Heat and Geometric light

Dr. Mahmoud Ibrahim Al-Saman

For first year students

(Science)

PART ONE: THE HEAT

Concept of heat

According to heat definition, it is one of the essential forms of energy for the survival of life on earth. Transfer of heat takes place from one body to another due to differences in temperature as per thermodynamics. We use heat energy for various activities like cooking, ironing, transportation, recreation, etc. This form of energy also plays a vital role in nature. The occurrence of the wind, rain, change of seasons, etc., depends on the gradient created due to uneven heating of different regions. In this article, let us learn what is heat and its classification.

What is Heat?

With the increase in a body's temperature, molecules or atoms' vibrations increase. These vibrations are then transferred from one part of the body to another. The measure of energy with which the molecules vibrate in a system is termed as heat stored in that object.

As per the definition of heat, it is defined as the flow of energy from a warm to a cooler object. The direction of flow of the heat energy takes from the substance of higher temperature to the substance of lower temperature. This is because the molecules are vibrating faster and transfer their energy to the molecules vibrating slower. The vibrational energy is also termed as its heat content. The heat content in the body makes it hot or cold. Greater the heat content, the hotter the body will be.

A substance may absorb heat without an increase in temperature by changing from one physical state to another. In the process of melting, the substance is changed from solid to liquid. In the sublimation process, the solid is converted into a vapour state. In the process of boiling, the liquid is converted to vapour. Heat is a form of energy that can be converted into work. The amount of energy is expressed in units of work. It is expressed in joules, foot-pounds, kilowatt-hours, or calories.

Heat as a form of energy can be converted to other forms of energy. For example, in motorized vehicles, heat is converted to mechanical energy. In electric bulbs, it is converted to light energy. In thermal power plants, it is finally converted to electrical energy.

Classification of Heat

Heat can be classified as follows:

1- Hot

Objects with high heat content are defined as hot.

Examples of hot objects around us include the sun, fire, hot pans, air from a hairdryer, lava from volcanic eruptions, etc.

2- Cold

Objects with lower heat content are defined as cold objects..

Examples of cold objects around us include ice, air from an air conditioner, cold drinks, metal vessels kept in open on cold winter days etc.

Sources of Heat

There are many sources of heat, but the following are the main sources of heat:

- Sun
- Chemical
- Electrical
- Nuclear

TEMPERATURE

The concept of temperature has evolved from the common concepts of hot and cold. The scientific definition of temperature explains more than our senses of hot and cold. As you may have already learned, many physical quantities are defined solely in terms of how they are observed or measured, that is, they are defined *operationally*. **Temperature** is operationally defined as the quantity of what we measure with a thermometer. Differences in temperature maintain the transfer of heat, or *heat transfer*, throughout the universe. **Heat transfer** is the movement of energy from one place or material to another as a result of a difference in temperature. (You will learn more about heat transfer later in this chapter.)

Let us take three beakers, first with cold water, the second with hot and the third with water at normal temperature. If we dip our fingers in beaker 1 and then in beaker 3, we will observe that the water in beaker 3 is hot compared to that in beaker 1. Whereas, if we dip our fingers in beaker 2 and then in beaker 3, we will observe that the water in beaker 3 is colder as compared to that in beaker 2. This shows that we cannot rely on our sense of touch to judge the hotness or coldness of something, and that's why the degree of hotness or coldness of any object is measured in terms of temperature.

Temperature is the measure of hotness or coldness of the body. Celsius (C) or Fahrenheit (F) scale, or in Kelvins (K). Relations are established on the amount of heat added to taken out from the body.

THERMAL EQUILIBRIUM

An important concept related to temperature is **thermal equilibrium**. Two objects are in thermal equilibrium if they are in close contact that allows either to gain energy from the other, but nevertheless, no net energy is transferred between them. Even when not in contact, they are in thermal equilibrium if, when they are placed in contact, no net energy is transferred between them. If two objects remain in contact for a long time, they typically come to equilibrium. In other words, two objects in thermal equilibrium do not exchange energy.

Experimentally, if object *A* is in equilibrium with object *B*, and object *B* is in equilibrium with object *C*, then (as you may have already guessed) object *A* is in equilibrium with object *C*. That statement of transitivity is called the **zeroth law of thermodynamics**. (The number "zeroth" was suggested by British physicist Ralph

Fowler in the 1930s. The first, second, and third laws of thermodynamics were already named and numbered then. The zeroth law had seldom been stated, but it needs to be discussed before the others, so Fowler gave it a smaller number.) Consider the case where *A* is a thermometer. The zeroth law tells us that if *A* reads a certain temperature when in equilibrium with *B*, and it is then placed in contact with *C*, it will not exchange energy with *C*; therefore, its temperature reading will remain the same (Figure 1.2). In other words, *if two objects are in thermal equilibrium, they have the same temperature*.

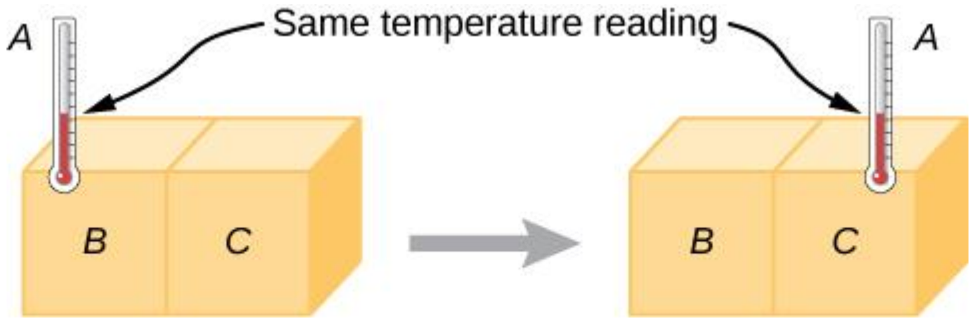


Figure 1.2 If thermometer *A* is in thermal equilibrium with object *B*, and *B* is in thermal equilibrium with *C*, then *A* is in thermal equilibrium with *C*. Therefore, the reading on *A* stays the same when *A* is moved over to make contact with *C*.

A thermometer measures its own temperature. It is through the concepts of thermal equilibrium and the zeroth law of thermodynamics that we can say that a thermometer measures the temperature of *something else*, and to make sense of the statement that two objects are at the same temperature.

Relationship between heat and temperature

Heat and temperature are two different but closely related concepts. Note that they have different units: temperature typically has units of degrees Celsius or Kelvin, and heat has units of energy, Joules. Temperature is a measure of the average kinetic energy of the atoms or molecules in the system. The water molecules in a cup of hot coffee have a higher average kinetic energy than the water molecules in a cup of iced tea, which also means they are moving at a higher velocity. Temperature is also an intensive property, which means that the temperature doesn't change no matter how much of a substance you have (as long as it is all at the same temperature!). This is why chemists can use the melting point to help identify a pure substance—minus the temperature at which it melts is a property of the substance with no dependence on the mass of a sample.

On an atomic level, the molecules in each object are constantly in motion and colliding with each other. Every time molecules collide, kinetic energy can be transferred. When the two systems are in contact, heat will be transferred through molecular collisions from the hotter system to the cooler system. The thermal energy will flow in that direction until the two objects are at the same temperature. When the two systems in contact are at the same temperature, we say they are in *thermal equilibrium.*

Difference between Heat and Temperature

Following is the table explaining heat vs temperature:

Parameter	**Heat**	**Temperature**
Definition	Heat is defined as the total energy of an object that has molecular motion inside it	Temperature is defined as the measure of the thermal energy of an object
SI Unit	Joule	Kelvin
Symbol	Q	T

Temperature gradual

The following temperature scales are in use or have historically been used for measuring temperature:

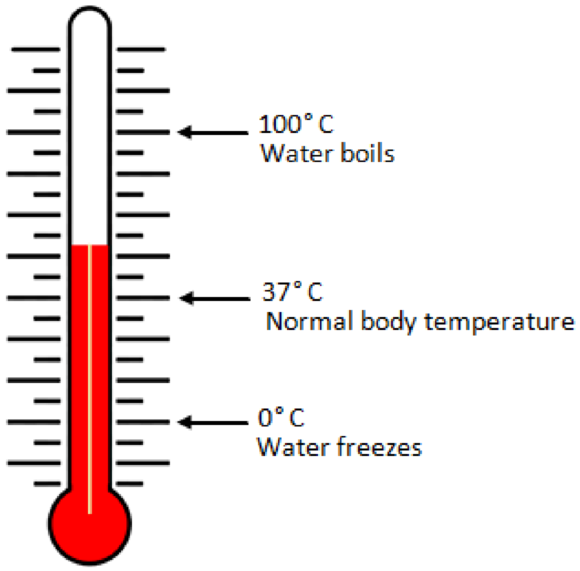
- Kelvin scale
- Celsius scale
- Fahrenheit scale

- Rankine scale
- Delisle scale
- Newton scale
- Réaumur scale
- Rømer scale

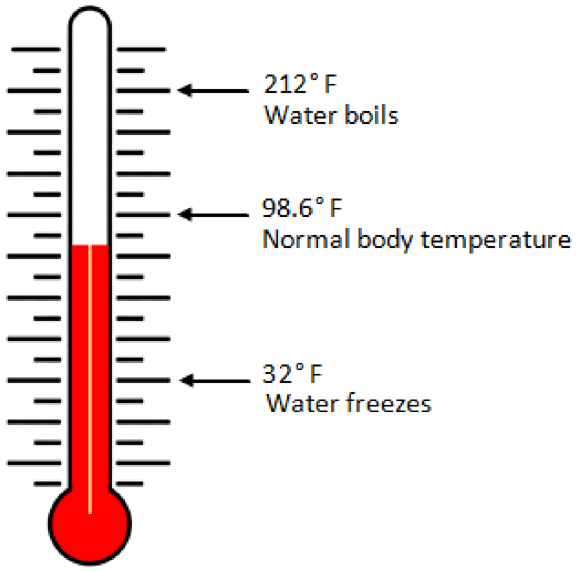
The Celsius Scale

The Celsius scale, also known as the centigrade scale, is a temperature scale based on 0^o for the freezing point of water and 100^o for the boiling point of water. This scale was first introduced by (and is named after) the Swedish physicist, astronomer, and engineer Anders Celsius. Initially, the celsius scale used 0^o in order to denote the boiling point of water and 100^o in order to denote freezing point of water. These values were later inverted to 0^o for the freezing point of water and 100^o for the boiling point of water. This form of the Celsius scale gained widespread use.

Celsius temperatures obey a system of relative scale or interval, rather than an absolute system of scale or ratio. Types of ratio scales include the ones used for calculating distance or weight. For example, when the mass is doubled (say from 10 kg to 20 kg), it is usually accompanied by an increase in volume, which accounts for twice the amount of matter. The increase in the amount of matter from 10 kg to 20 kg is the same as the increase in the amount of matter from 50 kg to 60 kg. However, it is important to note that the Celsius scale doesn’t work with heat energy in this manner. The disparity between 10 ^oC and 20 ^oC and that between 20 ^oC and 30 ^oC is 10 degrees because a temperature of 20 ^oC does not have two times the heat energy exerted by a temperature of 10 ^oC.



Celsius Thermometer



Fahrenheit Thermometer

The Fahrenheit scale,

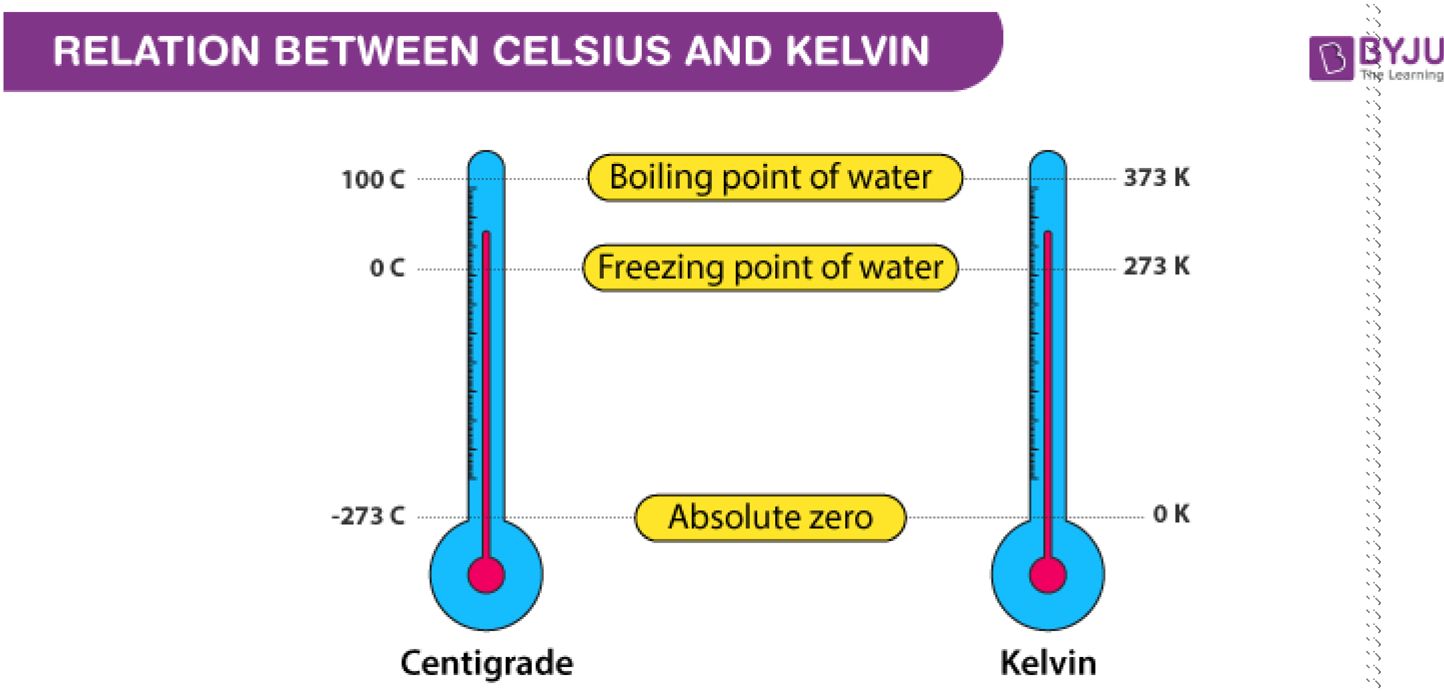
Scale based on 32° for the freezing point of water and 212° for the boiling point of water, the interval between the two being divided into 180 equal parts. The 18th-century German physicist Daniel Gabriel Fahrenheit originally took as the zero of his scale the temperature of an equal ice-salt mixture and selected the values of 30° and 90° for the freezing point of water and normal body temperature, respectively; these later were revised to 32° and 96°, but the final scale required an adjustment to 98.6° for the latter value.

The Fahrenheit temperature scale is used in the United States; the Celsius, or centigrade, scale is employed in most other countries and for scientific purposes worldwide. The conversion formula for a temperature that is expressed on the Celsius (°C) scale to its Fahrenheit (°F) representation is:

$$°F = ({}^{9}/_{5} \times °C) + 32.$$

Kelvin Scale

In 1848, Lord Kelvin defined an absolute temperature scale based on the Carnot cycle which was later named after him as Kelvin's absolute temperature scale. In Kelvin's scale, the zero point is 273.15 below that of the Celsius scale. The true origin of the universe, if it had one, remains a mystery for the present and likely will remain one far into the future.



Each division in the kelvin scale called a kelvin (K) is equal to a degree on the Celsius scale, but the difference is where zero is. In the Celsius scale 0^o is the freezing point of water while in the Kelvin scale the zero point is at absolute zero. Therefore, 0^oK is equal to -273.15^{o}C, 0^oC is equal to 273.15 kelvins. The Kelvin scale is used for very low or very high temperatures when water is not involved.

The kelvin scale of heat measurement differs from the centigrade and Fahrenheit scales in that it starts from absolute zero, the lowest possible temperature. In which there is no energy whatsoever present. The centigrade scale assigns 0^o to the temperature at which water freezes and 100^o to the temperature at which it boils, while in the Fahrenheit scale water freezes at 32^o and boils at 212^o. The Kelvin scale otherwise follows the centigrade scale. Absolute zero is -273.15^{o}C and -459.67^{o}F, water freezes at 273.15^{o}K and boils at 373.15^{o}K

Kelvin Scale Formula

A mathematical equation that gives the relationship between the Celsius and Kelvin scales:

$$K = °C + 273$$

TYPES OF THERMOMETERS AND THEIR USES

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

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

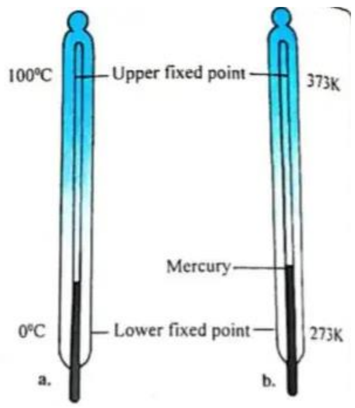
Types of thermometer

Type of thermometer	Thermometric substance	Physical property
Liquid-in-glass-thermometer	Mercury or Alcohol	Change in volume of liquid with temperature
Gas thermometer	Gas	Change of gas pressure at constant volume with temperature

Resistance thermometer	Resistance wire	Change in the electrical resistance of wire with temperature
thermocouple	Two dissimilar metals (e.g. copper and constantan)	Change in electric potential difference (or current) between two metal junctions at different temperatures
Bimetallic thermometer	Two dissimilar metals (e.g. iron and copper)	The differential expansion of the two metals of the bimetallic strip

Liquid -in-Glass Thermometer

The most common liquids used in thermometers are mercury and alcohol. The thermometer measures temperature by measuring the change in volume of a fixed mass of liquid due to a change in temperature.



For high sensitivity, liquid-in-glass thermometer should have

- A bulb is made of thin glass; this enables the liquid in the bulb to assume the temperature of its surrounding quickly

- A narrow capillary tube with a uniform bore. This makes it possible for small temperature changes to cause large changes in the length of the mercury column.
- A liquid with a high expansivity To be used as a thermometric liquid, such as a liquid should

    1- Expand or contract uniformly with temperature
    2- Have a high boiling point and a low melting point
    3- Be easily seen in a glass

- Water has none of the above properties. It has a small range of expansion; it freezes at 0 degrees and boils at 100 degrees. It does not expand uniformly (it also contracts from 0 degrees to 4 degrees). It wets glass and is colourless, making the meniscus in glass difficult to read. The above reasons make water unsuitable as a thermometric liquid.

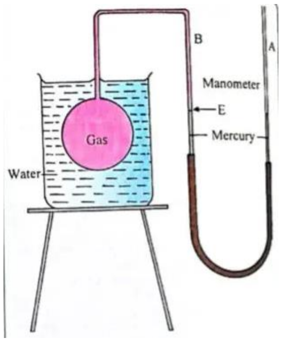
- Mercury-in-glass thermometers are more commonly used in school laboratories and hospitals than Alcohol-in-glass. Mercury-in-glass thermometer is cheap and simple, but it is not reliable enough for accurate work.

Clinical Thermometer

- This is a form of mercury-in-glass thermometer used in the hospital for measuring the temperature of the human body. The temperature of a normal healthy person is about 37 degrees Celsius but it may rise to about 41 degrees in case of high fever. The temperature range of the clinical thermometer is therefore between 35 degrees to 43 degrees Celsius.

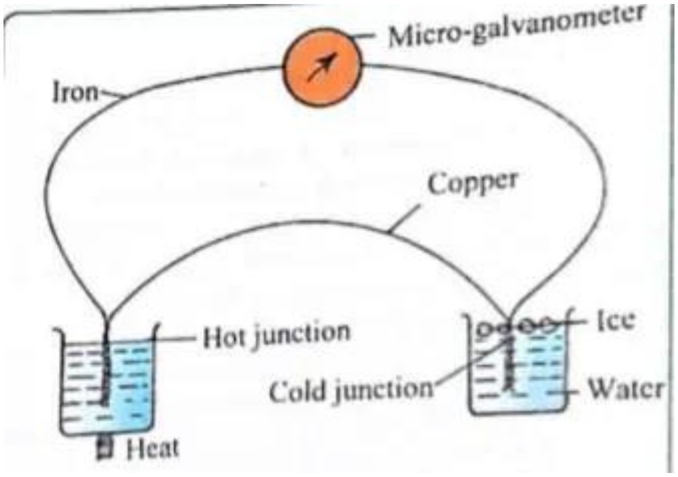
The Gas Thermometers

Gas thermometers are therefore used for accurate temperature measurements. The principle of the gas thermometer is based on the fact that at constant volume, the pressure of a gas increases linearly with an increase in temperature. A constant volume gas thermometer consists of a large bulb which contains a gas (e.g hydrogen or helium). The bulb is connected to a narrow glass tube attached to a mercury manometer.



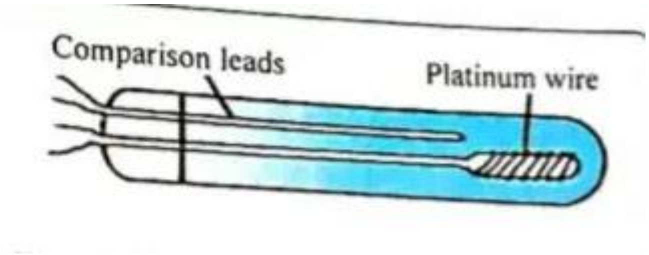
Thermoelectric Thermometer

These thermometers are used for measuring very high temperatures. They work on the principle of the thermocouple. When two different metals (e.g copper and constantan) are joined at the ends and one end (the hot junction) is heated, while the other end (the cold junction) is kept constant in melting the ice, an electric current flows along the metals. This is the thermoelectric effect and setup is called a thermocouple.



Resistance Thermometer

This is one of the types of thermometer and it uses the fact that the electrical resistance of a metallic conductor changes proportionally with its temperature. The higher the temperature the greater is the resistance. It consists of a long thin platinum wire wound round a small spool made of mica or silica. Resistance thermometers are useful in the accurate measurement of very low or very high temperatures.



Digital thermometers:

Digital thermometers measure temperature with an electronic sensor and display the results on a digital screen. They are often used for medical purposes to take the body temperatures of humans and animals. They are easy to use, quick, affordable, and precise. The dangerousness of mercury is one large motive for why digital thermometers are now commonly used instead of clinical ones. As a result, people now use digital thermometers rather than old-school mercury ones.

Different Uses of Thermometer:

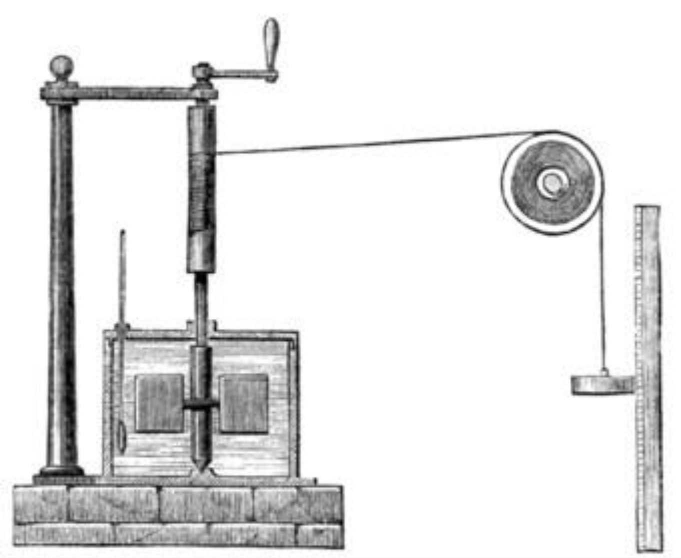
You can use this device in various medical, industrial, and scientific applications. Here are a few examples:

- Thermometers are used in the home to check food safety, cooking, and room temperatures. Digital thermometers can also measure body temperature for colds or fevers.
- Thermometers in the laboratory are used to measure various temperatures in experiments and monitor changes during chemical reactions. You can also use them to calibrate other instruments or devices. Marking the temperature of a solution during titration is another common use.
- Thermometers can be used in automobiles to measure engine temperature and cooling system performance. They are also commonly found on the dashboard of a car, so drivers can monitor the outside temperature when traveling.
- Industrial thermometers are used for various applications, such as monitoring temperatures in production processes and testing the quality of products to verify safety standards. They are also used to measure ambient temperatures in industrial settings.

- In restaurants and other food preparation establishments, thermometers are used to measure the temperatures of cooked food or ingredients to ensure proper storage conditions and food safety.

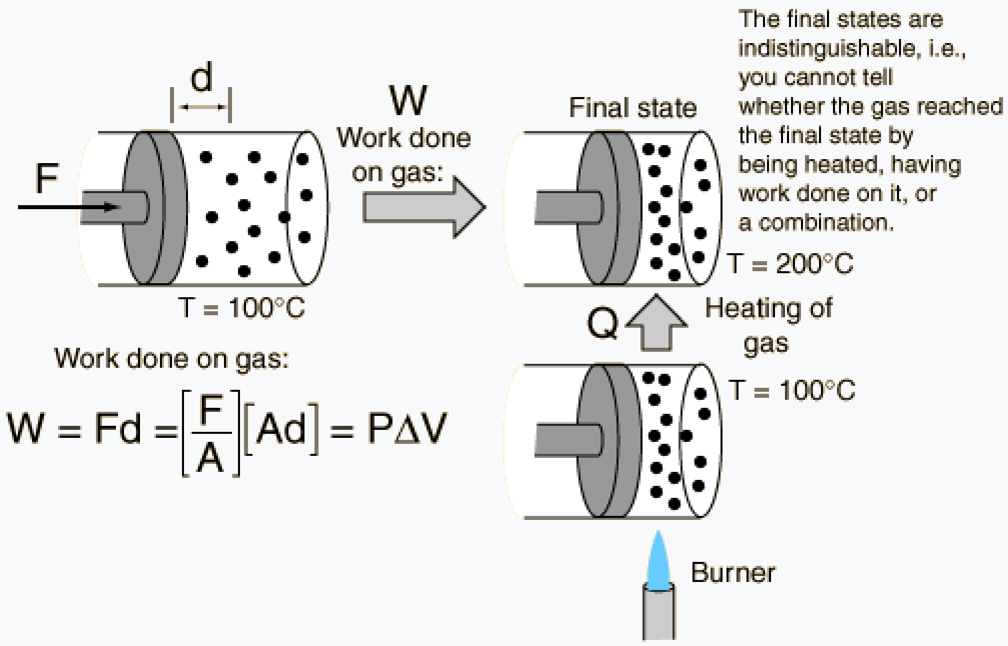
Overall, understanding how to use different types of thermometers is essential to accurately measure temperature and maintain safety standards. Thermometers provide an invaluable tool in everyday life and a variety of settings.

Mechanical equivalent of heat



James Joule's famous experiment which demonstrated the mechanical equivalence of heat

Mechanical energy can be converted into heat, and heat can be converted into some mechanical energy. This important physical observation is known as the **mechanical equivalent of heat**. This means one can change the internal energy of a system by either doing work to the system, or adding heat to the system. This concept is fundamental to thermodynamics which applies the ideas of heat and work in order to create useful systems such as engines, power plants, and refrigerators. This equivalence of heat and motion was tested in a classic experiment by James Joule in 1843, who used the change in potential energy of falling masses to stir water. The water increased in temperature, much like it would when put over a flame. This showed that the downward motion of the masses which caused the water to be stirred (a form of mechanical motion) could in fact be equated to an increase in water temperature—or an increase in the heat, This idea of work and heat equivalence is stated in the First law of thermodynamics, which says that **the change in internal energy of a system is the sum of the work done and the heat added to any system**. From this, if a system is observed at any state, it is impossible to tell whether it reached this state from an input of work, an input of heat, or a combination of the two. This is shown in Figure 2 below.



It is impossible to distinguish between work and heat when observing the final state of a system

Mechanical energy is the sum of **kinetic energy and potential energy within a system.** For systems that only have conservative forces (no non-conservative forces, like friction, to cause energy to be turned into thermal energy), the mechanical energy stays the same. When non-conservative forces are present, mechanical energy tends to decrease. In the case of friction, this is because the mechanical energy was converted into thermal energy (making the system warmer

Thermal energy: The **thermal energy** of an object **is the energy contained in the motion and vibration of its molecules.** Thermal energy is measured through temperature

The energy contained in the small motions of the object's molecules can be broken up into a combination of microscopic kinetic energy and potential energy. The total energy of an object is equal to:

$$E_T=E_K+E_P$$

- E_T is the total energy in an object.
- E_K is the kinetic energy of an object.
- E_P is the potential energy of an object.

Temperature is a direct measurement of thermal energy, meaning that the hotter an object is, and the more thermal energy it has. Heat is a measure of how much thermal energy is transferred between two systems. It is easy to turn mechanical energy into thermal energy, for example using friction. It's also possible to turn thermal energy into mechanical energy by using a heat engine, but there will always be waste heat with this method.

Specific heat

The specific heat of a substance is **the amount of energy required to raise the temperature of one kilogram of that substance by one degree Kelvin** (or Celsius,).

Latent heat (Enthalpy)

The latent heat of a substance is **the heat required for an object to change states**, also called a phase change. Generally speaking, values for latent heats are much higher than those for specific heat. This is also referred to as enthalpy.

Ice and water have enormous latent heats associated with them, which is why snow takes so long to melt and water is used for cooking. This is also important in keeping our planet comfortable to live on, and provides a fair amount of resistance to climate change.

Energy conversion technology

Energy conversion technology refers to any system that converts energy from one to another. Energy comes in different forms, including heat, work and motion. Moreover, potential energy can be in the form of nuclear, chemical, elastic, gravitational, or radiant energy (also known as light). All of these can be converted into useful energy, with the one of the most common and versatile forms being electricity.

The main goal of power plants is to take a fuel like coal, natural gas or uranium, and transform it into electricity. This makes power plants an energy conversion technology, and they are the largest energy conversion technologies by far. Other conversion technologies include cars, batteries, heaters and generators. Power plants have to make use of many energy conversions in order to get to the final goal—electricity. A coal plant provides a good example:

1. Chemical energy is stored in the hydrocarbon molecules in the coal. When the coal is combusted, this chemical energy is transformed into heat. **(Chemical energy → Heat)**
2. The hot exhaust gases from the combustion reaction is used to heat up water into steam, which travels through pipes at high pressures and speeds.**(Heat → Heat)**
3. The steam then expands through a turbine, producing mechanical energy of motion. **(Heat → Motion)**
4. The motion of the turbine spins an electrical generator, which causes electricity to flow. **(Motion → Electricity)**

In fact our own bodies are extremely complex conversion technologies. They take chemical energy from food and convert that into different forms of chemical energy that we need in order to operate. Our body can then use this energy to convert into many other forms: Heat, movement, sound, gravitational potential energy, and more.

More examples

- Heat engines (Chemical energy → Heat → Mechanical energy)
- Fire (Chemical energy → Heat and light)
- Electric circuit with a battery (Chemical energy → Electricity → an energy service like light)

- Wind turbines (Motion of wind → Electricity)
- Cell phones (Sound ↔ Electricity ↔ Electromagnetic radiation)

Heat

Heat is a transfer of thermal energy caused by a difference in temperature. This temperature difference is also called a temperature gradient. Since heat is a movement of energy, it is measured in the same units as energy: joules (J). It should also be noted that work and heat are closely related (see heat vs work for more information). Both can change the temperature of a substance, and heat can be turned into work (not perfectly) and work can be turned into heat. This equivalence is the basis of how heat engines power modern society.

The second law of thermodynamics explains why heat will always flow spontaneously from higher temperatures to lower temperatures. This energy flow can be harnessed by a heat engine to do useful work. Heat pumps can also force thermal energy to flow backward (from cold to hot), but these require energy input.

Methods of heat transfer

There are three heat transfer mechanisms:

- **Conduction** occurs between objects that are touching each other. Collisions between small particles allow fast-moving or vibrating particles to give some of their microscopic kinetic energy to slower particles.

- **Convection** is heat transfer caused by moving fluids. In a fluid, particles can mix together, move faster, and spread out, thus distributing their thermal energy. Warm air coming from a heating vent to flow around a cool room is an example of convection.

- **Radiation** occurs without the movement of matter. Thermal radiation is made of electromagnetic waves given off by moving particles.[4] These waves can also be absorbed by materials. Microwave ovens work by radiation and the entire surface of the Earth is heated by the sun's solar radiation.

Work

Work is the transfer of mechanical energy from one object to another. Since work is a movement of energy, it is measured in the same units as energy: joules (J). The definition of work in a physics context is quite different from how it is used in a person's daily life and is as follows:

Work is done when a force is applied to an object through a distance.

This means that when a force is applied to an object through a distance, the object's total energy will be affected. The object will either speed up or slow down, resulting in a change in its kinetic energy (seen in Figure), or it will have an altered potential energy if, for example, it was lifted a certain height under the force of gravity.

A pitcher does work on a baseball in order to increase its kinetic energy. His arm goes back as far as possible and then as forward as possible in order to maximize the distance the force was applied.

Work also extends beyond what a person can physically see. It can also affect the microscopic properties of a system, such as temperature. In 1843 this idea began to be explored by scientists, and its results led to the formulation of what is now known as thermodynamics. Doing work on a system can affect its internal energy, just like adding heat can. However, the two processes are fundamentally different, and can be explored on the heat vs work page.

All of the cases described so far of how work can affect a system can be summed up in a single equation:[1]

$$W=\Delta K+\Delta U+\Delta E_{th}$$

This equation says that work (W) can change (Δ) a system's kinetic energy (K), potential energy (U), thermal energy (E_{th}), or any combination of the three.

The actual work done can be calculated using the following formula:

$$W=\vec{F}\cdot\vec{d}\quad W=F\rightarrow\cdot d\rightarrow$$

Where

- W is work, or a change in mechanical energy, measured in joules (J)
- F is force measured in newtons (N)
- d is displacement of the object

The arrows above force and displacement indicate that they are vectors. This means that they have an associated direction with them, which have important implications for how much work is done to an object. If both directions are the same, as they are in Figure 1, the system's energy will increase meaning positive work was done. If the directions are opposite, such as the force applied by friction and air drag to a moving car, the system's energy will decrease resulting in negative work done.

In the physics sense, work is never something an object has. It is only something that one object does to another. Work changes the amount of mechanical and internal energy possessed by objects. When work is done **on** a system or object, energy is added to it. When work is done **by** a system or object, it gives some of its energy to something else.

Throwing a ball means a hand applies a force as an arm swings forward. By applying a force on the ball over this distance, the hand is doing work on the ball, and the ball gains kinetic energy. This is what gives it speed.

The mathematical relationships between total work and total energy are described by the work-energy theorem and conservation of energy. Simple machines can change the amount of force that is necessary to move an object, but the force must be applied through a larger distance; they don't change the amount of work done.

Pressure volume diagram

The **PV diagram** models the relationship between pressure (P) and volume (V) for an ideal gas. An ideal gas is one that never condenses regardless of the various changes its state variables (pressure, volume, temperature) undergo. [1] In addition, the processes plotted on PV diagrams only work for a closed system (in this case the ideal gas), so there is no exchange of matter, but still an exchange of energy.

Pressure and volume exhibit a causal relationship, meaning that the change of one variable will cause the change in the other. To understand how pressure directly affects volume (and vice versa)—imagine a sealed container, containing an ideal gas (the system), that has a moving piston. If a force is applied, the piston moves down, and the gas would compress—decreasing the volume in the system and causing an increase in pressure. Moreover, if the piston moves up, the volume of the system would increase, decreasing the pressure of the system. Therefore, an increase in one variable will cause the decrease in the other, and vice versa. However, if an increase (or decrease) in pressure and/or volume is desired, an external heat source (or a cooling source) from its surroundings must be added.

In addition, these diagrams not only model the relationship between pressure and volume for an ideal gas, but can also be used to calculate work done (on or by the system). This is done by calculating the *negative of the area under the curve* which can be done geometrically or by integration.[1] The general formula to calculate work done by an ideal gas is the integral:[1]

where:

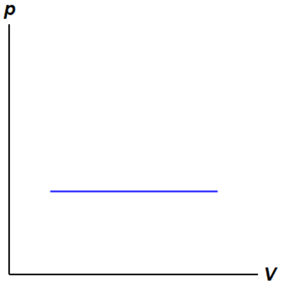
means that work is being done *on the system* (compression)

means that work is being done *by the system* (expansion)

no work is done (isochoric process—see figure below)

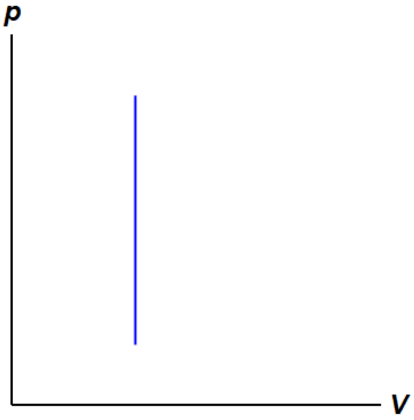
The fundamental thermodynamic processes modelled on PV diagrams (isochoric, isobaric, and isothermal processes) all follow the ideal gas law except for adiabatic processes—which will be discussed in detail on its main page. The following are the examples of each process modelled on the PV diagram. Each of their pages will describe their unique characteristics in detail:

- **Four main ideal gas law processes modelled on PV diagrams**

- 

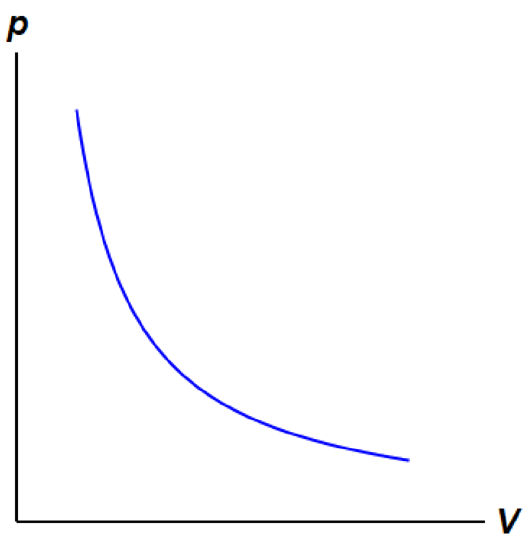
Isobaric Process:

Are occurrences when the volume of the system is changing (induced by external heating or cooling sources) but pressure is kept constant

- 

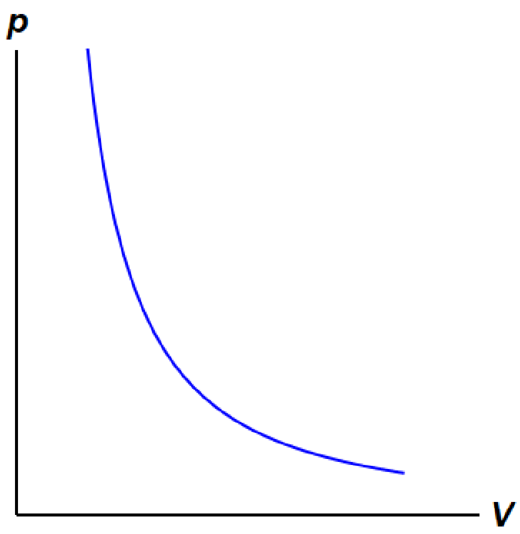
Isochoric Process:

This models a system where the volume stays constant (ex. locking the piston in place) but pressure is changing. This will require an external heating/cooling source to increase/decrease pressure. [3]



Isothermal Process:

This diagram is showing an ideal gas exhibiting constant temperature. This is possible because *heat is being exchanged* with its surroundings.[4]



Adiabatic Process:

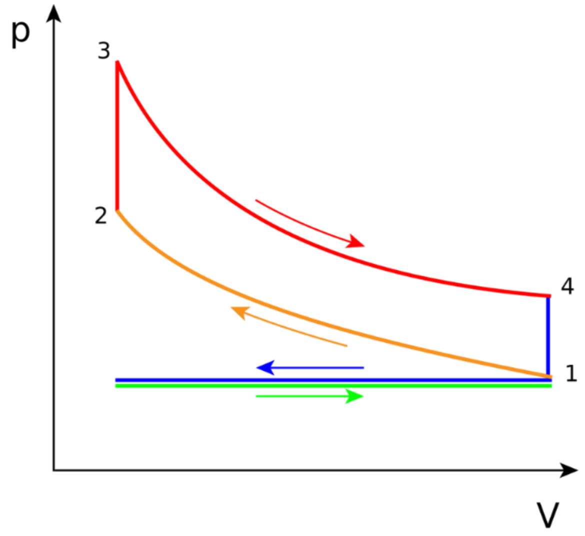
Similar to an isothermal process at first glance, adiabats represent an ideal gas exhibiting a change in temperature, because there is *no heat exchange* between the system and surroundings. The purple line represents an adiabat, while the dashed line (--) are isotherms. [5]

Applications of the PV diagram

The various processes seen above can be combined to create cycles found in most internal and external combustion engines. These diagrams are showing how pistons in engines (powered by fuel) or the various processes in a power plant, change the volume and pressure of a working fluid (ex. steam water for turbines, fuel-air mixture for engines) to create work. Then this work can be used to create electricity or move a vehicle. The work done would be calculated by finding the area inside the closed cycle (ex. the yellow shaded area of the Rankine cycle below).

The following are the main cycles used in various power plants and transportation mechanisms:

- **Four common PV cycles**



<u>Otto cycle</u>:
This is used in some automobiles and machines that use gasoline as fuel.

Effect of temperature change on the material

Internal energy: All kinds of energies that atoms or molecules can possess. Such as kinetic energy, vibration, nuclear, chemical and other

Thermal energy: If the energy goes from a high temperature body (the energy is vibrating to high atoms) to a low temperature body) the energy is vibrating to lower atoms (and the result of the temperature difference between them is called this is with thermal energy.

The thermal expansion of solids, liquids

Solids

For many solids, expansion is directly proportional to temperature change.

$$\Delta\ell = \alpha\ell_0\Delta T$$

Areas expand twice as much as lengths do.

$$\Delta A = 2\alpha A_0\Delta T$$

Volumes expand three times as much as lengths do.

$$\Delta V = 3\alpha V_0\Delta T$$

Applications

- buckling
- expansion gap/joint
- anti-scalding valve
- bimetallic strip, thermostat
- expansion of holes (mounting train tires)
- "What's more, the aircraft expands by 15-25 centimeters during flight because of the scorching heat created by friction with air. Designers used rollers to isolate the cabin from the body, so that stretching doesn't rip the plane apart

- "Concorde measures 204ft in length - stretching between six and ten inches in-flight due to heating of the airframe. She is painted in a specially developed white paint to accommodate these changes and to dissipate the heat generated by supersonic flight." source
- Thermal expansion is a small, but not always insignificant effect. Typical coefficients are measured in parts per million per kelvin (10^{-6}/K). That means your typical classroom meter stick never varies in length by more than a 100 μm in its entire lifetime — probably never more than 10 μm while students are using it.

Liquids

Liquids can only expand in volume.

$\Delta V = \beta V_0 \Delta T$

Liquids have higher expansivities than solids.

$\beta \sim 10^{-3}$/K, $3\alpha \sim 10^{-5}$/K

applications

- Liquid in glass thermometer. The alcohol is colored red to look like wine.

  ethyl alcohol 1120×10^{-6}/K
  mercury 181×10^{-6}/K
  glass $3(8.5 \times 10^{-6}\text{/K}) = 25.5 \times 10^{-6}$/K

- Cars have coolant overflow tanks.

1. **Describe qualitatively the thermal expansion of solids, liquids and gases.**
   When matter is heated, its particles gain energy, which is exerted as kinetic energy.

In solids, the particles vibrate harder and faster, creating more space between the particles, causing them to expand. This is most visible in metals. This process is thermal expansion.

In liquids, the particles move around faster, weakening the intermolecular forces of attractions, and are thus held less closely together. The liquid expands. If you want, you can test this out yourself, by measuring and comparing the volume of the same mass of water, before and after heating. A common example is the traditional thermometer – as the bulb of the thermometer heats up, the heat is conducted to the liquid. This causes the liquid to expand, forcing it to rise up the thermometer.

In gases, particles move faster as they are heated. If they are heated under constant pressure, the gas particles collide harder with the container surfaces, forcing them out, and allowing the gas to expand. This can be seen when warming the gas in a gas syringe.

If gases are heated at a constant volume, however, they do not expand – the gas pressure simply increases.

Note that the cooling down of substances tends to have the opposite effect – the particles lose kinetic energy, come closer together, and thus contract.

2. **Explain in terms of motion and arrangement of molecules the relative order of magnitude of the expansion of solids, liquids and gases.**
When considering thermal expansion, gases expand the most, followed by liquids, and solids expand the least. This is because gases have the weakest intermolecular forces of attraction, allowing their molecules to move the furthest apart, and solids have the strongest intermolecular forces, limiting the range of motion of the particles.

3. **Identify and explain some of the everyday applications and consequences of thermal expansion.**

- We often use hot water to warm up the lid of a jar. This expands the lid (metals expand more than glass), making it easier to remove.
- Liquid in thermometers expand and contract as the temperature changes. The volume of the liquid at a given temperature is how we read the temperature off of a thermometer.
- Overhead cables have to be slack so that on cold days when they contract, they won't snap or detach.
- Expansion joints – these are found on most large bridges. They look like two metal combs, their teeth interlocking, and have small gaps between each other. When heat causes the bridge to expand, the two sides of the expansion joint move towards each other. As the temperature cools, they gradually retract. This gives the bridge room for expansion and contraction, preventing the cracking/ deformation of the bridge. The expansion joints have interlocking 'teeth' because this minimizes the bump that motorcyclists feel as they ride over it. Thermostats are devices used to adjust the temperature of a heating or cooling system.

  In order to understand how they work, you'll need to know a little about expansion coefficients. Thermal expansion is expressed, in numbers, as the change in length, area, or volume per unit temperature change. For wires, as the cross-sectional area is often tiny and thus negligible, we don't have to concern ourselves with calculating the area or volume change – we can just measure the change in length of the wire per unit temperature change. This value would be the coefficient of linear expansion, For sheets, such as metal sheets, its thickness is negligible when compared to its area, so we don't have to calculate its volume change. We normally use the change in area per unit temperature. This is the coefficient of superficial expansion. For other substances, like materials in 3D shapes, or liquids or gases, we use the coefficient of cubical expansion. This is the change in area per unit temperature change.

  Bimetal thermostats have a bimetallic strip. This is a strip in which there are two metals, with different coefficients of linear expansion, placed side by side. Therefore, when the strips warm up, one of the metals linearly expand more than the other, causing the bimetallic strip to bend. When it becomes hot enough, the strip bends enough to close the circuit, and the air conditioner turns on, cooling down the room. Once the room has reached the desired temperature, the strip slowly unbends, opening the circuit and turning off the air conditioner. The same mechanism can be used for heaters – when it is warm, the strip bends away from the circuit, and is it grows colder, the strip straightens out until it closes the circuit and the heater can turn on again. When you adjust the temperature on a thermostat, you're adjusting how far the bimetal strip has to bend/ straighten out to close the gap.

Describe qualitatively the effect of a change of temperature on the volume of a gas at constant pressure.

This has already been explained in point 1. As the temperature increases, the gas molecules gain kinetic energy and move faster. This causes them to collide with the container surfaces harder, forcing the surfaces outwards and allowing the gas to expand. In other words, at constant pressure, the volume is directly proportional to the temperature in Kelvin (K).In formula form,

$$PV/T = k;$$

Where P is the pressure in Pascals (Pa), V is the volume in m^3, T is the temperature in Kelvin (K), and k is a constant.

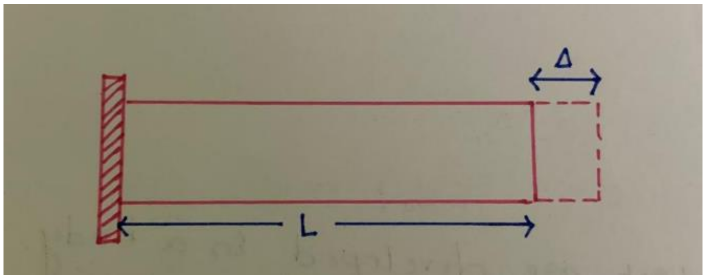
If we rearrange the formula to PV = kT, it becomes apparent that as T increases so does V.

Thermal stress

Thermal stress is the stress induced in a body when that body undergoes temperature changes,i.e when a body expands due to a rise in temperature or contracts due to falling in temperature. Thermal stress is highly dependent on the coefficient of thermal expansion (α) of the material of which the body is made. The greater the coefficient of thermal expansion (α) is, the more will the expansion and vice-versa.

Suppose a bar that is free to expand. Consider the below figure; assume the cross-sectional area A, length of bar L, and coefficient of thermal expansion is ‘α’. ‘t’ is the change in temperature

Δ is the free thermal expansion



Free thermal expansion for the above case is given by

$$\Delta = L\alpha t$$

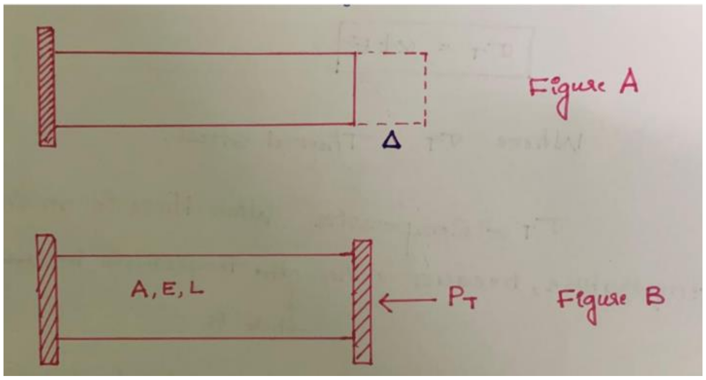
If the temperature is reducing then there will be a contraction given by

$$\Delta = L\alpha t$$

In this particular condition, no thermal stress is developed as there is no restriction for expansion or contraction. Stress is developed only when there is restriction or resistance to free motion.

Thermal Stress in Simple Bars

Case 1: When boundaries are fixed- Consider Figure A, as there is no restriction for expansion or contraction when there is a change in temperature, the thermal stress developed is zero and the free expansion is Lαt. Also Consider Figure B, as both ends are fixed, free movement is not possible when there is a change in temperature, this leads to the development of thermal stress in the body.



Deformation due to force P_T= P_TL/AE

Deformation due to force P_T= Δ

$$P_TL/AE=L\alpha t$$

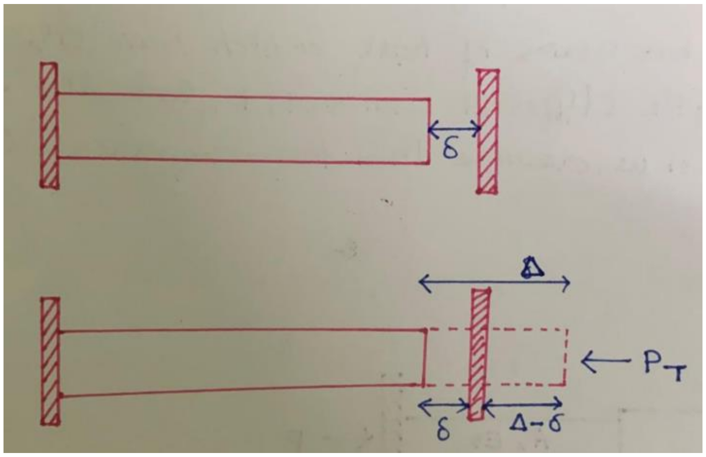
$$\sigma_T=\alpha tE$$

where σ_T = Thermal Stress

σ_T is compressive stress when there is an increase in temperature because when there is a temperature rise, the body tries to expand but boundaries will try to keep it in its original position, so the thermal forces will be compressive.

σ_T is tensile when there is a decrease in temperature because when there is a temperature drop, the body tries to contract, but the boundaries will try to keep it in its original position, so the thermal forces will be tensile.

Case 2: Thermal Stress when Support Yield



Free Expansion =Lαt

Net Deformation = Δ – δ (where δ is the support yield or gap)

Net Deformation = Lαt – δ

Deformation due to force P_T= P_TL/AE

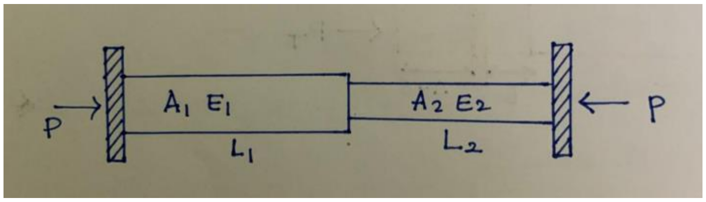
Deformation due to force P_T = Net Deformation

$$L\alpha t - \delta = P_T L/AE$$

$$L\alpha t - \delta = \sigma_T L/E$$

Thermal Stress in Varying Cross-Section

Consider a series of bars that have different cross-section areas and different lengths, different materials, to find the stress in different bars. Let us assume that the temperature is increasing. When there is an increase in temperature, the bars will try to expand, but the boundaries will restrict the expansion by exerting force (P).

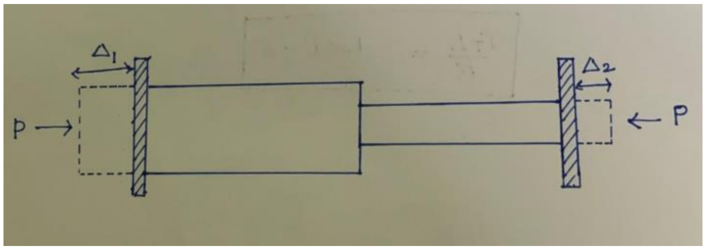


The force in both bars is the same.

$$(\text{Force})_1 = (\text{Force})_2$$

$$\sigma_1 A_1 = \sigma_2 A_2$$

$$\sigma_1 = \sigma_2 A_2 A_1$$



$$\text{Free Expansion} = \Delta = \Delta_1 + \Delta_2$$

$$= L_1\alpha_1 t + L_2\alpha_2 t$$

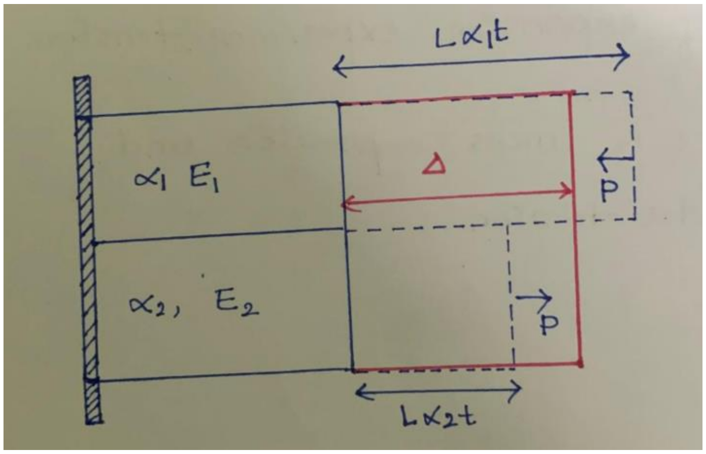
$$\text{Deformation due to force } P = PL_1/A_1E_1 + PL_2/A_2E_2$$

$$\text{Deformation in bars due to } P = \text{Free Expansion}$$

$$PL_1/A_1E_1 + PL_2/A_2E_2 = L_1\alpha_1 t + L_2\alpha_2 t$$

$$\sigma_1 L_1/E_1 + \sigma_2 L_2/E_2 = (L_1\alpha_1 + L_2\alpha_2)t$$

Thermal Stress in Composite Bars



Composite bars are the bars in which there will be bars of different materials whose coefficient of thermal expansion is different and are clubbed together so that they act as a single unit and there will be the same explanation in both bars. As both bars act as a single unit, the deformation in both bars will be the same. Thermal stress in composite bars can be given by the following formula:-

$$P = \left[\frac{A_1 A_2 E_1 E_2}{A_1 E_1 + A_2 E_2}\right]\left(\alpha_1 - \alpha_2\right)t$$

Thermal Stress Problems

1. A steel rail is 13m long and is laid at a temperature of 25ºC. The maximum temperature is expected to be 45ºC. Given, E = 2 x 105 N/mm2, α = 12 x 10-6 /ºC. Estimate the minimum gap to be left between the rails so that the temperature stress doesn't develop.

Solution: Given, E = 2 x 105 N/mm^{2}, α = 12 x 10^{-6} /ºC

T = 45º– 25º= 20ºC

We know that, δ = αtL

= 12 x 10^{-6}x 20 x 13000

= 3.12mm

Temperature stress won't get developed if the minimum gap left on the rails is equal to free expansion.

2. A steel rod is firmly held between two rigid supports as shown. Find the stress developed in the two portions of the rod, when it is heated through 20ºC. Given Given, E = 2 x 10^{5} N/mm^{2}, α = 12 x 10^{-6} /ºC.

Solution: We know that,

$\sigma_1 A_1 = \sigma_2 A_2$

$\sigma_1 \times 400 = \sigma_2 \times 500$

$\sigma_1 = 1.252\sigma_2$

$\sigma_1 L_1/E_1 + \sigma_2 L_2/E_2 = \alpha L t$

$= 12 \times 10^{-6} \times 1100 \times 20$

$\sigma_1 = 43.1$ MPa

$\sigma_2 = 53.87$ MPa

3. A bimetallic strip is made of two metals with one metal having twice the area as that of another. Due to temperature change, the stress in metal strips with a lesser area is -30 MPa. What is the stress developed in another component of the composite bar?

Solution: Metal 1 has twice the area of Metal 2.

$A_1 = 2A_2$

Metal 2 has a lesser area, as given in the question. Metal 2 has a stress of -30MPa.

Let us consider $A_2 = x$ and $A_1 = 2x$

$\sigma_1 \text{ x } 2x = 30 \text{ x } x$

$\sigma_1 = 15$ MPa

The stress developed in the first bar is equal to $\sigma_1 = 15$MPa with the opposite sign. Stress in composite bars is always the opposite.

Kinetic Theory of Gases

The kinetic theory describes a gas as a large number of submicroscopic particles (atoms or molecules), all of which are in constant, random motion. The rapidly moving particles constantly collide with each other and with the walls of the container. Kinetic theory explains macroscopic properties of gases, such as pressure, temperature, viscosity, thermal conductivity, and volume, by considering their molecular composition and motion. The theory posits that gas pressure is due to the impacts, on the walls of a container, of molecules or atoms moving at different velocities.

The Model

The five basic tenets of the kinetic-molecular theory are as follows:

1. A gas is composed of molecules that are separated by average distances that are much greater than the sizes of the molecules themselves. ***The volume occupied by the molecules of the gas is negligible compared to the volume of the gas itself*.**
2. The molecules of an ideal gas exert **no attractive forces** on each other, or on the walls of the container.
3. The molecules are in **constant random motion**, and as material bodies, they obey Newton's laws of motion. This means that the molecules move in **straight lines** (see demo illustration at the left) until they collide with each other or with the walls of the container.
4. Collisions are perfectly *elastic*; when two molecules collide, they change their directions and kinetic energies, but the total **kinetic energy is conserved**. *Collisions are not “sticky"*.
5. **The average kinetic energy of the gas molecules is directly proportional to the absolute temperature**. Notice that the term “average” is very important here; the velocities and kinetic energies of individual molecules will span a wide range of values, and some will even have zero velocity at a given instant. This implies that all molecular motion would cease if the temperature were reduced to absolute zero.

According to this model, most of the volume occupied by a gas is *empty space*; this is the main feature that distinguishes gases from *condensed* states of matter (liquids and solids) in which neighboring molecules are constantly in contact. Gas molecules are in rapid and continuous motion; at ordinary temperatures and pressures their velocities are of the order of 0.1-1 km/sec and each molecule experiences approximately 10^{10}collisions with other molecules every second.

If gases do in fact consist of widely-separated particles, then the observable properties of gases must be explainable in terms of the simple mechanics that govern the motions of the individual molecules. The kinetic molecular theory makes it easy to see why a gas should exert a pressure on the walls of a container. Any surface in contact with the gas is constantly bombarded by the molecules.

At each collision, a molecule moving with momentum mv strikes the surface. Since the collisions are elastic, the molecule bounces back with the same velocity in the opposite direction. This change in velocity ΔV is equivalent to a*n acceleration* a; according to Newton's second law, a *force* $f = ma$ is thus exerted on the surface of area A exerting a pressure $P = f/A$.

Kinetic Interpretation of Temperature

According to the kinetic molecular theory, the average kinetic energy of an ideal gas is directly proportional to the absolute temperature. Kinetic energy is the energy a body has by virtue of its motion:

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

As the temperature of a gas rises, the average velocity of the molecules will increase; a doubling of the temperature will increase this velocity by a factor of four. Collisions with the walls of the container will transfer more momentum, and thus more kinetic energy, to the walls. If the walls are cooler than the gas, they will get warmer, returning less kinetic energy to the gas, and causing it to cool until thermal equilibrium is reached. Because temperature depends on the *average* kinetic energy, the concept of temperature only applies to a statistically meaningful sample of molecules. We will have more to say about molecular velocities and kinetic energies farther on.

- **Kinetic explanation of Boyle's law**: Boyle's law is easily explained by the kinetic molecular theory. The pressure of a gas depends on the number of times per second that the molecules strike the surface of the container. If we compress the gas to a smaller volume, the same number of molecules are now acting against a smaller surface area, so the number striking per unit of area, and thus the pressure, is now greater.
- **Kinetic explanation of Charles' law:** Kinetic molecular theory states that an increase in temperature raises the average kinetic energy of the molecules. If the molecules are moving more rapidly but the pressure remains the same, then the molecules must stay farther apart, so that the increase in the rate at which molecules collide with the surface of the container is compensated for by a corresponding increase in the area of this surface as the gas expands.
- **Kinetic explanation of Avogadro's law**: If we increase the number of gas molecules in a closed container, more of them will collide with the walls per unit time. If the pressure is to remain constant, the volume must increase in proportion, so that the molecules strike the walls less frequently, and over a larger surface area.
- **Kinetic explanation of Dalton's law**: "Every gas is a vacuum to every other gas". This is the way Dalton stated what we now know as his law of partial pressures. It simply means that each gas present in a mixture of gases acts independently of the others. This makes sense because of one of the fundamental tenets of KMT theory that gas molecules have negligible volumes. So Gas A in mixture of A and B acts as if Gas B were not there at all. Each contributes its own pressure to the total pressure within the container, in proportion to the fraction of the molecules it represents.

Derivation of the Ideal Gas Law

One of the triumphs of the kinetic molecular theory was the derivation of the ideal gas law from simple mechanics in the late nineteenth century. This is a beautiful example of how the principles of elementary mechanics can be applied to a simple model to develop a useful description of the behavior of macroscopic matter. We begin by recalling that the pressure of a gas arises from the force exerted when molecules collide with the walls of the container. This force can be found from Newton's law

$$\mathrm{f} = \mathrm{ma} = m\frac{\mathrm{dv}}{dt}$$

in which vv is the velocity component of the molecule in the direction perpendicular to the wall and mm is its mass.

To evaluate the derivative, which is the velocity change per unit time, consider a single molecule of a gas contained in a cubic box of length l. For simplicity, assume that the molecule is moving along the *x*-axis which is perpendicular to a pair of walls, so that it is continually bouncing back and forth between the same pair of walls. When the molecule of mass *m* strikes the wall at velocity +*v* (and thus with a momentum *mv*) it will rebound elastically and end up moving in the opposite direction with –*v*. The total change in velocity per collision is thus 2*v* and the change in momentum is 2mv.

After the collision the molecule must travel a distance l to the opposite wall, and then back across this same distance before colliding again with the wall in question. This determines the time between successive collisions with a given wall; the number of collisions per second will be v/2l. The *force* F exerted on the wall is the rate of change of the momentum, given by the product of the momentum change per collision and the collision frequency:

$$\mathrm{F} = \frac{\mathrm{d}(m\mathrm{v})}{dt} = (2\mathrm{m}v_x)x\ \frac{v_x}{2l} = \frac{m\mathrm{v}^2{}_x}{l}$$

Pressure is force per unit area, so the pressure P exerted by the molecule on the wall of cross-section l^2 becomes

$$\mathrm{P} = \frac{mv^2}{\mathrm{l}^3} = \frac{mv^2}{\mathrm{v}}$$

in which Vis the volume of the box.

As noted near the beginning of this unit, any given molecule will make about the same number of moves in the positive and negative directions, so taking a simple average would yield zero. To avoid this embarrassment, we square the velocities before averaging them

$$v^{\vec{2}} = \frac{{v^2}_1 + {v^2}_2 + {v^2}_3 + {v^2}_4 + \cdots {v^2}_{\mathrm{N}}}{\mathrm{N}} = \frac{\sum {v^2}_i}{\mathrm{N}}$$

We have calculated the pressure due to a single molecule moving at a constant velocity in a direction perpendicular to a wall. If we now introduce more molecules, we must interpret v2v2 as an average value which we will denote by v2¯ Also, since the molecules are moving randomly in all directions, only one-third of their total velocity will be directed along any one Cartesian axis, so the total pressure exerted by NN molecules becomes

$$\mathrm{P} = \frac{N}{3} = \frac{mv^2}{\mathrm{v}}$$

Recalling that mv^{2}¯/2 is the average translational kinetic energy ϵ, we can rewrite the above expression as

$$\mathrm{Pv} = \frac{1}{3} Nmv^2 = \frac{2}{3} N\,\epsilon$$

The 2/3 factor in the proportionality reflects the fact that velocity components in each of the three directions contributes ½ *kT* to the kinetic energy of the particle. The average translational kinetic energy is directly proportional to temperature:

$$\epsilon = \frac{2}{3} \text{ kT}$$

in which the proportionality constant kk is known as the *Boltzmann constant*. Substituting Equation 2.6.92.6.9 into Equation 2.6.82.6.8 yields

$$\text{Pv} = (\frac{3}{2}\, N)(\frac{3}{2}\, kt)$$

The Boltzmann constant *k* is just the gas constant per molecule. For *n* moles of particles, the Equation 2.6.102.6.10 becomes

$$\text{PV=nRT}$$

which is the Ideal Gas law.

Part 2: Geometric light

GEOMETRICAL OPTICS

1-Introduction

What is light?

• Is it a flow of particles?

• Is it a wave?

• Is it a flow of particles and a wave? The light ... This is what the eye receives.

The science of light is a branch of physics that is concerned with the study of light phenomena.

The field of light is very wide, for example:

1- Sensory perception of the world that surrounds us (the formation of images and imagination).

2- Optical devices [binoculars, telescopes) to observe and approximate celestial bodies, microscopes.]

3- Diffusion and transmission of information mediated by light (optical fiber).

4- Light sources (laser, sodium lamp).... ‘

5- Infrared camera detectors, photon detector, semiconductor materials.

2- SOURCES OF LIGHT

Sources of light are called luminous object, while non-luminous objects do not emit light. Substances that allows the transmission of light through them are called transparent objects, while substances that totally absorb light are called opaque objects, they do not allow the transmission of light through them. Some other substances like light tinted glass partially allow the transmission of light and are called translucent objects.

Here we list various sources of light, both natural and artificial sources and processes and devices that emit light. In this list, light is considered to be electromagnetic radiation that is visible to the human eye, and not blackbody radiation in the more general sense. The list is also limited to sources of light, as opposed to objects such as the Moon that provide light by reflection.

i. Astronomical objects - Sun, Starlight (Stars forming groups such as star clusters and galaxies. Deep sky objects including quasars, accretion discs around black holes, blazars, magnetars, pulsars, Supernova/nova, Milky Way, Cosmic rays.
ii. Atmospheric entry (via ionization and/or heating) - Meteors, Meteor showers, Bolide/Fireball, Earth-grazing fireball
iii. Lightning (Plasma physics) – lightning of various forms, Dry Lightning, Aurorae, Cerenkon radiation (from cosmic rays hitting atmosphere).
iv. Terrestrial – (a) Bioluminescence - Glowworms, Fireflies, and certain bacteria, Antarctic Krill, Parchment Worm, Foxfire, luminescent fungus etc. (b) Incandescence – Lava, Volcanic, Volcanic Eruption (lightning, heated material). (c) Radioluminescene (d) Triboluminescence (e) Piezolumniescence (f) Earthquake Light.
v. Nuclear/High Energy – Sonoluminescence, Annihilation, Bremsstrahlung, Scintillation Cyclotron, Synchrotron, Cerenkov, etc.
vi. Direct Chemical – Chemoluminescence, Luminol, Florescence, Phosphorescence, Chemical explosives, Combustion Fires, etc.
vii. Incandescent lamps – Carbon Button Lamp, Conventional Incandescent lamps, Flashlights, Halogen Lamps, etc.
viii. Electron-Stimulated – Cathodluminescence, Cathode Ray Tubes, Electron Stimulated Luminescence, Crookes' Tube, Electroluminescent Lamps – (a) Light Emitting Diodes (LED) (b) Organic LEDs, (c) Polymer LEDs, (d) Solid State LEDs, (v) Light Emitting Electrochemical Cells (LECs), Electroluminescent Sheets, Electroluminescent Wires, Field Induced Polymer Electroluminescent (FIPEL), etc.

ix. Gas Discharge Lamps – Induction Lightning, Florescent Lamps – Compact Florescent Lamps, Tanning Lamp, Wood’s Lamp, Geissler Tube, Moore Tube, Hollow-Cathode Tube, Excimer Lamp, Neon, Argon and Xenon Lamps, Nixie Tube, Plasma Lamp, etc.

x. Lasers – Ruby Laser Gas Laser, Semiconductor Laser, Chemical Laser, Dye Laser, Metal-Vapor Laser, Solid State Laser, Ion Laser, Quantum-Well Laser, Free-Electron Laser, Gas Dynamic Laser, etc.

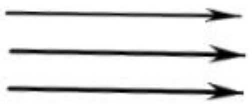
3 - Nature of Light: The Nature of Light

Light: It is electromagnetic waves that travel in vacuum in straight lines at a very high speed.

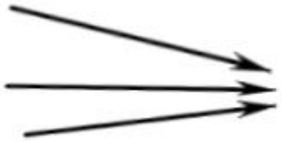
Engineering Optics: Geometrical optics, describes light propagation in terms of rays of light. The ray in geometric optics is an abstraction (mathematical formulation) which can be used to approximately model how light will propagate. Light rays are defined to propagate in a rectilinear path (straight line) as they travel in a homogeneous (uniform density and orientation) medium. Rays bend (and may split in two) at the interface between two dissimilar media, may curve in a medium where the refractive index changes, and may be absorbed and reflected. The refraction, reflection, absorption and dispersion of light by the medium through which it propagates are generally referred to as scattering. Geometrical optics provides rules, which may depend on the color (wavelength/frequency) of the ray, for propagating these rays through an optical system. This mathematical simplification of the ray optics fails to account for optical effects such as diffraction and interference. It is an excellent approximation when the wavelength is very small compared with the size of structures with which the light interacts. Geometric optics can be used to describe the geometrical aspects of imaging, including optical aberrations.

As light travels through space, it oscillates in amplitude. In this description of the image caused by the light propagation, each maximum amplitude crest is marked with a plane to illustrate the wave front. The ray is the arrow perpendicular to these parallel surfaces. A light ray is a line or curve that is perpendicular to the light's wave fronts. A slightly more rigorous definition of a light ray follows from Fermat's principle, which states that the path taken between two points by a ray of light is the path that can be traversed in the least time. Geometrical optics is often simplified by making the paraxial approximation, or "small angle approximation." The mathematical behavior then becomes linear, allowing optical components and systems to be described by simple matrices (linear equations). This leads to the techniques of paraxial ray (rays of 7 light parallel to the principle axis) tracing, which are used to find basic properties of optical systems, such as approximate image and object positions and magnifications.

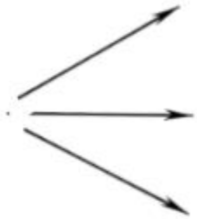
A light beam is a mathematical construct to aid in the geometric analysis of light propagation. It can also be considered a drawn line in space corresponding to the direction of flow of radiant energy (light). Geometrically, it is a straight line with an arrow indicating the path and direction of light propagation. A set of light rays is called a light beam. There are different beams of light (i) parallel beam (ii) convergent beam (iii) divergent beam (iv) scattered beam.



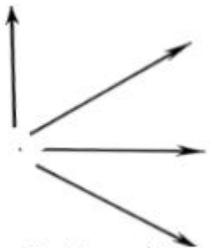
Parallel Beam



Convergent Beam



Diveragent Beam



Scattered Beam

Light = waves and photons A photon is a massless particle whose speed is equal to the speed of light we denote as c and is equal to:

$$c = 299792456\ (m.s^{-1}) \approx 3 \times 10^{8} \left(\frac{m}{s}\right)$$

The energy of a photon is given by the following relationship:

$$E = h.\nu \text{ (joule)}$$

Where h is a constant called "Called Planck's constant" which is equal to:

$$h = 6,626 \times 10^{-34}\ (J.s)$$

The frequency is estimated in the reciprocal of seconds (1/s), called hertz (Hz).

Since light is of a dual nature: palpation and wave, the photon co-wave (light wave) will not be characterized by:

• Wave without carrier,

• Spread in the open at the speed of (C) the speed of light.

The wavelength is given by

الآتية:

$$\lambda = \frac{c}{\nu} = c.T$$

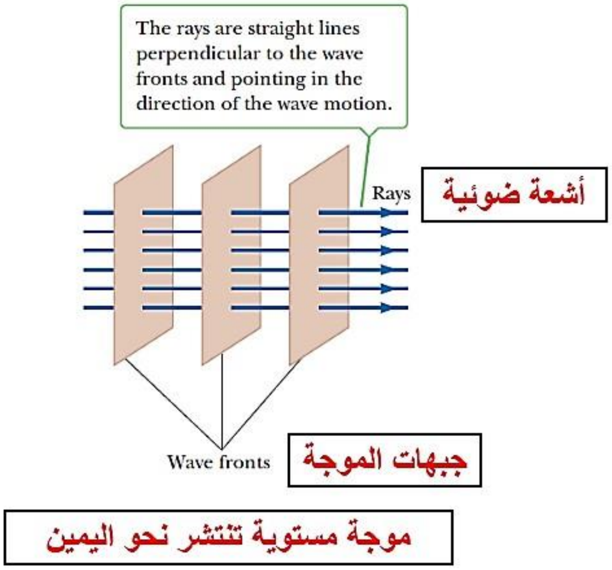
where T stands for wavelength, estimated at one length.

Some reference values:

- The age of the universe is estimated at (31.7) billion years,
- The Sun is a 5.4 billion years old star whose light takes about 8 minutes to reach us. In other words, a light wave (photon) needs the distance between the Earth and the Sun with a time of approximately 8 minutes,

• The light wave (photon) rotates around the Earth 7 times per second.

Rays are tangent lines perpendicular to the fronts of the wave and directed towards the motion of the wave, see the attached figure.



REFLECTION AND REFRACTION OF LIGHT

Reflectance

Reflection: The bounce of rays to the medium itself when an object intercepts its path.

Vertical: An imaginary line perpendicular to the surface of the mirror at the point where the rays fall on it.

Angle of incidence: It is the angle between the perpendicular and the ray incident on the mirror.

Reflection angle: It is the angle between the reflected ray from the mirror and the perpendicular.

Random reflection: The reflection of incident rays in all directions, even if they are parallel before reflection.

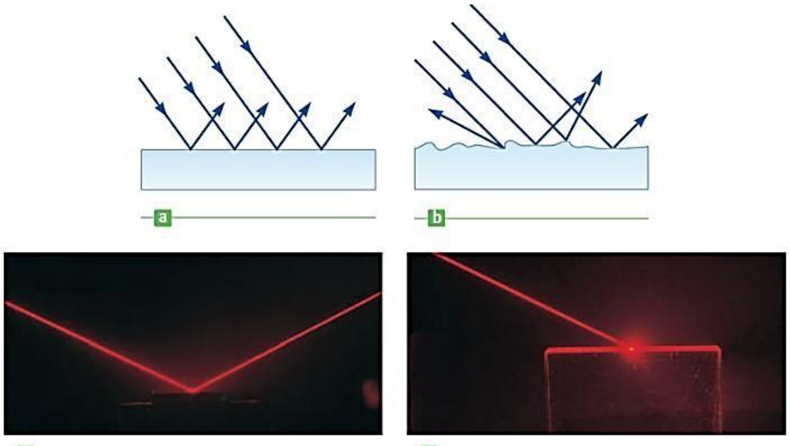
Regular reflection: The reflection of the rays so that they follow a certain pattern after their reflection, as the parallel rays incident on the surface of two plane mirrors are reflected in parallel.

Note:

- The surface itself may be polished for one ray and rough for others.

- The surface is considered polished if its zigzags are small compared to the wavelength of the light used

Smooth, polished and glossy surfaces such as mirrors reflect light in a simple and predictable way. This allows the production of reflected images that can be linked to a physical (real) or inductive (virtual) location in space. With such surfaces, the direction of the reflected beam is determined by the angle that the incident ray makes with the natural surface, which is a line perpendicular to the surface at the point where the ray hits the boundary between the two mediums.



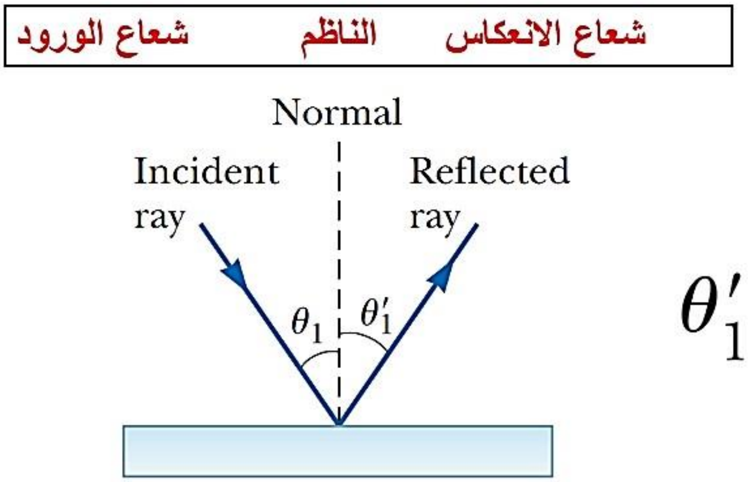
انعكاس مرآوي
Specular Reflection

انعكاس متبعثر
Diffuse Reflection

Laws of reflection:

1- The angle of incidence is equal to the angle of reflection (Θ1 = Θ1)

2- The incident ray and the reflected and vertical rays are located in one plane.



$$\theta'_1 = \theta_1$$

Mirrors

Mirror: It is a tool that has the ability to reflect light so that it preserves most of its properties.

Flat mirror: a flat light-reflecting surface.

The light ray incident on a plane mirror perpendicular to it reflects on itself.

Each object emits millions of light rays (or reflects off it) that makes us see these objects.

To locate the image, it is sufficient to select two rays of light emanating from the object to determine where the image is formed.

Characteristics of the image formed on a plane mirror:

1- Imaginary (estimated): It is the image that is formed as a result of the convergence of extensions of reflected rays and cannot be received on a display screen.

2- List (moderate): not inverted.

3- Equal and identical to the body ($H_1 = H_0$)

4- Mirrored: If you look at a mirror, your right is to the left of the picture.

5- The distance of the image from the mirror is equal to the dimension of the object ($x_i = x_o$)

Spherical mirrors: They are mirrors whose reflective surface is part of the surface of the sphere.

- If the inner surface of the ball is the reflective surface, it is called a concave mirror, and it gives magnified images, so it is used in:

Like the mirror that the shaver uses to enlarge the image.

Mirrors used in telescopes.

If the outer surface of the sphere is the reflective surface, it is called a convex mirror, and it gives a wide field of view, so it is used in:

The side mirror in the car.

mirrors used in parking at junctions.

For each spherical mirror:

1- Center of curvature (C): It is the center of the ball from which the mirror is cut.

2- Curvature radius (r): It is the radius of the time from which the mirror was cut.

3- Focal point (F): It is the point of gathering of the rays reflected from the concave mirror and is located halfway between the center of curvature and the surface of the mirror.

4- Focal length (f): The distance between the focal point and the surface of the mirror ($f = r/2$)

Images

Images are formed due to real or apparent intersection of rays of light. There are two types of images

(i) Real Images

Real Images are formed by the real intersection of two or more rays of light. They can be focused on a screen.

(ii) Virtual Images.

Virtual images are formed by the apparent intersection of light rays, they cannot be focused on a screen. In complex optical instruments consisting of more than one optical device, the image of one device (whether real or virtual) forms the object of the second device. For example, the virtual image formed by an eyeglass is the object that the eye focused on to form an image.

Formation of Images by Spherical Mirrors

In tracing ray diagram to obtain the image formed by spherical mirrors, four important rays are used, the intersection of any two of such rays, describes the nature and position of the image formed by the object. The rays are

i. All Parallel rays are reflected from the mirror through the principal focus.
ii. All rays passing through the principal focus are reflected from the mirror parallel to the principal axis
iii. Ray incident on the pole making an angle T with the principal axis, is reflected from the mirror with an angle T from the principal axis.
iv. Ray of light passing through the center of curvature is reflected un-deviated from the mirror.

Plane Mirror vs Spherical Mirrors

Mirrors are made into different shapes for different purposes.

The two of the most prominent types of mirrors are:

- Plane Mirrors

- Spherical Mirrors

A plane mirror is a flat, smooth reflective surface. A plane mirror always forms a virtual image that is upright, and of the same shape and size as the object, it is reflecting. A spherical mirror is a mirror that has a consistent curve and a constant radius of curvature. The images formed by a spherical mirror can either be real or virtual.

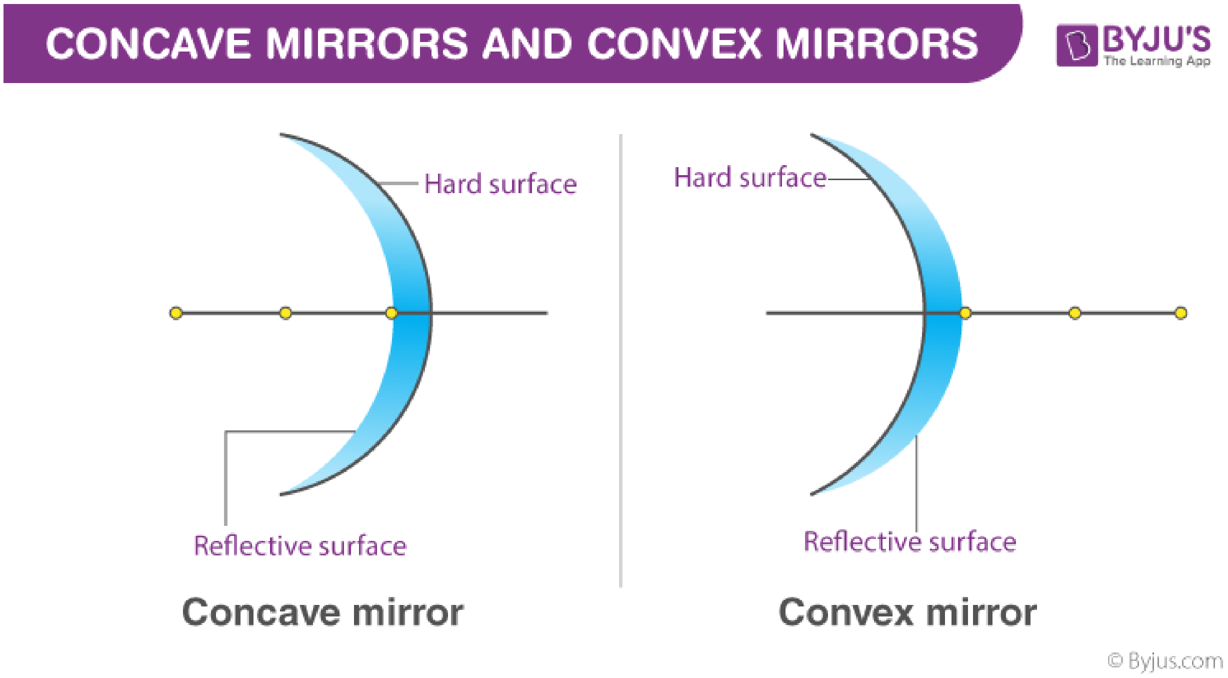
Spherical mirrors are of two types as:

  -
  - Concave Mirror
  - Convex Mirror

In the next few sections, let us learn in-depth about the characteristics of convex and concave mirrors and the images formed by them when the object is kept at different positions.

Spherical Mirrors

Spherical mirrors are mirrors having curved surfaces that are painted on one of the sides. Spherical mirrors in which inward surfaces are painted are known as convex mirrors, while the spherical mirrors in which outward surfaces are painted are considered concave mirrors.



Concave Mirror

If a hollow sphere is cut into parts and the outer surface of the cut part is painted, then it becomes a mirror with its inner surface as the reflecting surface. This type of mirror is known as a concave mirror.

Characteristics of Concave Mirrors

- Light converges at a point when it strikes and reflects back from the reflecting surface of the concave mirror. Hence, it is also known as a converging mirror.
- When the concave mirror is placed very close to the object, a magnified, erect and virtual image is obtained.
- However, if we increase the distance between the object and the mirror then the size of the image reduces and a real and inverted image is formed.
- The image formed by the concave mirror can be small or large and can be real or virtual.

Convex Mirror

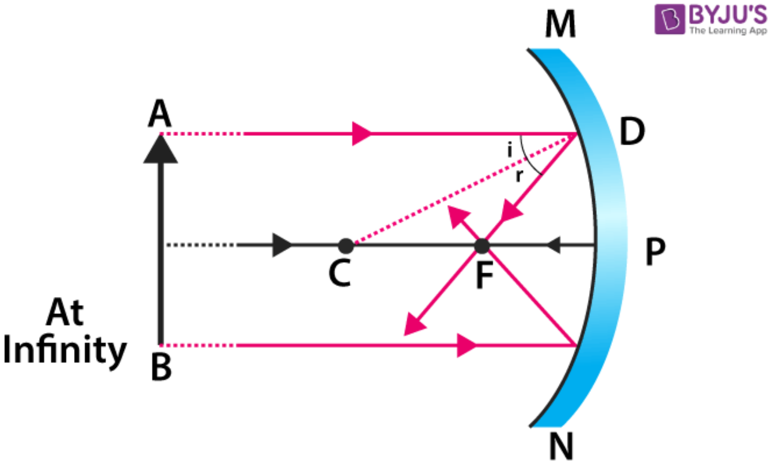
If the cut part of the hollow sphere is painted from the inside, then its outer surface becomes the reflecting surface. This kind of mirror is known as a convex mirror.

Characteristics of Convex Mirrors

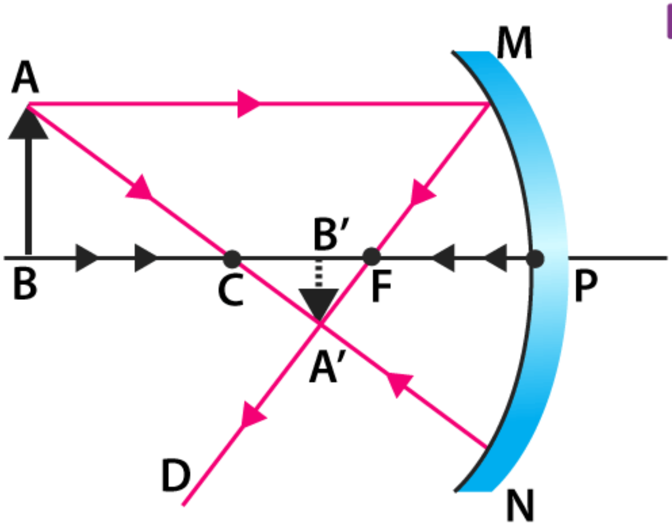
- A convex mirror is also known as a diverging mirror as this mirror diverges light rays when they strike its reflecting surface.
- Virtual, erect, and diminished images are always formed with convex mirrors, irrespective of the distance between the object and the mirror.

Concave Mirror Ray Diagram

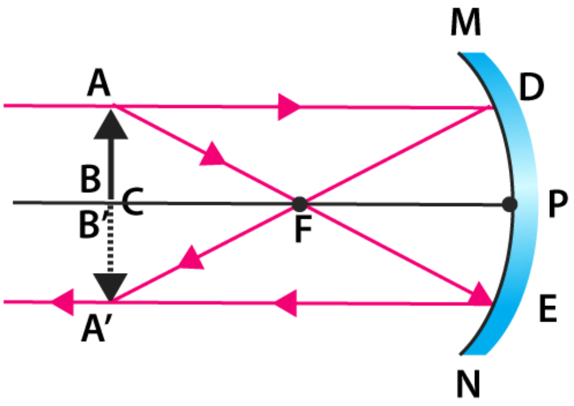
- Concave Mirror Ray Diagram lets us understand that, when an object is placed at infinity, a real and inverted image is formed at the focus. The size of the image is much smaller compared to that of the object.



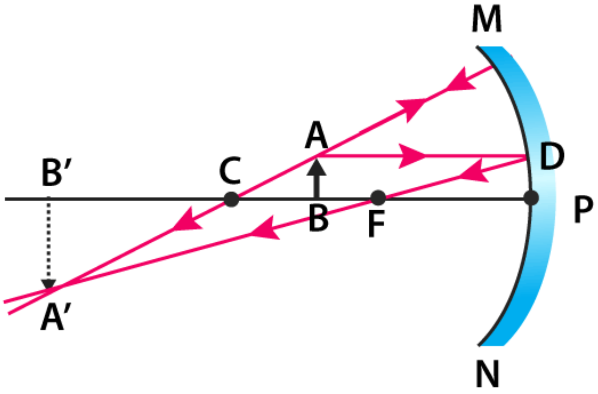
- When an object is placed behind the centre of curvature, a real image is formed between the centre of curvature and focus. The size of the image is smaller than compared to that of the object.



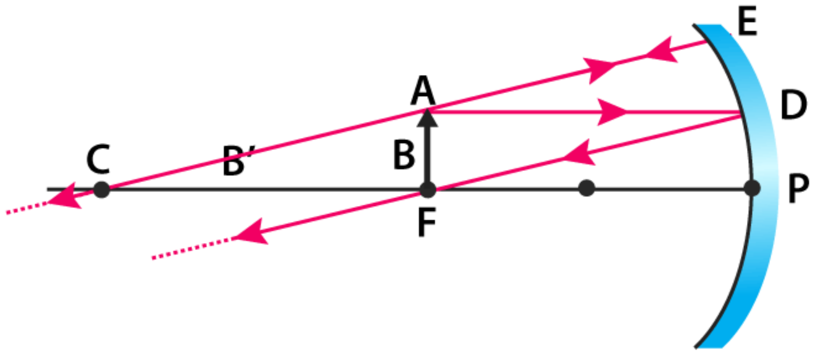
- When an object is placed at the centre of curvature and focus, the real image is formed at the centre of curvature. The size of the image is the same as compared to that of the object.



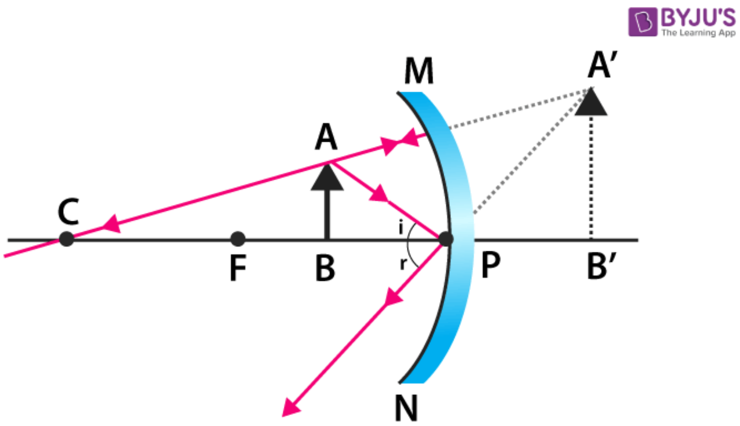
- When an object is placed in between the centre of curvature and focus, the real image is formed behind the centre of curvature. The size of the image is larger than compared to that of the object.



- When an object is placed at the focus, the real image is formed at infinity. The size of the image is much larger than compared to that of the object.



- When an object is placed in between focus and pole, a virtual and erect image is formed. The size of the image is larger than compared to that of the object.



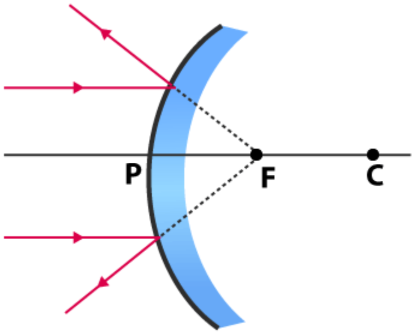
Summary

S. No	Position of Object	Position of Image	Size of Image	Nature of Image
1	At infinity	At the focus F	Highly Diminished	Real and Inverted
2	Beyond the centre of curvature C	Between F and C	Diminished	Real and Inverted
3	At the centre of curvature C	At C	Same Size	Real and Inverted
4	Between C and F	Beyond C	Enlarged	Real and Inverted
5	At focus F	At Infinity	Highly Enlarged	Real and Inverted

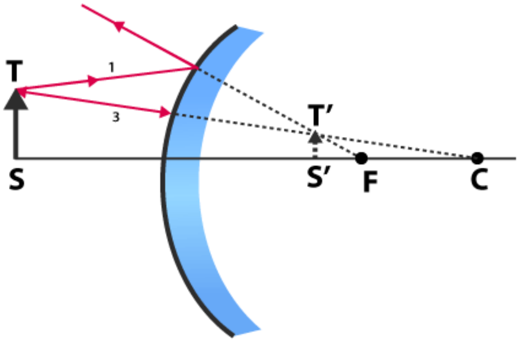
Image Formation By Convex Mirror

The image formed in a convex mirror is always virtual and erect, whatever be the position of the object. In this section, let us look at the types of images formed by a convex mirror.

- When an object is placed at infinity, a virtual image is formed at the focus. The size of the image is much smaller than compared to that of the object.



- When an object is placed at a finite distance from the mirror, a virtual image is formed between the pole and the focus of the convex mirror. The size of the image is smaller than compared to that of the object.



Watch the video below to understand the concave and convex mirrors

Mirror Formula

If an object is at a distance *u* from a curved mirror (concave or convex), of focal length *f*, and radius *r*, and the image is formed at a distance *υ* form the mirror, it can be shown that (we will later develop the Lens maker's equation), the distances are related by

$$\frac{1}{f} = \frac{1}{u} + \frac{1}{\upsilon} = \frac{2}{r}$$

The magnification m is defined as (here h_1 is the image height and h_0 is the object height)

$m = \frac{h1}{h0} = \frac{\upsilon}{u} + \frac{\upsilon}{\mathrm{f}} - 1 - - - - - - \frac{1}{m} = \frac{\upsilon}{\mathrm{f}} - 1$

Example 2.1

An object is placed (i) 15 cm (ii) 5 cm in front of a concave mirror of radius of curvature 20 cm Calculate the position, nature and magnification of the image in each case.

Solution

$f = \frac{20}{2} = 10\ cm$, from$f = \frac{2}{r}$, u = 15 cm;

$\frac{1}{f} = \frac{1}{10} + \frac{1}{15} = \frac{2}{30}$ then $\upsilon = 30; m = \frac{30}{10} = 3$

Image is real, magnified and inverted

(ii) u = 5 cm , $\frac{1}{f} = \frac{1}{u} + \frac{1}{\upsilon} = \frac{2}{r}$ then , $\frac{1}{\upsilon} = \frac{1}{10} - \frac{1}{5} = -\frac{1}{10}$; $\upsilon = -10$

M = $\frac{\upsilon}{u} = -\frac{10}{5} = -2$

Image is virtual, magnified and erect.

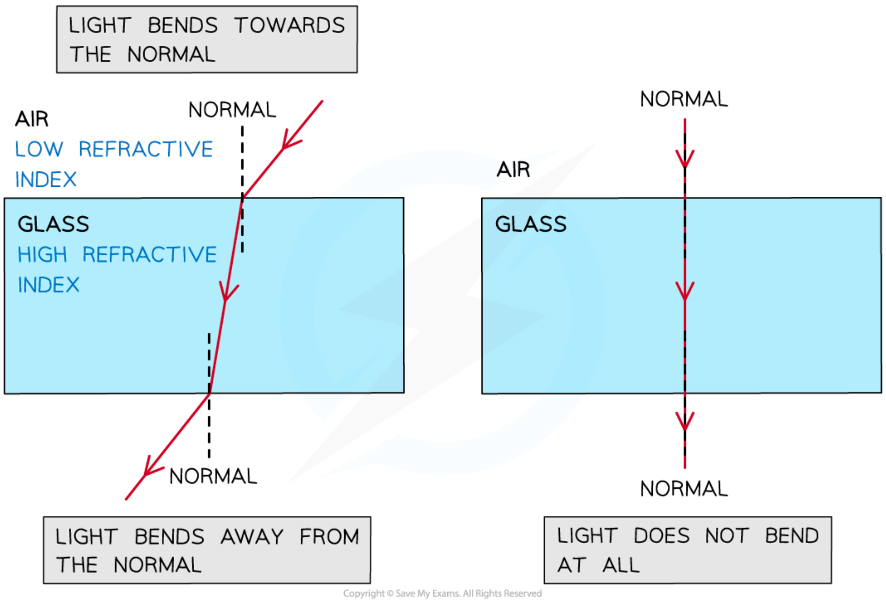
Refraction

REFRACTION AT PLANE SURFACES

The apparent shortening of a spoon placed inside a glass of water; the apparent reduction in the depth of swimming pools; the rise in the letters of a word when a block of glass is placed over the letter, etc. are clear manifestation of refraction of light as it propagates from one medium optical density to another. When light rays propagate from optical less dense medium to denser medium, it is refracted towards the normal, but if it propagates from optical denser to less dense it is refracted away from the normal.

Refractive Index

- Refraction occurs when light passes a boundary between two different transparent media
- At the boundary, the rays of light undergo a **change in direction**
- The direction is taken as the angle from a hypothetical line called the normal
  - This line is perpendicular to the surface of the boundaries and is represented by a straight dotted line
- The change in direction depends on which media the light rays pass between:
  - From air to glass (less dense to more dense): light bends **towards** the normal
  - From glass to air (more dense to less dense): light bends **away** from the normal
  - When passing along the normal (perpendicular) the light **does not bend** at all
-



- ***Refraction of light through a glass block***

Calculating Refractive Index

- The refractive index, *n*, is a property of a material which measures how much light slows down when passing through it

$$n = \frac{c}{c_s}$$

  - Where:
    - c = **the speed of light** in a vacuum (m s^{-1})
    - c_s = the speed of light in a substance (m s^{-1})
- Light travels at different speeds within different substances depending on their refractive index
  - A material with a high refractive index is called **optically dense**, such material causes light to travel **slower**
- Since the speed of light in a substance will always be less than the speed of light in a vacuum, the value of the n is **always greater than 1**
- In calculations, the refractive index of air can be taken to be approximately **1**

- This is because light does not slow down significantly when travelling through air (as opposed to travelling through a vacuum)

Refraction occurs when light travels through an area of space that has a changing index of refraction (from one medium to another). The simplest case of refraction occurs when there is an interface between a uniform medium with index of refraction and another medium with index of refraction μ_1. In such situations, Snell's Law describes the resulting deflection of the light ray from its original line of propagation as

$$\mu_1 \text{Sin}\,\Theta_1 = \mu_2 \text{Sin}\,\Theta_2$$

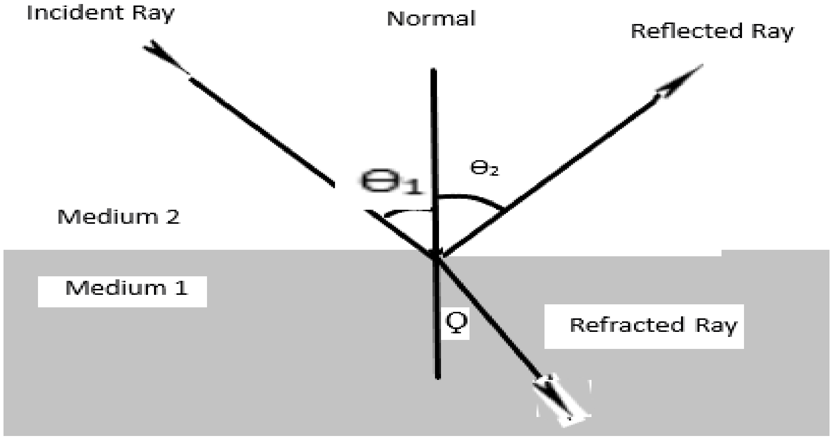
where Θ_1 and Θ_2 are the angles between the normal (to the interface) and the incident and refracted waves, respectively. This phenomenon is also associated with a changing Parallel Beam Divergent Beam Convergent Beam Scattered Beam Fig 1.1 Different Beams of Light 10 speed of light as it propagates from one medium to another, as seen from the definition of index of refraction provided above which implies:

$$\upsilon_1 \text{Sin}\,\Theta_1 = \upsilon_2 \text{Sin}\,\Theta_2$$

where υ_1 and υ_2 are the light velocities through the respective media

Various consequences of Snell's Law include the fact that for light rays traveling from a material with a high index of refraction to a material with a low index of refraction, it is possible for the interaction with the interface to result in zero transmission. This phenomenon is called total internal reflection and allows for fiber optics technology. As light signals travel down a fiber optic cable, it undergoes total internal reflection allowing for essentially no light lost over the length of the cable. It is also possible to produce polarized light rays using a combination of reflection and refraction: When a refracted ray and the reflected ray form a right angle, the reflected ray has the property of "plane polarization". The angle of incidence required for such a scenario is known as Brewster's angle.

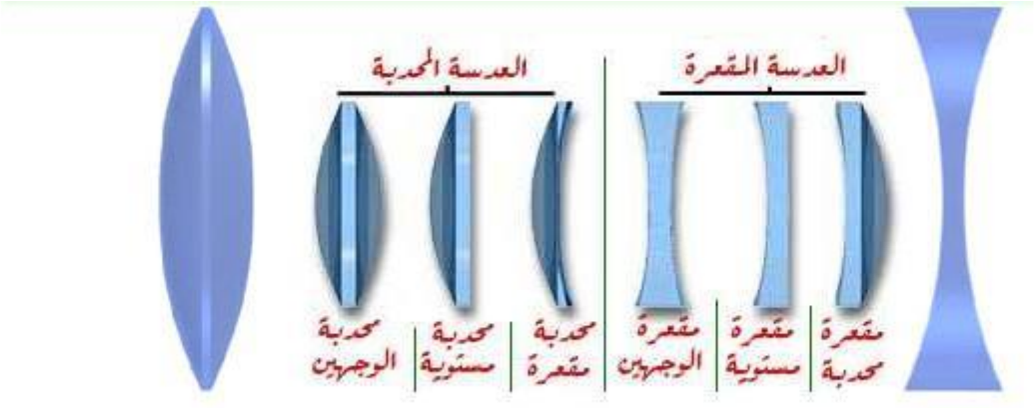
Snell's Law can be used to predict the deflection of light rays as they pass through "linear media" as long as the indexes of refraction and the geometry of the media are known. For example, the propagation of light through a prism results in the light ray being deflected depending on the shape and orientation of the prism. Additionally, since different frequencies of light have slightly different indexes of refraction in most materials, refraction can be used to produce dispersion spectra that appear as rainbows. Some media have an index of refraction which varies gradually with position and, thus, light rays curve through the medium rather than travel in straight lines. This effect is what is responsible for mirages seen on hot days where the changing index of refraction of the air causes the light rays to bend creating the appearance of specular reflections in the distance (as if on the surface of a pool of water). Material that has a varying index of refraction is called a gradient-index (GRIN) material and has many useful properties used in modern optical scanning technologies including photocopiers and scanners.



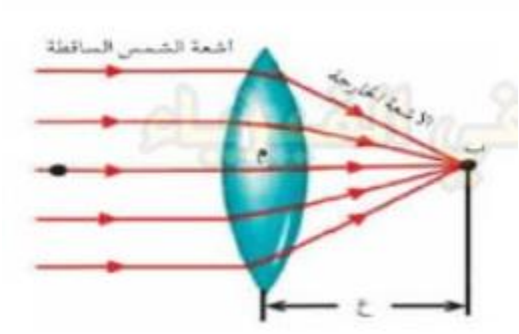
Reflection and Refraction of Light

Lenses

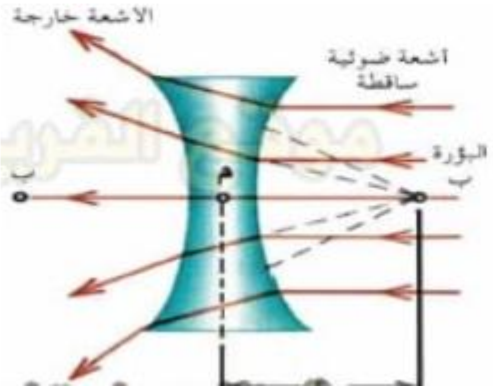
Lenses are considered one of the most important optical devices, so you find lenses in eyeglasses, cameras, telescope, microscope and projector, there are two types of lenses, the first type is the convex lens, also called the converging lens, and the second type is the concave lens or diverging lens, in this lecture we will study only thin lenses and how the image is.



Lenses come in the previous two types in several forms according to the convexity or concavity of the lens surfaces, and the following figure shows the types of thin lenses. Just as mirrors had a center of concavity and focal point, so is the case for lenses, as the surface of the lens is a spherical surface, it also has a center of concavity and focal point, and since the lens has two surfaces, each surface has a center of concavity and focus. focal length.



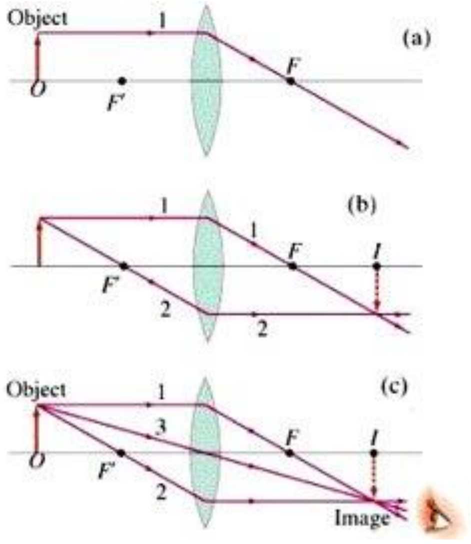
The corresponding figure shows a band of parallel rays falling on a convex lens that collects in focal point, and each ray that falls on the lens has a refraction at the surface of the lens and a refraction occurs when light runs out of the lens, fulfilling Snell's law.



In the case of concave lens, parallel rays fall on the surface of the lens but come out of the opposite surface scattered and do not gather at a point as before, but the extension of the penetrating rays in the direction of the first surface of the lens (dotted lines in the figure) converge at point F, which is the focus of the lens in this case, and the distance is f, which is the focal length.

Note: The focal length of the convex lens is positive and the focal length of the concave lens is negative.

The graphic method to determine the characteristics of the image formed by lensesThe characteristics of the image resulting from convex or concave lenses can be determined by drawing, through the intersection of three main light rays as in the following figure:



Suppose an object located at a greater distance than the focal length of a convex lens as in the corresponding figure, and to determine the image specifications, we follow the following:

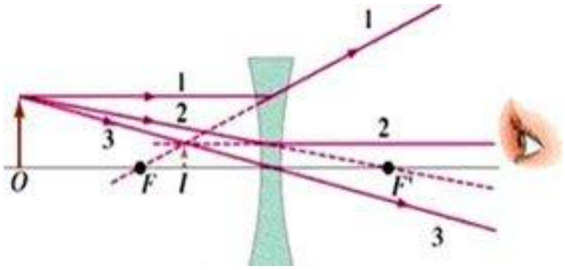
(a) We draw a beam from the object parallel to the optical axis of the lens to fall on the lens and penetrate refracted through the focal point F. (ray No. 1)

(b) We draw a ray of the object that passes through the focal point to fall on the lens and permeate the optical axis. (Ray No. 2)

(C) We draw a beam from the object passing through the center of the lens and it runs through without refracting. (Beam No. 3)

Note that the image formed I is an inverted and real thumbnail.

The intersection of the three rays determines the location of the image and can determine whether the image is enlarged, inverted miniature, moderate, real or imaginary, and the following are some different cases of the image when the distance of the body from the woman changes.



He obtained the image formed by the concave lens in the same way that the image was formed in the convex lens we follow. Knowing that the image consists of the intersection of the extension of the three rays with each other, so the image is imaginary.

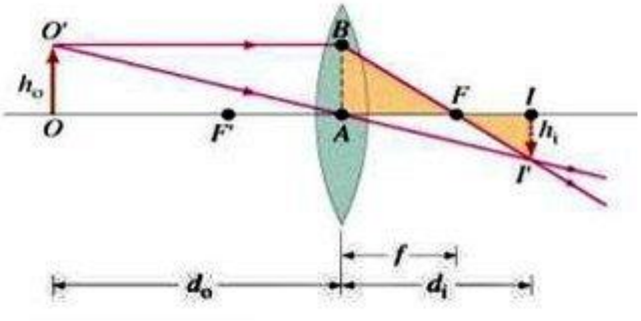
Derivation of the lens equation

Suppose an object at a distance of do from a convex lens so that do is between the focal length and radius of curvature, as in the following figure: The image of the body is formed through the use of two rays, one of which falls parallel to the optical axis and refracts passing through the focal point, and the second falls in the center of the lens at point A and is carried out without refraction. Suppose that the length of the object ho and the length of the resulting image hi.From the triangles FI'I and FBA shown in the diagram below in the area shaded in orange, we find that they are similar, so we conclude from this that

$$\frac{h_i}{h_o} = \frac{d_i - f}{f}$$

It is also from the similar triangles O'AO and I'AI that we get

$$\frac{h_i}{h_o} = \frac{d_i}{d_o}$$



Equalizing the equations and dividing both sides of the resulting equation by di gives us

$$\frac{1}{f} = \frac{1}{d_o} + \frac{1}{d_i}$$

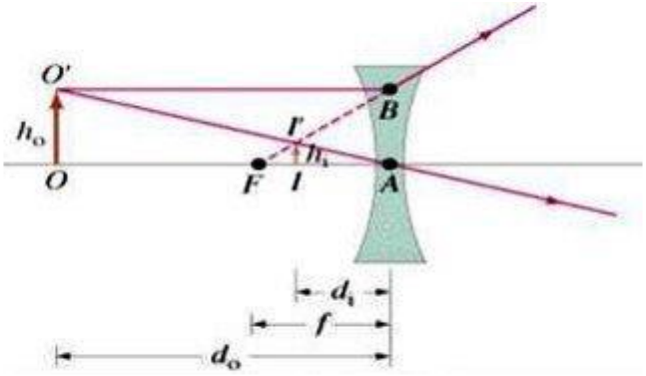
Whereas,

f = focal length (m)

do = distance from lens to object (m)

di= distance from lens to image (m)

The same equation can be derived in the same way using a concave lens



Magnification

The magnification m of the lens is defined as the height of the image hi divided by the height of the object ho, if the magnification is greater than one, the image is greater than the object, but if the magnification is less than one, the image is smaller than the object.

$$m = \frac{h_i}{h_o}$$

But from the above, we found that the ratio between hi/ho is equal to the ratio between di/do, and therefore the magnification can be calculated from the following equation as well if the information is available for that, so that

$$m = -\frac{d_i}{d_o}$$

The negative sign was added to fulfill the concept of signal convention that we will explain in the next topic. So magnification is given by the following equation:

$$m=\frac{h_i}{h_o}=\frac{-d_i}{d_o}$$

h_i = height of the image (m)

h_o = height of object (m)
m = magnification (how many times bigger or smaller)

Sign convention for lenses

The do and di signals determine whether the object or image is real or virtual, while the zoom signal determines whether the image is upright or inverted as follows:

d_o	+	'When the object is on the side from which the light comes from the lens	real object
d_o	–	When the object is opposite to the side from which the light comes from the lens	virtual object
d_i	+	When the image is formed against the side from which the light comes from the lens	`real image
d_i	–	When the image is formed on the side from which the light comes from the lens	virtual image

As for the signs of both f and r, they are as follows

r & f	+	convex mirror
r & f	–	concave mirror

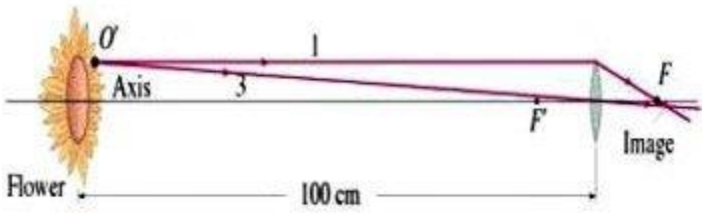
As for the M magnification signal

M	+	upright (على افتراض ان الجسم معتدل)
M	–	inverted (على افتراض ان الجسم معتدل)

The concept of signal convention will be illustrated by the following solved examples:

Example 1

What is (a) the position, and (b) the size, of a large 7·6cm high flower placed 1m from 50mm focal length camera lens?



Solution

Using the above figure and using the equation of lenses, we get the following

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f} \quad \frac{1}{d_i}=\frac{1}{d_o}-\frac{1}{f}=\frac{1}{5cm}-\frac{1}{100cm}=\frac{20-1}{100cm}$$

Accordingly

$$d_i=\frac{100cm}{19}=5.26cm$$

To get the image size, we calculate the magnification as follows

$$m=-\frac{d_i}{d_o}=-\frac{5.26cm}{100cm}=-0.0526 \quad h_i=mh_o=-0.0526\times 7.6cm=-0.4cm$$

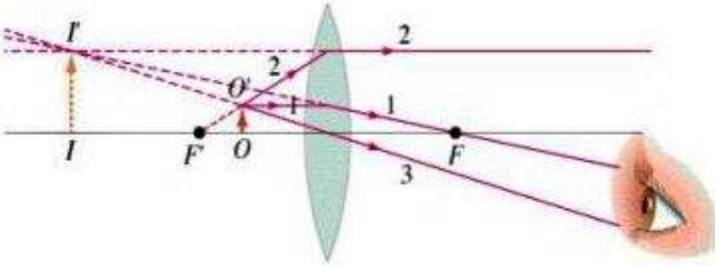
That is, the height of the image is 4mm and inverted because the magnification signal is negative.

Example 2

An object is placed 10cm from a 15cm focal length converging lens. Determine the image position and size.

Solution

$$\frac{1}{d_o}+\frac{1}{d_i}=\frac{1}{f} \quad \frac{1}{d_i}=\frac{1}{d_o}-\frac{1}{f}=\frac{1}{15cm}-\frac{1}{10cm}=-\frac{1}{30cm}$$



$$d_i=-30cm$$

That is, the image is imaginary, and to get the size of the image, we calculate the magnification as follows

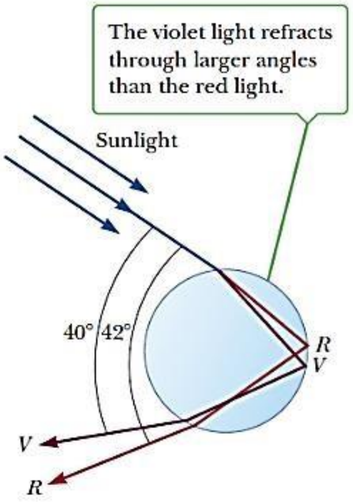
$$m = -\frac{d_i}{d_o} = -\frac{-30cm}{10cm} = 3$$

The image is magnified, moderate and imaginative

RAINBOW

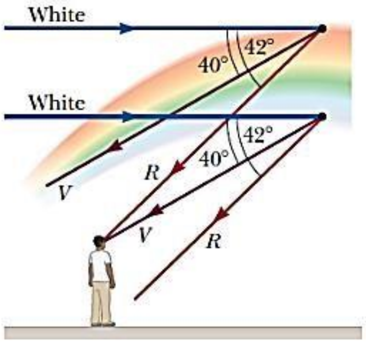
A rainbow is an optical and meteorological phenomenon that is caused by reflection, refraction and dispersion of light in water droplets resulting in a spectrum of light appearing in the sky. It takes the form of a multicolored arc. Rainbows caused by sunlight always appear in the section of sky directly opposite the sun. Rainbows can be full circles; however, the average observer sees only an arc formed by illuminated droplets above the ground, and centered on a line from the sun to the observer's eye. Rainbows can be caused by many forms of airborne water – rain, mist, spray, and airborne dew. In a primary rainbow, the arc shows red on the outer part and violet on the inner side. This rainbow is caused by light being bent when entering a droplet of water, then reflected inside on the back of the droplet and refracted again when leaving it. In a double rainbow, a second arc is seen outside the primary arc, and has the order of its colors reversed, red facing toward the other one in both rainbows. This second rainbow is caused by light reflecting twice inside the water droplets.

A rainbow is not located at a specific distance from the observer, but comes from an optical illusion caused by any water droplets viewed from a certain angle relative to a light source. Thus, a rainbow is not an object and cannot be physically approached. Indeed, it is impossible for an observer to see a rainbow from water droplets at any angle other than the customary one of 42° from the direction opposite the light source. Light rays enter a raindrop from one direction (typically a straight line from the sun), reflect off the back of the raindrop, and fan out as they leave the raindrop. The light leaving the rainbow is spread over a wide angle, with a maximum intensity at the angles 40.89°– 42°. Between 2 and 100% of the light is reflected at each of the three surfaces encountered, depending on the angle of incidence



Refraction of sunlight by a spherical raindrop.

انكسار ضوء الشمس بوساطة نقطة مطر كروية



REFRACTION THROUGH A PRISM

In a prism the two surfaces are inclined at some angle ά called refraction angle, so that the deviation produced by the first surface is not annulled by the second but it further enhanced. This leads to chromatic dispersion of white light. Let. represent the total angle of deviation, we note the following equality from simple trigonometry (i) $\alpha + \beta =°180$ - Opposite angle of a quadrilateral. (ii) $\beta + \gamma = 180^o$ Angle in a straight line, $\alpha = \gamma$, iii) $\alpha = r_1 + r_2$ – External angle of a triangle is equal to the two interior opposite. Deviation of ray at the first surface. $d_1 = i_1 - r_1$, and at the second surface, $d_2 = i_2 - r_2$, total deviation is given by

$$d = d_1 + d_2 = i_1 - r_1 + i_2 - r_2 = (i_1 + i_2) - (r_1 + r_2) = (i_1 + i_2) - \alpha$$

Experiments show that as the angle of incidence is increased, the angle of deviation decreases until it reaches a minimum value. d_{min} before it starts to increase again as is increased to 90°. To obtain the minimum deviation, we write from Snell's law

$(\sin i_1 + \sin i_2) = \mu (\sin r_1 + \sin r_2)$

Using trigonometric relation equation (2.7) may be written as

$$\sin\left(\frac{i_1 + i_2}{2}\right) = \mu \frac{\sin\left(\frac{r_1 + r_2}{2}\right) + \cos\left(\frac{r_1 - r_2}{2}\right)}{\sin\left(\frac{i_1 + i_2}{2}\right)}$$

But $\alpha = r_1 + r_2$; $d = i_1 - r_1 + i_2 - r_2$; then $\alpha + d = i_1 + i_2$

Thus, equation (2.8) becomes

$$\sin\left(\frac{\alpha + d}{2}\right) = \mu \frac{\sin\left(\frac{\alpha}{2}\right) + \cos\left(\frac{r_1 - r_2}{2}\right)}{\sin\left(\frac{i_1 + i_2}{2}\right)}$$

For minimum deviation to occur, light must past symmetrically through the glass prism, which implies that $i_1 = i_2$., $r_1 = r_2$ Using this condition and re-arranging equation (2.10), we have

$$\mu = \frac{\sin\left(\frac{\alpha + d_{min}}{2}\right)}{\sin\left(\frac{\alpha}{2}\right)}$$

Equation (2.11) gives one of the methods one can use to accurately obtain the refractive index of a glass prism. The equations for the glass prism becomes much simpler when the refractive angle † becomes small enough that its sine and the sines of the angle of deviations may be set equal to the angles themselves (especially for angular measure in radians). For such prism, equation (2.11) reduces to $= \frac{\alpha + d}{\alpha}$. The subscript in has been dropped because such prisms are always used at their minimum deviation. It is customary to measure the power of a prism by the deflection it produces in cm at a distance of 1. The unit of prism power is the prism Diopter, defined as the deflection 1 on a screen 1 away.

DISPERSION OF WHITE LIGHT BY A PRISM

When white light falls on a glass prism and the emergent beam focused on a screen, different colors made up of Red-Orange-Yellow-Green-Blue-Indigo-Violet are seen. This collection of colors is called the spectrum of white light. Usually the colors are not distinctly separated but overlap, thus impure spectrum is formed. Using two or more glass prisms properly arranged as in a spectrum analyzer produces pure spectrum. For a small angled prism, we can obtain an expression for the deviation. In case of monochromatic light, the refractive index of that color of light is $\mu = \frac{\sin i}{\sin r}$, and for small angle $\sin \Theta \approx \tan \Theta = \Theta$ in radian. This implies we can write $i_j = \mu r_j$; where $j = 1,2,3\ldots$ The deviation has been defined as

$$d = i_1 - r_1 + i_2 - r_2 = r_1 + r_2 = \mu r_1 - r_1 + \mu r_2 - r_2 = (r_1 + r_2)(\mu - 1) = (\mu - 1)\alpha$$

Equation (2.12) defines the magnitude of the deviation given by a prism for any small angle of incidence. We note that the deviation is independent of the value of the incident angle. The angular dispersion between the emergent red and blue light is defined as the angle between the two rays, and is given by

$$\Theta = (\mu_b - 1)\alpha - (\mu_r - 1)\alpha = (\mu_b - \mu_r)\alpha$$

where μ_b and μ_r is the refractive indices for blue light and red light respectively. For white light, the mean deviation is the deviation of the yellow light, since it is the color approximately in the middle of the spectrum. The mean refractive index of the material is also quoted for yellow light. The amount of dispersion of any material is measured by its dispersive power defined as

$$w = \frac{angular\ dispration\ between\ blue\ and\ red\ rays}{mean\ diviation} = \frac{d_b - d_r}{(\mu - 1)\,\alpha} = \frac{\mu_b - \mu_r}{(\mu - 1)`}$$

OPTICAL INSTRUMENTS

INTRODUCTION

An optical instrument either processes light waves to enhance an image for viewing, or analyzes light waves (or photons) to determine one of a number of characteristic properties of the light. The eye being a natural optical instrument, it is the most complicated, no artificial optical instrument can yet match its ability for accommodation and dynamic range. The first optical instruments were magnifying glasses and telescopes. Telescope were used for magnification of distant images, and microscopes used for magnifying very tiny images. Since the days of Galileo, these instruments have been greatly improved and extended into other portions of the electromagnetic spectrum. The binocular device is a generally compact instrument for both eyes designed for mobile use. A camera could be considered a type of optical instrument, with the pinhole camera being very simple examples of such devices. Other classes of optical instrument used for the analyses of the properties of light or optical materials include:

i. Interferometer for measuring the interference (wave propagation) properties of light waves
ii. Photometer for measuring light intensity
iii. Polarimeter for measuring dispersion or rotation of polarized light
iv. Reflectometer for measuring the reflectivity of a surface or object.
v. Refractometer for measuring refractive index of various materials
vi. Spectrometer or monochromator for generating or measuring a portion of the optical spectrum, for the purpose of chemical or material analysis
vii. Autocollimator which is used to measure angular deflections
viii. Vertometer which is used to determine refractive power of lenses such as glasses, contact lenses and magnifier lens
ix. Polarization Controller
x. DNA Sequencers can be considered optical instruments as they analyze the color and intensity of the light emitted by a fluorochrome attached to a specific nucleotide of a DNA strand
xi. Surface Plasmon resonance-based instruments use refractometry to measure and analyze bio-molecular interactions

THE EYE

Eyes are the organs of vision. They detect light and convert it into electro-chemical impulses in neurons. In higher organisms, the eye is a complex optical system which collects light from the surrounding environment, regulates its intensity through a diaphragm, focuses it through an adjustable assembly of lenses to form an image, converts this image into a set of electrical signals, and transmits these signals to the brain through complex neural pathways that connect the eye via the optic nerve to the visual cortex and other areas of the brain. Eyes with resolving power have come in fundamentally different forms, and 96% of animal species possess such a complex optical system. The simplest "eyes", such as those in microorganisms, do nothing but detect whether the surroundings are light or dark. For the more complex eyes, retinal photosensitive cells send signals to the brain through the neurons for adjustments of the light intensity, image formation and interpretations. Complex eyes can distinguish shapes and colors. The visual fields of many organisms, involve large areas of binocular vision to improve depth perception and to maximize the field of view

The Human Eye

The human eye is an organ that reacts to light and has several purposes. As a sense organ, the eye allows vision. Rod and cone cells in the retina allow conscious light perception and vision and interpretation, including color differentiation and the perception of depth. The human eye can distinguish about 10 million colors, for those that can enjoy ‘normal’ vision with overall power as p ~58.64.Yet in some instances like Optical Illusion, our perception of vision cannot be relied upon. In spite of any imperfection in human vision, we can perceive beauty, form and motion with illumination from white light and its constituent colors.

The eye is like a fine camera, with a shutter, iris, and lens system on one side and a light sensitive film called retina on the other side. The lens focuses the real but inverted diminished image of the object on the retina, the iris acts like a diaphragm which opens wide for faint light and reduces its aperture for bright light. The iris also determines the color of the eyes. The retina contains hundreds of light sensitive nerves called cones and rods that changes light pulses into electric signal for transmission to the brain for interpretation. While the cones responds to bright light and are responsible for distinction in colors, rods are sensitive to faint light, to motions and variation in intensity. Our perception of light may be divided into two parts – (i) the optical components leading to the formation of image on the retina and (ii) the property of the nerve canal and brain to interpret the electrical impulse produced.

Structure

The eye is not shaped like a perfect sphere, rather it is a fused two-piece unit. The smaller frontal unit, more curved, called the cornea is linked to the larger unit called the sclera. The corneal segment is typically about 8mm in radius. The sclerotic chamber constitutes the remaining larger part of the eye with radius typically about 12mm. The cornea and sclera are connected by a ring called the limbus. The iris – the color of the eye – and its black center, the pupil, are seen instead of the cornea due to the cornea's transparency. The area opposite the pupil called the fundus, shows the characteristic pale optic disk, where vessels entering the eye pass across and optic nerve fibers depart the globe. The eye includes a lens similar to lenses found in optical instruments such as cameras and the same principles can be applied. The pupil of the human eye is its aperture; the iris is the diaphragm that serves as the aperture stop. Refraction in the cornea causes the effective aperture (the entrance pupil) to differ slightly from the physical pupil diameter. The entrance pupil is typically about 4mm in diameter, although it can range from 2mm in a brightly lit place to 8mm in the dark. The latter value decreases slowly with age; older people's eyes sometimes dilate to not more than 5 – 6 mm.

Summarizing, the eye being one of the most intricate and sensitive organ has the following basic structures

i. Eye Lens – This is what focuses the light entering the eye.
ii. Ciliary Muscles – This are attached to the eye lens surfaces and is used in altering the focal length of the eye lens
iii. Retina – The light sensitive area of the eye where the image of the object is formed.

iv. Yellow Spot – The most sensitive spot on the retina.

v. Iris – The colored circle round the eye lens.

vi. Cornea – The thick transparent protective covering in front of the lens which also acts as refractive medium

vii. Vitreous Humor and Aqueous Humor – Liquid behind and in front of the eye lens in which the eye lens floats.

viii. Blind Spot – This is the region where the optic nerves enter the eye and is insensitive to light. Image formed at the blind spot cannot be perceived.

ix. Pupil – The circular opening or diaphragm in the iris through which light passes.

Size

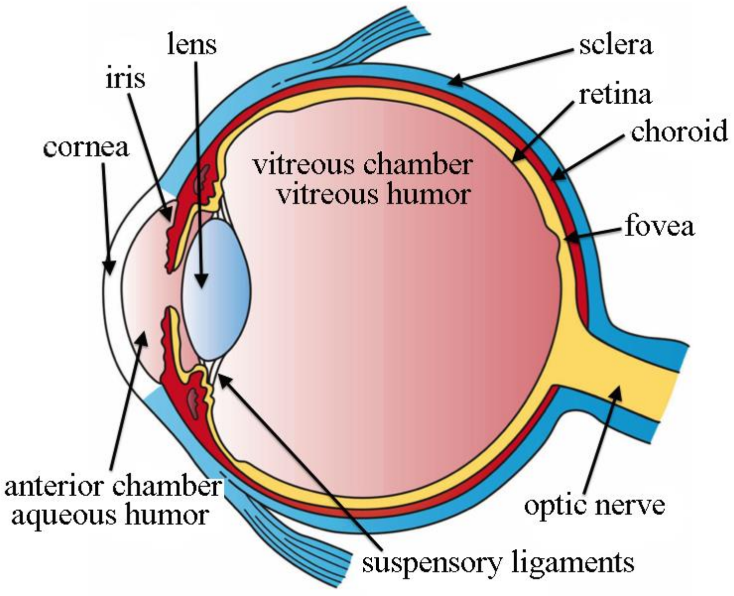
The dimensions differ among adults by only one or two millimeters; it is remarkably consistent across different ethnicities. The vertical measure, generally less than the horizontal distance, is about 24 mm among adults, at birth about 16– 17 mm. The eyeball grows rapidly, increasing to 22.5– 23 mm, by three years of age. By age 13, the eye attains its full size. The typical adult eye has an anterior to posterior diameter of 24 mm, a volume of 6 cm^3 and a mass of 7.5g.

Components

The component of the eye is made up of three coats, enclosing three transparent structures. The outermost layer, known as the fibrous tunic, is composed of the cornea and sclera. The middle layer, known as the vascular tunic, consists of the choroid, ciliary body, and iris. The innermost is the retina, within these coats are the aqueous humor, the vitreous body, and the flexible lens. The aqueous humor is a clear fluid that is contained in two areas: the anterior chamber between the cornea and the iris, and the posterior chamber between the iris and the lens. The lens is suspended to the ciliary body by the suspensory ligament, made up of fine transparent fibers. The vitreous body is a clear jelly that is much larger than the aqueous humor present behind the lens, and the rest is bordered by the sclera, and lens. They are connected via the pupil

Field of View

The approximate field of view of an individual human eye is 95° away from the nose, 75° downward, 60° toward the nose, and 60° upward, allowing humans to have an almost 180-degree forward-facing horizontal field of view. With eyeball rotation of about 90°, horizontal field of view is as high as 270°. About 12– 15° temporal and 1.5° below the horizontal is the optic nerve or blind spot which is roughly 7.5° high and 5.5° wide.



Dynamic Range

The retina has a static contrast ratio of around 100: 1 (by implication it can differentiate between two objects that are 100 times brighter than each other). As soon as the eye moves it re-adjusts its exposure both chemically and geometrically by adjusting the iris which regulates the size of the pupil. The process is nonlinear and multifaceted, so an interruption by light merely starts the adaptation process over again. The human eye can detect a luminance range of 10^{14}. At the low end of the range is the absolute threshold of vision for a steady light across a wide field of view, about 10^{-6} cdm^{-2} . while the upper end of the range is given in terms of normal visual performance as 10^{8} cdm^{-2} (cdm^{-2} is defined as candela per square meter – the unit of luminance).

Accommodation of the Lens

Accommodation is achieved by changing the curvature of the lens is carried out by the ciliary muscles surrounding the lens. They narrow the diameter of the ciliary body, relax the fibers of the suspensory ligament, and allow the lens to relax into a more convex shape. A more convex (more contracted and thicker) lens refracts light more strongly and focuses divergent light rays onto the retina allowing for closer objects to be brought into focus. On the other hand, distant objects are brought into focus by relaxing the curvature of the lens by making them more extended and thinner.

3.2.8 Binocular Vision

The world appears to us as three-dimensional because the images seen by our two eyes are slightly different; the left eye sees more of the left side of the object than the right, and vice-versa, enabling the solidity of an object to be appreciated. The possession of two eyes also helps to judge distances. When looking at near objects, the lines of vision of the two eyes must converge and the muscular effort involved helps to give an idea of the distance.

3.2.9 Dark Adaptation

One of the outstanding properties of the eye is the enormous range of its sensitivity to light. When we enter a darkened room, from the daylight, our eyes take some time to become accustomed to the darkness and we may be quite unable to find anything without assistance initially. The process of becoming accustomed to the darkness is known as dark adaptation of the eye and is believed to involve the manufacture of extra quantities of visual purple. It is slow during the first 10 minutes and rapid in the next 20-30 minutes. Night-blind people are very slow in becoming adapted and may take up to an hour to get adapted.

3.2.10 The Purkinje Effect

In 1825 J.E. Purkinje, observed that, in twilight, red flowers appear darker than blue ones, although they may appear equally bright in sunlight. Eventually, at dusk, the red flowers look black and the blue flowers grey. This change of the spectral sensitivity of the eye with a decrease in light intensity is known as Purkinje Effect. Vision at low intensity, when all color disappear, is known as scotopic vision; vision at high intensity is known as photopic vision.

3.2.11. Color Adaptation

If the eye is exposed to a bright red light (as an example) for some minutes its sensitivity to red light is depressed. Consequently, the colors of objects appear different to an eye 41 which has been so exposed than they do so to a normal eye. This phenomenon is known as color adaptation.

3.2.12 After-Image

If one looks for a second or two at a bright object and then closes one's eyes, a bright image of the object will be seen, known as a positive after-image. The after-image may change color and the phenomenon is very complex. If one looks at a bright red source of light for a short time and then transfers one's gaze to a brightly illuminated white sheet of paper, a blue-green image of the source of light will be seen. This is known as negative after-image. And its color is complimentary to that of the original image. Usually, it is explained by assuming that the sensitivity of the red receptors, in that part of the retina where the original image was formed, is depressed, and hence the white paper stimulates chiefly the blue and the green receptors giving rise to a blue-green image. The phenomenon is sometimes called successive contrast. Another phenomenon the enhancement of colors of an object when placed beside other colored objects is called simultaneous contrast. In general, every colored object tends to modify and enhance the colors of neighboring objects in the direction of its own complementary color.

3.3. DEFECTS OF THE EYE

There are many diseases, disorders, and age-related changes that may affect the eyes and surrounding structures. As the eye ages, certain changes occur that can be attributed solely to the aging process. Most of these eye defect which are anatomic and physiologic processes follow a gradual decline. With aging, the quality of vision worsens due to reasons independent of diseases of the aging eye. While there are many changes of significance in the non-diseased eye, the most functionally important changes seem to be a reduction in pupil size and the loss of accommodation. Other eye defect include the presbyopia, hypermetropia, astigmatism.

3.3.1 Myopia

Myopia commonly known as near-sightedness or short-sightedness is a condition of the eye where the light that comes in does not directly focus on the retina but in front of it, causing the image that one sees when looking at a distant object to be out of focus, but in focus when looking at a close object. It may also be corrected by refractive surgery, though there are cases of associated side effects or with corrective lenses that have a negative optical power (concave lenses) which compensates for the excessive convergence of the myopic eye.

3.3.2 Hypermetropia

Hyperopia or hypermetropia commonly known as being farsighted or longsighted is a defect of vision caused by an imperfection in the eye. Occurring when the eyeball is 42 too short or the lens cannot become round enough, causing difficulty focusing on near objects, and in extreme cases causing a sufferer to be unable to focus on objects at any distance. As an object moves toward the eye, the eye must increase its optical power to keep the image in focus on the retina. If the power of the cornea and lens is insufficient, as in hyperopia, the image will appear blurred. The causes of hyperopia are typically genetic and involve an eye that is too short or a cornea that is too flat, so that images focus at a point behind the retina. It may be corrected with convex lenses in eyeglasses or contact lenses. Convex lenses have a positive power value, which causes the light to focus closer than its normal range.

3.3.3 Lack of Accommodation or Presbyopia

Presbyopia is a condition associated with aging in which the eye exhibits a progressively diminished ability to focus on objects. Presbyopia’s exact mechanisms are not fully understood; research evidence most strongly supports a loss of elasticity of the crystalline lens, although changes in the lens's curvature from continual growth and loss of power of the ciliary muscles (the muscles that bend and straighten the lens) have also been postulated as its cause. The first signs of presbyopia – eyestrain, difficulty seeing in dim light, problems focusing on small objects and/or fine print – are usually first noticed between the ages of 40 and 50. Corrective lenses that provide a range of vision correction, are used in treatment, including varifocal or bifocal lenses to eliminate the need for a separate pair of reading glasses, newer bifocal or varifocal spectacle lenses attempt to correct both near and far vision with the same lens.

3.3.4 Astigmatism

Astigmatism is an optical defect in which vision is blurred due to the inability of the optics of the eye to focus a point object into a sharp focused image on the retina. Astigmatism causes difficulties in seeing fine detail resulting in blurred vision, for example, the image may be clearly focused on the retina in the horizontal plane, but not in the vertical plane. This may be due to an irregular curvature of the cornea or lens. The refractive error of the astigmatic eye stems from a difference in degree of curvature refraction of the two different meridians (i.e., the eye has different focal points in different planes). The two types of astigmatism are regular and irregular. Three options exist for the treatment of astigmatism: glasses, contact lenses (either hard contact lenses or toric contact lenses), and refractive surgery. Irregular astigmatism is often caused by a corneal scar or scattering in the crystalline lens, and cannot be corrected by standard spectacle lenses, but can be corrected by contact lenses. The more common regular astigmatism arising from either the cornea or crystalline lens can be corrected by cylindrical eyeglasses or toric lenses. 43

3.3.5 Color Blindness

This is the absence or paralysis of the fibers of the retina which are sensitive to the color one is blind to. There are various types: (i) Protanopia – Absence/Failure of Red receptors (ii) Deuteranopia – Red and Green (iii) Tritanopia – Blues and Greens confused (iv) Monochromatism – Total color blindness (v) Anomalous Trichromatism – Though may appear normal but require different amounts of Green and Red color in their color mixture than normal people.