medium = $\frac{speed\ of\ light\ in\ vaccum}{speed\ of\ light\ in\ the\ meidum}$

Refraction is described by Snell's law, which states that the angle of incidence θ1 is related to the angle of refraction θ2 by

$$\frac{\sin\theta_1}{\sin\theta_2} = \frac{v_1}{v_2} = \frac{n_2}{n_1}$$

v1 and v2 are the wave velocities in the respective media, and n1 and n2 the refractive indices. In general, the incident wave is partially **refracted and partially reflected**.

Atmospheric refraction

Atmospheric refraction is the deviation of light due to the variation in air density as a function of altitude. The density of the atmosphere surrounding the earth decrease with increasing altitude. Thus if light enters the atmosphere from outside, it encounters layers of air of increasing density and , therefore, bends gradually producing a curved path.

- ✓ Atmospheric refraction causes astronomical **objects to appear higher in the sky** than they are in reality.
- ✓ It affects not only light rays but all electromagnetic radiation, although in varying degrees. Like light waves, radio waves are affected by the phenomena of reflection, refraction, diffraction, absorption, polarization and scattering.
- ✓ In the visible light, blue is more affected than red. This may cause astronomical objects to be spread out into a spectrum in high-resolution images.
- ✓ To avoid the errors due to refraction, the astronomers schedule their observations around the time of culmination of an object when it is highest in the sky.
- ✓ It is due to refraction, produced by the earth's atmosphere, that the sun is visible for several minutes after it has set below the horizon. Thus atmospheric refraction tends to lengthen the day.
- ✓ When the sun (or moon) is near the horizon, it appears elliptical i.e. with the vertical diameter less than the horizontal diameter. This happens because rays from the lower edge of the sun are bent more than those from the upper edge.
- ✓ Please note that amount of atmospheric refraction is a function of temperature and pressure as well as humidity. This is because the speed of light is a function of all these.
- ✓ Atmospheric refraction becomes more severe when the atmospheric refraction is not homogenous, when there is turbulence in the air .
- ✓ This is the cause of twinkling of the stars and deformation of the shape of the sun at sunset and sunrise.

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Mirage

Mirage is caused by **Total Internal Reflection and Refraction**. The air in the desert is hot near the ground and cool rapidly with height. The hotter air is optically less dense. Rays of light from the top of a tree (or the sky) suffer successive bending as they pass through the warmer layers of decreasing density. This results in the gradual increase of the angle of incidence. Eventually, a stage comes when the angle of incidence exceeds the critical angle and, therefore, total internal reflection takes place. After this the rays start bending upwards. An observer sees the three upside down (as well as the actual tree) as if he were seeing the reflection on a surface of water.

Total Internal Reflection

Total internal reflection happens when a ray of light 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, no light can pass through and all of the light is reflected. The critical angle is the angle of incidence above which the total internal reflection occurs.

When light crosses a boundary between materials with different refractive indices, the light beam will be partially refracted at the boundary surface, and partially reflected. However, if the angle of incidence is greater than the critical angle – the angle of incidence at which light is refracted such that it travels along the boundary – then the light will stop crossing the boundary altogether and instead be totally reflected back internally.

- ✓ This can only occur where light travels from a medium with a higher [n1=higher refractive index] to one with a lower refractive index [n2=lower refractive index].

For example, it will occur when passing from glass to air, but not when passing from air to glass.

Optical Fibers

In an optical fiber the light signal undergoes total internal reflection. The light hits the fibers at the glancing angle and is transmitted forward. They have different layers of glass protected in layers of buffers, namely, hard buffer, soft buffer, core glass, and cladding glass. The cladding glass has a low refractive index toward the core glass. When total internal reflection occurs the signal is transmitted. The soft and the hard buffer are protective coating which provide the necessary protection to the inner glass from external environments.

Please note that Optical communication employs a beam of **modulated monochromatic light** to carry information from transmitter to receiver. The light spectrum spans a tremendous range in the electromagnetic spectrum, i.e. extending from the region of (10^4 gigahertz to 10^9 gigahertz) covering the far infrared to visible to near ultraviolet.

Bundles of tiny optical fibers are used by doctors to see the inside of a patient's stomach via endoscopy. Light is piped down some of the fibers to illuminate the inside of the stomach and is reflected back along some other fibers. Today, optical fibers have largely replaced copper cables for telecommunication and networking. Optical fibers are being used because these are flexible and can be bundled as cables. It is especially advantageous for long-distance communications, because light propagates through the fibre with little attenuation compared to electrical cables. Also, each using a different wavelength of light.

Dispersion

White light consists of seven colors viz. violet, indigo, blue, green, yellow, orange, and red. Violet has the minimum wavelength (or maximum frequency) and red the maximum wavelength (or minimum frequency).

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In a vacuum, all these waves travel with the same speed but in a transparent medium they have different speeds. Violet travels the slowest through glass while red travels the fastest. Due to different speeds, the colours are refracted through different angles and, therefore, when a narrow beam of white light passes through a glass prism, it is split up into its constituent colors. Separation of light into colors is called dispersion.

Rainbow

Rainbow is the most spectacular illustration of **dispersion as well as Total Internal Reflection as well as Refraction**☺. When the sun shines soon after a shower of rain, a rainbow are due to the dispersion of sunlight by water droplets suspended in the air after rain. The droplets act like prisms. In each droplet there is dispersion as well as total internal reflection. A similar effect is produced by droplets of water from a fountain in sunlight.

Why is the rainbow arc -shaped?

The rainbow's appearance is caused by dispersion of sunlight as it is refracted by (approximately spherical) raindrops. The light is first refracted as it enters the surface of the raindrop, reflected off the back of the drop, and again refracted as it leaves the drop. The overall effect is that the incoming light is reflected back over a wide range of angles, with the most intense light at an angle of about 40-42 degrees. The different colors (wavelengths) of light have different refractive indices which cause them to bend unequally. Thus, a rainbow is arc-shaped.

Scattering of light

In Scattering, the radiation, such as light, sound, or moving particles, are forced to deviate from a straight trajectory by one or more localized non-uniformities in the medium through which they pass. So, scattering uses deviation of reflected radiation also from the angle predicted by the law of reflection.

- ✓ Reflections that undergo scattering are often called diffuse reflections
- ✓ Unscattered reflections are called specular (mirror-like) reflections

Bubbles, droplets, density fluctuations in fluids, crystallites in polycrystalline solids, defects in monocrystalline solids, surface roughness, cells in organisms, and textile fibers in clothing are examples of scattering. Scattering is useful in radar sensing, medical ultrasound, semiconductor wafer inspection, polymerization process monitoring, acoustic tiling, free-space communications, and computer-generated imagery.

Atmospheric Scattering

Scattering of light in atmosphere is due to the molecules of air. Thus when sunlight, consisting of seven colors, violet, indigo, blue, green, yellow, orange and red, enters the earth's atmosphere, it is scattered by the atmospheric molecules. Violet and blue and scattered the most followed by green, yellow, orange and red. Thus the scattered light is predominantly violet and blue. We see a blue sky because of this.

Red light is scattered the least and therefore, can transverse more atmosphere than any other colour.At dusk, the sun is lower in the sky and its light has to traverse a longer path through the atmosphere to reach an observer. So, at this time, blue, green, and other colors having been scattered, only red and some orange light us and the sun appears a deep orange-red.

We cannot see stars during the day because of the preponderance of the light scattered by the atmosphere. In outer space, i.e. beyond the atmosphere, there is nothing to scatter the sunlight and therefore the sky appears dark and stars are visible even in the presence of the sun.

Interference of light

The suspension of two or more waves of the same kind that pas the same point in space at the same time is called interference. If the waves are in the same phase, e.g. crest on crest, their amplitudes combine to produce a strong wave. This is called constructive interference. If the waves are out of phase, e.g. if crests of one are superposed on the troughs of another, we get destructive interference.

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This explains the rainbows in thin films. Light falling on thin films is reflected twice, once from the upper surface and once from the lower surface. Light rays from the two surfaces produce constructive and destructive interference thus produce interference patterns. Beautiful colours seen in soap bubbles and oil films on water are produced due to the **interference** of white light **reflected** by these surfaces.

Why we see rainbow in Compact Discs?

We have read in our previous modules that CD is an optical device whose surface is striped with a set of closely and uniformly spaced lines, such that **light is reflected by the gaps and absorbed by the lines.**

When light falls on a plane reflection grating, it is scattered in all directions by each of its reflecting stripes, thus giving rise to wavelets from each individual gap.

When we look at the grating from a distance, wavelets from different stripes travel different distances to reach the retina of our eye. Their crests or troughs do not reach a given point at the same time. Generally, crests of some wavelets and troughs of others reach a point. Troughs have the property of partially or totally nullifying crests and vice versa, depending on their strengths. In this case the wavelets are said to interfere destructively.

On certain orientations of the grating, it so happens that troughs (or crests) of all wavelets reach a point together, enhancing the effect of each other. The wavelets are then said to interfere constructively. Since the conditions of constructive interference hold good only for some particular wavelength, light intensity at the receiving point is exceptionally high only for that wavelength. Light from the grating from the related direction is thus rich in the corresponding colour. Similarly light from slightly different direction is rich in another colour. A CD has a data recording track, which spirals from its outer periphery to the inner circular boundary. This takes many thousands rounds about the CD's centre. When examined along a radius of the CD, it is found to have a structure similar to that of a reflection grating — a set of almost straight tracks running perpendicular to the radius and separated by gaps. Therefore, like a grating the CD also displays colors.

Holography

Holography is an illustration of interference. The Holograms are tools of recording and reproducing three-dimensional images. A laser beam partly reflected from an object and partly from a mirror produces interference fringes on a photographic plate, which then becomes a hologram. When laser light is transmitted through the hologram, one can see a three-dimensional virtual image of the object. Holograms are recorded using a flash of light that illuminates a scene and then imprints on film, much in the way a photograph is recorded. A hologram, however, requires a laser as the light source, since lasers can be precisely controlled and have a fixed wavelength; unlike white light, which contains many different wavelengths.

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