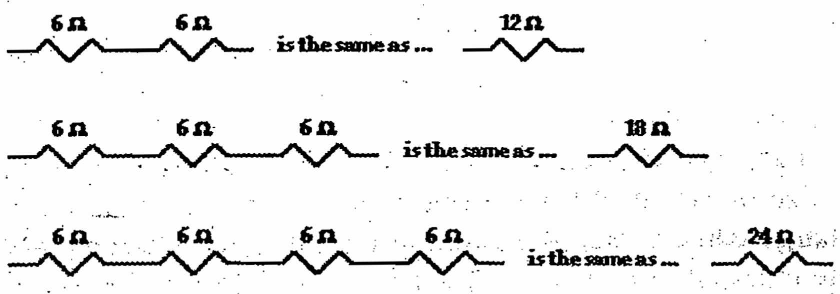
Equivalent Resistance



This is the concept of equivalent resistance. The **equivalent resistance** of a circuit is the amount of resistance which a single resistor would need in order to equal the overall affect of the collection of resistors which are present in the circuit. For series circuits, the mathematical formula for computing the equivalent resistance (R_{eq}) is

$$\mathbf{R_{eq} = R_1 + R_2 + R_3 + ...}$$

where R_1, R_2, and R_3 are the resistance values of the individual resistors which are connected in series.

The current in a series circuit is everywhere the same. Charge does NOT pile up and begin to accumulate at any given location such that the current at one location is more than at other locations. Charge does NOT become used up by resistors such that there is less of it at one location compared to another. The charges can be thought of as marching together through the wires of an electric circuit, everywhere marching at the same rate. Current - the rate at which charge flows - is everywhere the same. It is the same at the first resistor as it is at the last resistor as it is in the battery. Mathematically, one might write

$$\mathbf{I_{battery} = I_1 = I_2 = I_3 = ...}$$

where I_1, I_2, and I_3 are the current values at the individual resistor locations.

These current values are easily calculated if the battery voltage is known and the individual resistance values are known. Using the individual resistor values and the equation above, the equivalent resistance can be calculated. And using Ohm's law ($\Delta V = I \cdot R$), the current in the battery and thus through every resistor can be determined by finding the ratio of the battery voltage and the equivalent resistance.

$$\mathbf{I_{battery} = I_1 = I_2 = I_3 = \Delta V_{battery} / R_{eq}}$$

Parallel Circuits

When all the devices are connected using parallel connections, the circuit is referred to as a **parallel circuit**. In a parallel circuit, each device is placed in its own separate *branch*. The presence of branch lines means that there are multiple pathways by which charge can traverse the external circuit. Each charge passing through the loop of the external circuit will pass through a single resistor present in a single branch. When arriving at the branching location or node, a charge *makes a choice* as to which branch to travel through on its journey back to the low potential terminal.

Current

In a parallel circuit, charge *divides* up into separate branches such that there can be more current in one branch than there is in another. Nonetheless, when taken as a whole, the total amount of current in all the branches when added together is the same as the amount of current at locations outside the branches. The rule that *current is everywhere the same* still works, only with a twist. The current outside the branches is the same as the sum of the current in the individual branches. It is still the same amount of current, only split up into more than one pathway.

In equation form, this principle can be written as

$$I_{total} = I_1 + I_2 + I_3 + ...$$

where I_{total} is the total amount of current outside the branches (and in the battery) and I_1, I_2, and I_3 represent the current in the individual branches of the circuit.

This is illustrated in the examples. In the examples a new circuit symbol is introduced - **the letter A enclosed within a circle. This is the symbol for an ammeter - a device used to measure the current at a specific point.** An ammeter is capable of measuring the current while offering negligible resistance to the flow of charge.

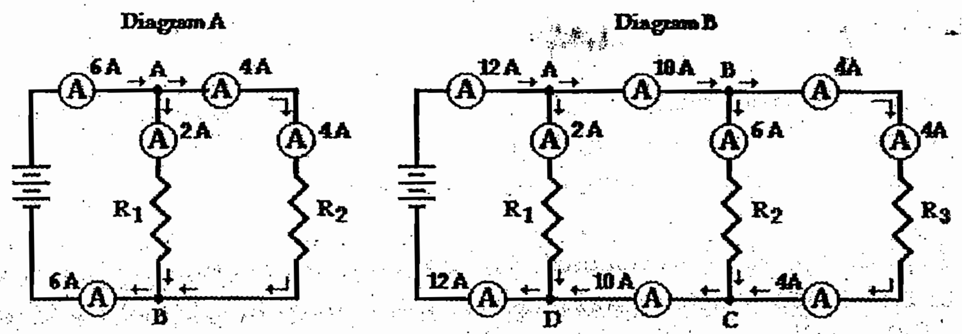


Diagram A displays two resistors in parallel with nodes at point A and point B. Charge flows into point A at a rate of 6 amps and divides into two pathways - one through resistor 1 and the other through resistor 2. The current in the branch with resistor 1 is 2 amps and the current in the branch with resistor 2 is 4 amps. After these two branches meet again at point B to form a single line, the current again becomes 6 amps. Thus we see the principle that the current outside the branches is equal to the sum of the current in the individual branches holds true.

$I_{total} = I_1 + I_2$

6 amps = 2 amps + 4 amps

Diagram B above may be slightly more complicated with its three resistors placed in parallel. Four nodes are identified on the diagram and labeled A, B, C and D. Charge flows into point A at a rate of 12 amps and divides into two pathways - one passing through resistor 1 and the other heading towards point B (and resistors 2 and 3). The 12 amps of current is divided into a 2 amp pathway (through resistor 1) and a 10 amp pathway (heading toward point B). At point B, there is further division of the flow into two pathways - one through resistor 2 and the other through resistor 3. The 10 amps of current approaching point B is divided into a 6 amp pathway (through resistor 2) and a 4 amp pathway (through resistor 3). Thus, it is seen that the current values in the three branches are 2 amps, 6 amps and 4 amps and that the sum of the current values in the individual branches is equal to the current outside the branches.

$I_{total} = I_1 + I_2 + I_3$

12 amps = 2 amps + 6 amps + 4 amps

A flow analysis at points C and D can also be conducted and it is observed that the sum of the flow rates heading into these points is equal to the flow rate which is found immediately beyond these points.

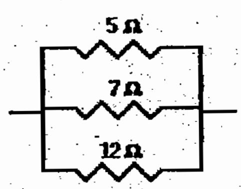
Equivalent Resistance

The actual amount of current always varies inversely with the amount of overall resistance. There is a clear relationship between the resistance of the individual resistors and the overall resistance of the collection of resistors.

This is the concept of equivalent resistance. The **equivalent resistance** of a circuit is the amount of resistance which a single resistor would need in order to equal the overall effect of the collection of resistors which are present in the circuit. For parallel circuits, the mathematical formula for computing the equivalent resistance (R_{eq}) is

$1 / R_{eq} = 1 / R_1 + 1 / R_2 + 1 / R_3 + ...$where R_1, R_2, and R_3 are the resistance values of the individual resistors which are connected in parallel. For instance, consider the application of the equation to the one case below.

A 5.0 Ω, 7.0 Ω, and 12 Ω resistor are placed in parallel



$1/R_{eq} = 1/R_1 + 1/R_2 + 1/R_3$

$1/R_{eq} = 1/(5.0\ \Omega) + 1/(7.0\ \Omega) + 1/(12\ \Omega)$

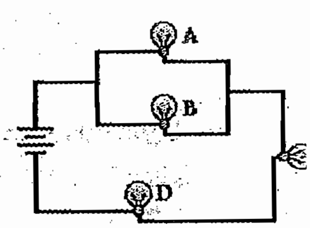
Using a calculator ...

$1/R_{eq} = 0.42619\ \Omega^{-1}$

$R_{eq} = 1 / (0.42619\ \Omega^{-1})$

$R_{eq} = 2.3\ \Omega$

Combination Circuits When all the devices in a circuit are connected by series connections, then the circuit is referred to as a series circuit. When all the devices in a circuit are connected by parallel connections, then the circuit is referred to as a parallel circuit. A third type of circuit involves the dual use of series and parallel connections in a circuit; such circuits are referred to as compound circuits or combination circuits. The circuit depicted at the right is an example of the use of both series and parallel connections within the same circuit. In this case, light bulbs A and B are connected by parallel connections and light bulbs C and D are connected by series connections. This is an example of a **combination circuit.**



When analyzing combination circuits, it is critically important to have a solid understanding of the concepts which pertain to both series circuits and parallel circuits. Since both types of connections are used in combination circuits, the concepts associated with both types of circuits apply to the respective parts of the circuit. The main concepts associated with series and parallel circuits are organized in the table below.

Series Circuits

- The current is the same in every resistor; this current is equal to that in the battery.
- The sum of the voltage drops across the individual resistors is equal to the voltage rating of the battery.
- The overall resistance of the collection of resistors is equal to the sum of the individual resistance values,

$R_{tot} = R_1 + R_2 + R_3 + ...$

Parallel Circuits

- The voltage drop is the same across each parallel branch.
- The sum of the current in each individual branch is equal to the current outside the branches.
- The equivalent or overall resistance of the collection of resistors is given by the equation

$1/R_{eq} = 1/R_1 + 1/R_2 + 1/R_3 ...$

Each of the above concepts has a mathematical expression. Combining the mathematical expressions of the above concepts with the Ohm's law equation ($\Delta V = I \cdot R$) allows one to conduct a complete analysis of a combination circuit.

Analysis of Combination Circuits

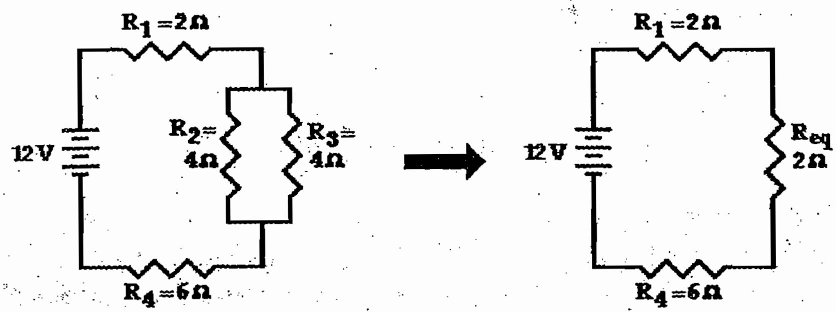
The basic strategy for the analysis of combination circuits involves using the meaning of equivalent resistance for parallel branches to transform the combination circuit into a series circuit. Once transformed into a series circuit, the analysis can be conducted in the usual manner

Consider the following diagrams below. Diagram A represents a combination circuit with resistors R_2 and R_3 placed in parallel branches. Two 4-Ω resistors in parallel is equivalent to a resistance of 2 Ω. Thus, the two branches can be replaced by a single resistor with a resistance of 2 Ω. This is shown in Diagram B. Now that all resistors are in series, the formula for the total resistance of series resistors can be used to determine the total resistance of this circuit: The formula for series resistance is

$$R_{tot} = R_1 + R_2 + R_3 + ...$$

So in Diagram B, the total resistance of the circuit is 10 Ω.

Diagram A Diagram B

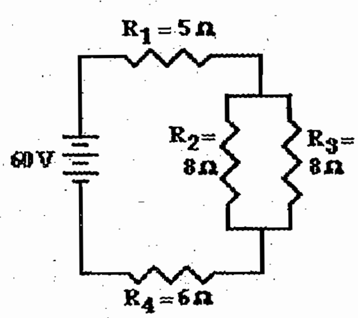


Once the total resistance of the circuit is determined, the analysis continues using Ohm's law and voltage and resistance values to determine current values at various locations.

The entire method is illustrated below with an example.

Example

The first example is the easiest case - the resistors placed in parallel have the same resistance. The goal of the analysis is to determine the current in and the voltage drop across each resistor.



R_{tot} = ________ I_{tot} = ________

I_1= ________ ΔV_1 = ________

I_2= ________ ΔV_2 = ________

I_3= ________ ΔV_3= ________

I_4= ________ ΔV_4= ________

As discussed above, the first step is to simplify the circuit by replacing the two parallel resistors with a single resistor which has an equivalent resistance. Two 8 Ω resistors in series is equivalent to a single 4 Ω resistor. Thus, the two branch resistors (R_2 and R_3) can be replaced by a single resistor with a resistance of 4 Ω. This 4 Ω resistor is in series with R_1 and R_4. Thus, the total resistance is

$R_{tot} = R_1 + 4\,\Omega + R_4 = 5\,\Omega + 4\,\Omega + 6\,\Omega$

$\mathbf{R_{tot} = 15\,\Omega}$

Now the Ohm's law equation ($\Delta V = I \cdot R$) can be used to determine the total current in the circuit. In doing so, the total resistance and the total voltage (or battery voltage) will have to be used.

$I_{tot} = \Delta V_{tot} / R_{tot} = (60\ V) / (15\ \Omega)$

$\mathbf{I_{tot} = 4\ Amp}$

The 4 Amp current calculation represents the current at the battery location. Yet, resistors R_1 and R_4 are in series and the current in series-connected resistors is everywhere the same. Thus,

$\mathbf{I_{tot} = I_1 = I_4 = 4\ Amp}$

For parallel branches, the sum of the current in each individual branch is equal to the current outside the branches. Thus, $I_2 + I_3$ must equal 4 Amp. There is an infinite possibilities of I_2 and I_3 values which satisfy this equation. Since the resistance values are equal, the current values in these two resistors is also equal. Therefore, the current in resistors 2 and 3 are both equal to 2 Amp.

$\mathbf{I_2 = I_3 = 2\ Amp}$

Now that the current at each individual resistor location is known, the Ohm's law equation ($\Delta V = I \cdot R$) can be used to determine the voltage drop across each resistor. These calculations are shown below.

$\Delta V_1 = I_1 \cdot R_1 = (4\ Amp) \cdot (5\ \Omega)$

$\mathbf{\Delta V_1 = 20\ V}$

$\Delta V_2 = I_2 \cdot R_2 = (2\ Amp) \cdot (8\ \Omega)$

$\mathbf{\Delta V_2 = 16\ V}$

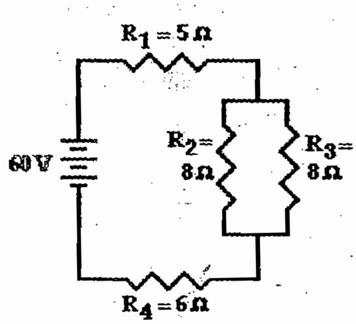
$\Delta V_3 = I_3 \cdot R_3 = (2\ Amp) \cdot (8\ \Omega)$

$\mathbf{\Delta V_3 = 16\ V}$

$\Delta V_4 = I_4 \cdot R_4 = (4\ Amp) \cdot (6\ \Omega)$

$\mathbf{\Delta V_4 = 24\ V}$

The analysis is now complete and the results are summarized in the diagram below.



R_{tot} = 15 Ω	I_{tot} = 4 Amp
I_1 = 4 Amp	ΔV_1 = 20 V
I_2 = 2 Amp	ΔV_2 = 16 V
I_3 = 2 Amp	ΔV_3 = 16 V
I_4 = 4 Amp	ΔV_4 = 24 V

9. Waves

A wave can be described as a disturbance that travels through a medium from one location to another location. Consider a slinky wave(**A Slinky is a coil-shaped toy**) as an example of a wave. When the slinky is stretched from end to end and is held at rest, it assumes a natural position known as the **equilibrium or rest position**. The coils of the slinky naturally assume this position, spaced equally far apart. To introduce a wave into the slinky, the first particle is displaced or moved from its equilibrium or rest position. The particle might be moved upwards or downwards, forwards or backwards; but once moved, it is returned to its original equilibrium or rest position. The act of moving the first coil of the slinky in a given direction and then returning it to its equilibrium position creates a **disturbance** in the slinky. We can then observe this disturbance moving through the slinky from one end to the other. If the first coil of the slinky is given a single back-and-forth vibration, then we call the observed motion of the disturbance through the slinky a *slinky pulse*. A **pulse** is a single disturbance moving through a medium from one location to another location. However, if the first coil of the slinky is continuously and periodically vibrated in a back-and-forth manner, we would observe a repeating disturbance moving within the slinky which endures over some prolonged period of time. The repeating and periodic disturbance which moves through a medium from one location to another is referred to as a **wave**.

When a slinky is stretched, the individual coils assume an equilibrium or rest position.

When the first coil of the slinky is repeatedly vibrated back and forth, a disturbance is created which travels through the slinky from one end to the other.

What is a Medium?

But what is meant by the word *medium*? A **medium** is a substance or material which carries the wave.

A Wave Transports Energy and Not Matter

Waves are said to be an **energy transport phenomenon**. As a disturbance moves through a medium from one particle to its adjacent particle, energy is being transported from one end of the medium to the other.

In conclusion, a wave can be described as a disturbance which travels through a medium, transporting energy from one location (its source) to another location without transporting matter. Each individual particle of the medium is temporarily displaced and then returns to its original equilibrium positioned.

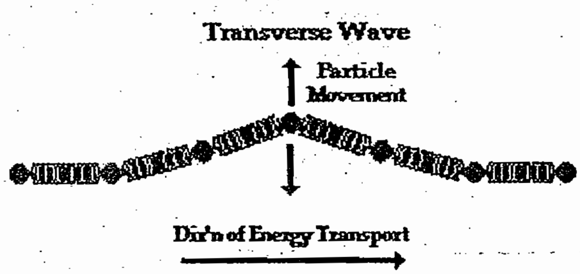
Categories of Waves

Waves come in many shapes and forms. While all waves share some basic characteristic properties and behaviors, some waves can be distinguished from others based on some observable (and some non-observable) characteristics. It is common to categorize waves based on these distinguishing characteristics.

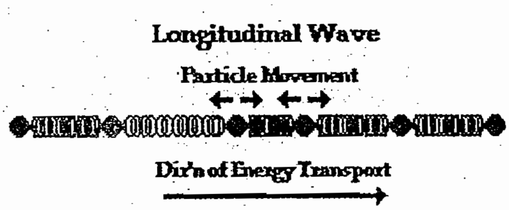
Longitudinal versus Transverse Waves versus Surface Waves

One way to categorize waves **is on the basis of the direction of movement** of the individual particles of the medium relative to the direction which the waves travel. Categorizing waves on this basis leads to **three notable categories: transverse waves, longitudinal waves, and surface waves.**

A **transverse wave** is a wave in which particles of the medium move in a direction perpendicular to the direction which the wave moves.



A **longitudinal wave** is a wave in which particles of the medium move in a direction parallel to the direction which the wave moves.



A sound wave traveling through air is a classic example of a longitudinal wave.

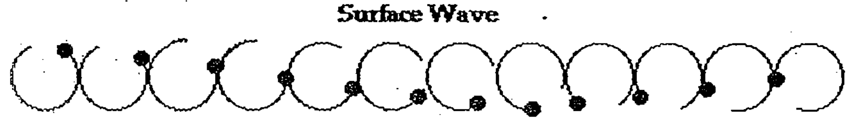
Waves traveling through a solid medium can be either transverse waves or longitudinal waves. Yet waves traveling through the bulk of a fluid (such as a liquid or a gas) are always longitudinal waves.

Transverse waves require a relatively rigid medium in order to transmit their energy. As one particle begins to move it must be able to exert a pull on its nearest neighbor. If the medium is not rigid as is the case with fluids, the particles will slide past each other. This sliding action which is characteristic of liquids and gases prevents one particle from displacing its neighbor in a direction perpendicular to the energy transport. It is for this reason that only longitudinal waves are observed moving through the bulk of liquids such as our oceans.

Earthquakes are capable of producing both transverse and longitudinal waves which travel through the solid structures of the Earth. When seismologists began to study earthquake waves they noticed that only longitudinal waves were capable of traveling through the core of the Earth. For this reason, geologists believe that the Earth's core consists of a liquid - most likely molten iron.

While waves which travel within the depths of the ocean are longitudinal waves, the waves which travel along the surface of the oceans are referred to as surface waves. A **surface wave** is a wave in which particles of the medium undergo a circular motion. Surface waves are neither longitudinal nor transverse. In longitudinal and transverse waves, all the particles in the entire bulk of the medium move in a parallel and a perpendicular direction (respectively) relative to the direction of energy transport. In a surface wave, it is only the particles at the surface of the medium which undergo the circular motion. The motion of particles tend to decrease as one proceeds further from the surface.

Surface Wave



A surface wave is sometimes referred to as a circular wave since particles of the medium undergo a motion in a complete circle.

Electromagnetic versus Mechanical Waves

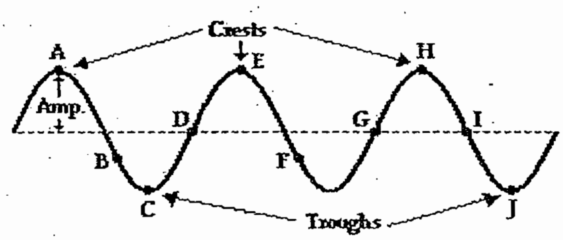
Another way to categorize waves is on the basis of **their ability or inability to transmit energy through a vacuum (i.e., empty space)**. Categorizing waves on this basis leads to **two notable categories: electromagnetic waves and mechanical waves**.

An **electromagnetic wave** is a wave which is capable of transmitting its energy through a vacuum (i.e., empty space). Electromagnetic waves are produced by the vibration of charged particles. Electromagnetic waves which are produced on the sun subsequently travel to Earth through the vacuum of outer space. Were it not for the ability of electromagnetic waves to travel to through a vacuum, there would undoubtedly be no life on Earth. All light waves are examples of electromagnetic waves.

A **mechanical wave** is a wave which is not capable of transmitting its energy through a vacuum. Mechanical waves require a medium in order to transport their energy from one location to another. A sound wave is an example of a mechanical wave. Sound waves are incapable of traveling through a vacuum. Slinky waves, water waves, stadium waves, and jump rope waves are other examples of mechanical waves; each requires some medium in order to exist. A slinky wave requires the coils of the slinky; a water wave requires water; a stadium wave requires fans in a stadium; and a jump rope wave requires a jump rope.

The Anatomy of a Wave

A transverse wave is a wave in which the particles of the medium are displaced in a direction perpendicular to the direction of energy transport. A transverse wave can be created in a rope if the rope is stretched out horizontally and the end is vibrated back-and-forth in a vertical direction. If a snapshot of such a transverse wave could be taken so as to *freeze* the shape of the rope in time, then it would look like the following diagram.

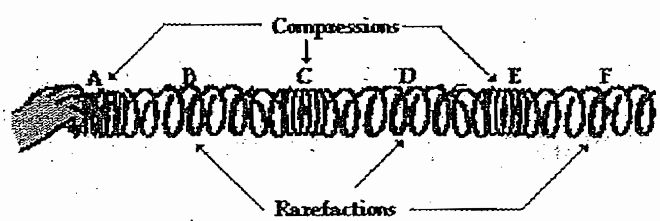


The dashed line drawn through the center of the diagram represents the equilibrium or rest position of the string. This is the position that the string would assume if there were no disturbance moving through it. Once a disturbance is introduced into the string, the particles of the string begin to vibrate upwards and downwards. At any given moment in time, a particle on the medium could be above or below the rest position. Points A, E and H on the diagram represent the crests of this wave. The **crest** of a wave is the point on the medium which exhibits the maximum amount of positive or upwards displacement from the rest position. Points C and J on the diagram represent the troughs of this wave. The **trough** of a wave is the point on the medium which exhibits the maximum amount of negative or downwards displacement from the rest position.

The wave shown above can be described by a variety of properties. One such property is amplitude. The **amplitude** of a wave refers to the maximum amount of displacement of a particle on the medium from its rest position. In a sense, the amplitude is the distance *from rest to crest.* Similarly, the amplitude can be measured from the rest position to the trough position. In the diagram above, the amplitude could be measured as the distance of a line segment which is perpendicular to the rest position and extends vertically upward from the rest position to point A.

The wavelength is another property of a wave which is portrayed in the diagram above. The **wavelength** of a wave is simply the length of one complete wave cycle. If you were to trace your finger across the wave in the diagram above, you would notice that your finger repeats its path. A wave is a repeating pattern. It repeats itself in a periodic and regular fashion over both time and space. And the length of one such spatial repetition (known as a *wave cycle*) is the wavelength. The wavelength can be measured as the distance from crest to crest or from trough to trough. In fact, the wavelength of a wave can be measured as the distance from a point on a wave to the corresponding point on the next cycle of the wave. In the diagram above, the wavelength is the horizontal distance from A to E, or the horizontal distance from B to F, or the horizontal distance from D to G, or the horizontal distance from E to H. Any one of these distance measurements would suffice in determining the wavelength of this wave.

A longitudinal wave is a wave in which the particles of the medium are displaced in a direction parallel to the direction of energy transport. A longitudinal wave can be created in a slinky if the slinky is stretched out horizontally and the end coil is vibrated back-and-forth in a horizontal direction. If a snapshot of such a longitudinal wave could be taken so as to *freeze* the shape of the slinky in time, then it would look like the following diagram.



Because the coils of the slinky are vibrating longitudinally, there are regions where they become pressed together and other regions where they are spread apart. A region where the coils are pressed together in a small amount of space is known as a compression. A **compression** is a point on a medium through which a longitudinal wave is traveling which has the maximum density. A region where the coils are spread apart, thus maximizing the distance between coils, is known as a rarefaction. A **rarefaction** is a point on a medium through which a longitudinal wave is traveling which has the minimum density. Points A, C and E on the diagram above represent compressions and points B, D, and F represent rarefactions. While a transverse wave has an alternating pattern of crests and troughs, a longitudinal wave has an alternating pattern of compressions and rarefactions.

In the case of a longitudinal wave, a wavelength measurement is made by measuring the distance from a compression to the next compression or from a rarefaction to the next rarefaction. On the diagram above, the distance from point A to point C or from point B to point D would be representative of the wavelength.

Frequency and Period of a Wave

The **frequency** of a wave refers to how often the particles of the medium vibrate when a wave passes through the medium.Given this definition, it is reasonable that the quantity *frequency* would have units of cycles/second, waves/second, vibrations/second, or something/second. Another unit for frequency is the **Hertz** (abbreviated Hz) where 1 Hz is equivalent to 1 cycle/second. If a coil of slinky makes 2 vibrational cycles in one second, then the frequency is 2 Hz.

The **period** of a wave is the time for a particle on a medium to make one complete vibrational cycle. Period, being a time, is measured in units of time such as seconds, hours, days or years. The period of orbit for the Earth around the Sun is approximately 365 days; it takes 365 days for the Earth to complete a cycle.

Frequency and period are distinctly different, yet related, quantities. Mathematically, the period is the reciprocal of the frequency and vice versa. In equation form, this is expressed as follows.

$$\text{period} = \frac{1}{\text{frequency}} \qquad \text{frequency} = \frac{1}{\text{period}}$$

Since the symbol **f** is used for frequency and the symbol **T** is used for period, these equations are also expressed as:

$$T = \frac{1}{f} \qquad f = \frac{1}{T}$$

The Speed of a Wave

The speed of an object refers to how fast an object is moving and is usually expressed as the distance traveled per time of travel. In the case of a wave, the speed is the distance traveled by a given point on the wave (such as a crest) in a given interval of time. In equation form,

$$\text{speed} = \frac{\text{distance}}{\text{time}}$$

The Wave Equation

the speed of a wave is the wavelength/period.

$$\text{Speed} = \frac{\text{Wavelength}}{\text{Period}}$$

Since the period is the reciprocal of the frequency, the expression 1/f can be substituted into the above equation for period. Rearranging the equation yields a new equation of the form:

Speed = Wavelength • Frequency

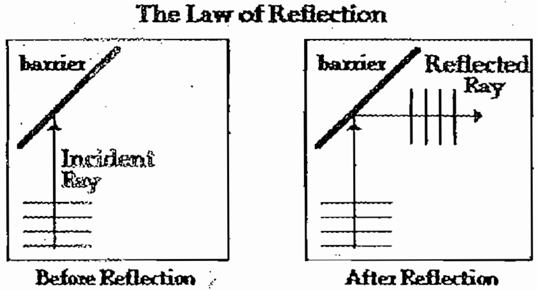
The above equation is known as the wave equation. It states the mathematical relationship between the speed (**v**) of a wave and its wavelength (**λ**) and frequency (**f**). Using the symbols **v**, **λ**, and **f**, the equation can be rewritten as

$$v = f \cdot \lambda$$

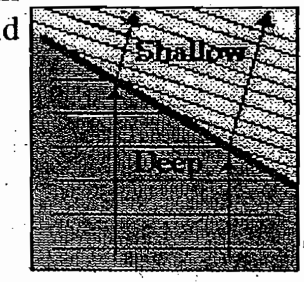
Reflection, Refraction, and Diffraction

The waves will always **reflect** in such a way that the angle at which they approach the barrier equals the angle at which they reflect off the barrier. This is known as the **law of reflection**.

The Law of Reflection

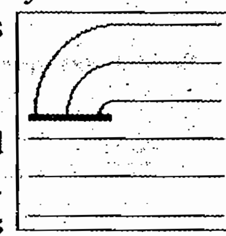


Refraction of waves involves a change in the direction of waves as they pass from one medium to another. Refraction, or the bending of the path of the waves, is accompanied by a change in speed and wavelength of the waves



Diffraction involves a change in direction of waves as they pass through an opening or around a barrier in their path. Water waves have the ability to travel around corners, around obstacles and through openings. This ability is most obvious for water waves with longer wavelengths

Diffraction of water waves is observed in a harbor as waves bend around small boats and are found to disturb the water behind them. The same waves however are unable to diffract around larger boats since their wavelength is smaller than the boat.


Diffraction of Waves

Reflection, refraction and diffraction are all boundary behaviors of waves associated with the bending of the path of a wave.. Reflection of waves off straight barriers follows the law of reflection. **Reflection of waves off parabolic barriers results in the convergence of the waves at a focal point.** Refraction is the change in direction of waves which occurs when waves travel from one medium to another. Refraction is always accompanied by a wavelength and speed change. Diffraction is the bending of waves around obstacles and openings. The amount of diffraction increases with increasing wavelength.

Interference of Waves

Wave interference is the phenomenon which occurs when two waves meet while traveling along the same medium. The interference of waves causes the medium to take on a shape which results from the net effect of the two individual waves upon the particles of the medium.

The **principle of superposition** is sometimes stated as follows:

When two waves interfere, the resulting displacement of the medium at any location is the algebraic sum of the displacements of the individual waves at that same location.

The Doppler Effect

The Doppler effect is observed whenever the source of waves is moving with respect to an observer. The **Doppler effect** can be described as the effect produced by a moving source of waves in which there is an apparent upward shift in frequency for observers towards whom the source is approaching and an apparent downward shift in frequency for observers from whom the source is receding

The Doppler effect can be observed for any type of wave - water wave, sound wave, light wave, etc. We are most familiar with the Doppler effect because of our experiences with sound waves.

The Doppler effect is of intense interest to astronomers who use the information about the shift in frequency of electromagnetic waves produced by moving stars in our galaxy and beyond in order to derive information about those stars and galaxies. The belief that the universe is expanding is based in part upon observations of electromagnetic waves emitted by stars in distant galaxies. Furthermore, specific information about stars within galaxies can be determined by application of the Doppler effect. Galaxies are clusters of stars which typically rotate about some center of mass point. Electromagnetic radiation emitted by such stars in a distant galaxy would appear to be shifted downward in frequency (a *red shift*) if the star is rotating in its cluster in a direction which is away from the Earth. On the other hand, there is an upward shift in frequency (a *blue shift*) of such observed radiation if the star is rotating in a direction that is towards the Earth.

Sound Properties and Their Perception

Human ear is capable of detecting sound waves with a wide range of frequencies, ranging between approximately 20 Hz to 20 000 Hz. Any sound with a frequency below the audible range of hearing (i.e., less than 20 Hz) is known as an **infrasound** and any sound with a frequency above the audible range of hearing (i.e., more than 20 000 Hz) is known as an **ultrasound**. Humans are not alone in their ability to detect a wide range of frequencies. Dogs can detect frequencies as low as approximately 50 Hz and as high as 45 000 Hz. Cats can detect frequencies as low as approximately 45 Hz and as high as 85 000 Hz. Bats, being nocturnal creature, must rely on sound echolocation for navigation and hunting. Bats can detect frequencies as high as 120 000 Hz. Dolphins can detect frequencies as high as 200 000 Hz. While dogs, cats, bats, and dolphins have an unusual ability to detect ultrasound, an elephant possesses the unusual ability to detect infrasound, having an audible range from approximately 5 Hz to approximately 10 000 Hz.

The sensation of a frequencies is commonly referred to as the **pitch** of a sound. A high pitch sound corresponds to a high frequency sound wave and a low pitch sound corresponds to a low frequency sound wave. Amazingly, many people, especially those who have been musically trained, are capable of detecting a difference in frequency between two separate sounds which is as little as 2 Hz. When two sounds with a frequency difference of greater than 7 Hz are played simultaneously, most people are capable of detecting the presence of a complex wave pattern resulting from the interference and superposition of the two sound waves. Certain sound waves when played (and heard) simultaneously will produce a particularly pleasant sensation when heard, are are said to be **consonant**. Such sound waves form the basis of **intervals** in music. For example, any two sounds whose frequencies make a 2:1 ratio are said to be separated by an **octave** and result in a particularly pleasing sensation when heard. That is, two sound waves sound good when played together if one sound has twice the frequency of the other. Similarly two sounds with a frequency ratio of 5:4 are said to be separated by an interval of a **third**; such sound waves also sound good when played together. Examples of other sound wave intervals and their respective frequency ratios are listed in the table below.

Interval	**Frequency Ratio**	**Examples**
Octave	2:1	512 Hz and 256 Hz
Third	5:4	320 Hz and 256 Hz
Fourth	4:3	342 Hz and 256 Hz
Fifth	3:2	384 Hz and 256 Hz

Since the range of intensities which the human ear can detect is so large, the scale which is frequently used by physicists to measure intensity is a scale based on multiples of 10. This type of scale is sometimes referred to as a logarithmic scale. The scale for measuring intensity is the **decibel scale**.

The table below lists some common sounds with an estimate of their intensity and decibel level.

Source	**Intensity**	**Intensity Level**	**# of Times Greater Than TOH**
Threshold of Hearing (TOH)	$1*10^{-12}$ W/m^2	0 dB	10^0
Rustling Leaves	$1*10^{-11}$ W/m^2	10 dB	10^1
Whisper	$1*10^{-10}$ W/m^2	20 dB	10^2
Normal Conversation	$1*10^{-6}$ W/m^2	60 dB	10^6
Busy Street Traffic	$1*10^{-5}$ W/m^2	70 dB	10^7
Vacuum Cleaner	$1*10^{-4}$ W/m^2	80 dB	10^8

Large Orchestra	$6.3*10^{-3}$ W/m^2	98 dB	$10^{9.8}$
Walkman at Maximum Level	$1*10^{-2}$ W/m^2	100 dB	10^{10}
Front Rows of Rock Concert	$1*10^{-1}$ W/m^2	110 dB	10^{11}
Threshold of Pain	$1*10^{1}$ W/m^2	130 dB	10^{13}
Military Jet Takeoff	$1*10^{2}$ W/m^2	140 dB	10^{14}
Instant Perforation of Eardrum	$1*10^{4}$ W/m^2	160 dB	10^{16}

Factors Affecting Wave Speed

The speed of any wave depends upon the properties of the medium through which the wave is traveling. Typically there **are two essential types** of properties which affect wave speed - **inertial properties** and **elastic properties.**

Elastic properties are those properties related to the tendency of a material to **maintain its shape** and not deform whenever a force or stress is applied to it. A material such as steel will experience a very small deformation of shape (and dimension) when a stress is applied to it. Steel is a rigid material with a high elasticity. On the other hand, a material such as a rubber band is highly flexible; when a force is applied to stretch the rubber band, it deforms or changes its shape readily. A small stress on the rubber band causes a large deformation. Steel is considered to be a stiff or rigid material, whereas a rubber band is considered a flexible material. At the particle level, a stiff or rigid material is characterized by atoms and/or molecules with strong attractions for each other. When a force is applied in an attempt to stretch or deform the material, its strong particle interactions prevent this deformation and help the material maintain its shape. Rigid materials such as steel are considered to have a high elasticity. (**Elastic modulus is the technical term**). The phase of matter has a tremendous impact upon the elastic properties of the medium. In general, solids have the strongest interactions between particles, followed by liquids and then gases. For this reason, longitudinal sound waves travel faster in solids than they do in liquids than they do in gases. Even though the inertial factor may favor gases, the elastic factor has a greater influence on the speed (**v**) of a wave, thus yielding this general pattern:

$v_{solids} > v_{liquids} > v_{gases}$

Inertial properties are those properties related to the material's tendency to be sluggish to changes in it's state of motion. **The density of a medium** is an example of an **inertial property**. The greater the inertia (i.e., mass density) of individual particles of the medium, the less responsive they will be to the interactions between neighboring particles and the slower that the wave will be. As stated above, sound waves travel faster in solids than they do in liquids than they do in gases. However, within a single phase of matter, the inertial property of density tends to be the property which has a greatest impact upon the speed of sound. A sound wave will travel faster in a less dense material than a more dense material. Thus, a sound wave will travel nearly three times faster in Helium as it will in air. This is mostly due to the lower mass of Helium particles as compared to air particles.

The speed of a sound wave in air depends upon the properties of the air, namely the temperature and the pressure. The pressure of air (like any gas) will affect the mass density of the air (an inertial property) and the temperature will affect the strength of the particle interactions (an elastic property). At normal atmospheric pressure, the temperature dependence of the speed of a sound wave through air is approximated by the following equation:

$v = 331 \text{ m/s} + (0.6 \text{ m/s/C}) \cdot T$

where T is the temperature of the air in degrees Celsius. Using this equation to determine the speed of a sound wave in air at a temperature of 20 degrees Celsius yields the following solution

Speed of sound in different media at 25 °C

State	Substance	Speed in m/s
Solids	Aluminium	6420
	Nickel	6040
	Steel	5960
	Iron	5950
	Brass	4700
	Glass (Flint)	3980
Liquids	Water (Sea)	1531
	Water (distilled)	1498
	Ethanol	1207
	Methanol	1103
Gases	Hydrogen	1284
	Helium	965
	Air	346
	Oxygen	316

ECHO

Another phenomenon related to the perception of time delays between two events is an echo. A person can often perceive a time delay between the production of a sound and the arrival of a reflection of that sound off a distant barrier.

While an echo is of relatively minimal importance to humans, echolocation is an essential *trick of the trade* for bats. Being a nocturnal creature, bats must use sound waves to navigate and hunt. They produce short bursts of ultrasonic sound waves which reflect off objects in their surroundings and return. Their detection of the time delay between the sending and receiving of the pulses allows a bat to approximate the distance to surrounding objects. Some bats, known as Doppler bats, are capable of detecting the speed and direction of any moving objects by monitoring the changes in frequency of the reflected pulses.

Beats

A final application of physics to the world of music pertains to the topic of beats. **Beats** are the periodic and repeating fluctuations heard in the intensity of a sound when two sound waves of very similar frequencies interfere with one another.

sonic boom

A **sonic boom** occurs as the result of the piling up of compressional wavefronts along the conical edge of the wave pattern. These compressional wavefronts pile up and interfere to produce a very high pressure zone. Instead of these compressional regions (high pressure regions) reaching you one at a time in consecutive fashion, they all reach you at once. Since every compression is followed by a rarefaction, the high pressure zone will be immediately followed by a low pressure zone. This creates a very loud noise.

If you are standing on the ground as the supersonic aircraft passes by, there will be a short time delay and then you will hear the **boom** - the sonic boom. This boom is merely a loud noise resulting from the high pressure sound followed by a low pressure sound. Do not be mistaken into thinking that this boom only happens the instant that the aircraft surpasses the speed of sound and that it is the signature that the aircraft just attained supersonic speed. Sonic booms are observed when any aircraft which is traveling faster than the speed of sound passes overhead. It is

not a sign that the aircraft just overcame the sound barrier, but rather a sign that the aircraft is traveling faster than sound.

Reverberation

Reverberation is the persistence of sound in a particular space after the original sound is removed. When sound is produced in a space, a large number of echoes build up and then slowly decay as the sound is absorbed by the walls and air, creating reverberation, or **reverb**. This is most noticeable when the sound source stops but the reflections continue, decreasing in amplitude, until they can no longer be heard.

Large chambers, especially such as cathedrals, gymnasiums, indoor swimming pools, large caves, etc., are examples of spaces where the reverberation time is long and can clearly be heard. To reduce reverberation, the roof and wallsof the auditorium are generally covered with sound absorbent materials like compressed fibreboard, rough plaster or draperies. The seat materials are also selected on the basis of their sound absorbing properties.

USES OF MULTIPLE REFLECTION OF SOUND

1. Megaphones or loudhailers, horns,musical instruments such as trumpets and *shehanais*, are all designed to send sound in a particular direction without spreading it in all directions curved soundboard may be placed behind the stage so that the sound, after reflecting from the sound board,
spreads evenly across the width of the hall In these instruments, a tube followed by a conical opening reflects sound successively to guide most of the sound waves from the source in the forward direction towards the audience.

2. Stethoscope is a medical instrument used for listening to sounds produced within the body, chiefly in the heart or lungs. In stethoscopes the sound of the patient's heartbeat reaches the doctor's ears by multiple reflection of sound

3. Generally the ceilings of concert halls, conference halls and cinema halls are curved so that sound after reflection reaches all corners of the hall. Sometimes a curved soundboard may be placed behind the stage so that the sound, after reflecting from the sound board, spreads evenly across the width of the hall

Range of Hearing

The audible range of sound for human beings extends from about 20 Hz to 20000 Hz (one Hz = one cycle/s). Children under the age of five and some animals, such as dogs can hear up to 25 kHz (1 kHz = 1000 Hz). As people grow older their ears become less sensitive to higher frequencies. Sounds of frequencies below 20 Hz are called infrasonic sound or infrasound. If we could hear infrasound we would hear the vibrations of a pendulum just as we hear the vibrations of the wings of a bee. Rhinoceroses communicate using infrasound of frequency as low as 5 Hz. Whales and elephants produce sound in the infrasound range. It is observed that some animals get disturbed before earthquakes. Earthquakes produce low-frequency infrasound before the main shock waves begin which possibly alert the animals. Frequencies higher than 20 kHz are called ultrasonic sound or ultrasound. Ultrasound is produced by dolphins, bats and porpoises. Moths of certain families have very sensitive hearing equipment. These moths can hear the high frequency squeaks of the bat and know when a bat is flying nearby, and are able to escape capture. Rats also play games by producing ultrasound.

Hearing Aid: People with hearing loss may need a hearing aid. A hearing aid is an electronic, battery operated device. The hearing aid receives sound through a microphone. The microphone converts the sound waves to electrical signals. These electrical signals are amplified by an amplifier. The amplified electrical signals are given to a speaker of the hearing aid. The speaker converts the amplified electrical signal to sound and sends to the ear for clear hearing.

Applications of Ultrasound

- Ultrasounds are high frequency waves. Ultrasounds are able to travel along well defined paths even in the presence of obstacles. Ultrasounds are used extensively in industries and for medical purposes.

- Ultrasound is generally used to clean parts located in hard-to-reach places, for example, spiral tube, odd shaped parts, electronic components etc. Objects to be cleaned are placed in a cleaning solution and ultrasonic waves are sent into the solution. Due to the high frequency, the particles of dust, grease and dirt get detached and drop out. The objects thus get thoroughly cleaned.

- Ultrasounds can be used to detect cracks and flaws in metal blocks. Metallic components are generally used in construction of big structures like buildings, bridges, machines and also scientific equipment. The cracks or holes inside the metal blocks, which are invisible from outside reduces the strength of the structure. Ultrasonic waves are allowed to pass through the metal block and detectors are used to detect the transmitted waves. If there is even a small defect, the ultrasound gets reflected back indicating the presence of the flaw or defect

- Ordinary sound of longer wavelengths cannot be used for such purpose as it will
- bend around the corners of the defective location and enter the detector.
- Ultrasonic waves are made to reflect from various parts of the heart and form the image of the heart. This technique is called 'echocardiography'.

- Ultrasound scanner is an instrument which uses ultrasonic waves for getting images of internal organs of the human body. A doctor may image the patient's organs such as the liver, gall bladder, uterus, kidney, etc. It helps the doctor to detect abnormalities, such as stones in the gall bladder and kidney or tumours in different organs. In this technique the ultrasonic waves travel through the tissues of the body and get reflected from a region where there is a change of tissue density. These waves are then converted into electrical signals that are used to generate images of the organ. These images are then displayed on a monitor or printed on a film. This technique is called 'ultrasonography'. Ultrasonography is also used for examination of the foetus during pregnancy to detect congenial defects and growth abnormalities.

- Ultrasound may be employed to break small 'stones' formed in the kidneys into fine grains. These grains later get flushed out with urine.

SONAR

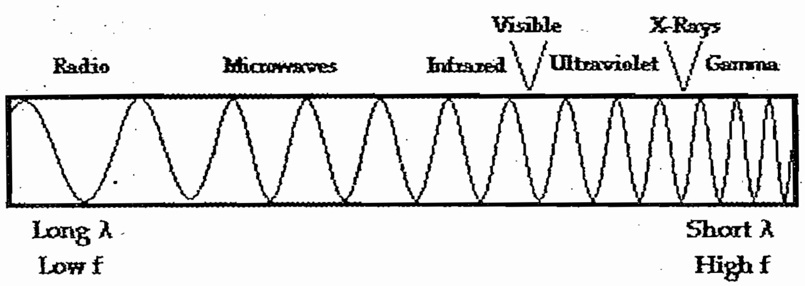
The acronym SONAR stands for Sound Navigation And Ranging. Sonar is a device that uses ultrasonic waves to measure the distance, direction and speed of underwater objects. How does the sonar work? Sonar consists of a transmitter and a detector and is installed in a boat or a ship .The transmitter produces and transmits ultrasonic waves. These waves travel through water and after striking the object on the seabed, get reflected back and are sensed by the detector. The detector converts the ultrasonic waves into electrical signals which are appropriately interpreted. The distance of the object that reflected the sound wave can be calculated by knowing the speed of sound in water and the time interval between transmission and reception of the ultrasound. Let the time interval between transmission and reception of ultrasound signal be t and the speed of sound through seawater be v. The total distance, $2d$ traveled by the ultrasound is then, $2d = vt$. The above method is **called echo-ranging.** The sonar technique is used to determine the depth of the sea and to locate underwater hills, valleys, submarine, icebergs, sunken ship etc.

10. Light

The Electromagnetic and Visible Spectra

Electromagnetic waves are capable of transporting energy through the vacuum of outer space. Electromagnetic waves are produced by a vibrating electric charge and as such, they consist of both an electric and a magnetic component.

Electromagnetic waves exist with an enormous range of frequencies. This continuous range of frequencies is known as the **electromagnetic spectrum**. The entire range of the spectrum is often broken into specific regions. The subdividing of the entire spectrum into smaller spectra is done mostly on the basis of how each region of electromagnetic waves interacts with matter. The diagram below depicts the electromagnetic spectrum and its various regions. The longer wavelength, lower frequency regions are located on the far left of the spectrum and the shorter wavelength, higher frequency regions are on the far right. Two very narrow regions within the spectrum are the visible light region and the X-ray region. You are undoubtedly familiar with some of the other regions of the electromagnetic spectrum.



Visible Light Spectrum

Though electromagnetic waves exist in a vast range of wavelengths, our eyes are sensitive to only a very narrow band. Since this narrow band of wavelengths is the means by which humans see, we refer to it as the **visible light spectrum**. Normally when we use the term "light," we are referring to a type of electromagnetic wave which stimulates the retina of our eyes. In this sense, we are referring to visible light, a small spectrum from the enormous range of frequencies of electromagnetic radiation. This visible light region consists of a spectrum of wavelengths which range from approximately 700 nanometers (abbreviated nm) to approximately 400 nm. Expressed in more familiar units, the range of wavelengths extends from 7×10^{-7} meter to 4×10^{-7} meter. Each individual wavelength within the spectrum of visible light wavelengths is representative of a particular color.

That is, when light of that particular wavelength strikes the retina of our eye, we perceive that specific color sensation. Isaac Newton showed that light shining through a prism will be separated into its different wavelengths and will thus show the various colors that visible light is comprised of. **The separation of visible light into its different colors is known as dispersion.** Each color is characteristic of a distinct wavelength; and different wavelengths of light waves will bend varying amounts upon passage through a prism. For these reasons, visible light is dispersed upon passage through a prism.. The red wavelengths of light are the longer wavelengths and the violet wavelengths of light are the shorter wavelengths. Between red and violet, there is a continuous range or spectrum of wavelengths.

When all the wavelengths of the visible light spectrum strike your eye at the same time, white is perceived. The sensation of white is not the result of a single color of light. Rather, the sensation of white is the result of a mixture of two or more colors of light. Thus, visible light - the mix of ROYGBIV - is sometimes referred to as **white light.** Technically speaking, white is not a color at all - at least not in the sense that there is a light wave with a wavelength which is characteristic of white. Rather, white is the combination of all the colors of the visible light spectrum. If all the wavelengths of the visible light spectrum give the appearance of white, then none of the wavelengths would lead to the appearance of black. Once more, black is not actually a color. Technically speaking, black is merely the absence of the wavelengths of the visible light spectrum. So when you are in a room with no lights and everything around you appears black, it means that there are no wavelengths of visible light striking your eye as you sight at the surroundings.

Color Addition

The subject of color perception can be simplified if we think in terms of primary colors of light. We have already learned that white is not a color at all, but rather the presence of all the frequencies of visible light. When we speak of white light, we are referring to ROYGBIV - the presence of the entire spectrum of visible light. But combining the range of frequencies in the visible light spectrum is not the only means of producing white light. White light can also be produced by combining only three distinct frequencies of light, provided that they are widely separated on the visible light spectrum. **Any three colors (or frequencies) of light which produce white light when combined with the correct intensity are called primary colors of light**. There are a variety of sets of primary colors. **The most common set of primary colors is red (R), green (G) and blue (B)**. When red, green and blue light are mixed or added together with the proper intensity, white (W) light is obtained. This is often represented by the equation below:

R + G + B = W

In fact, the mixing together (or addition) of two or three of these three primary colors of light with varying degrees of intensity can produce a wide range of other colors. For this reason, many television sets and computer monitors produce the range of colors on the monitor by the use of of red, green and blue light-emitting phosphors.

R + G = Y

R + B = M

G + B = C

Yellow (Y), magenta (M) and cyan (C) are sometimes referred to as **secondary colors of light** since they are produced by the addition of equal intensities of two primary colors of light. The addition of these three primary colors of light with varying degrees of intensity will result in the countless other colors which we are familiar (or unfamiliar) with.

Complementary Colors of Light

Any **two colors of light** which when mixed together in equal intensities produce **white** are said to be **complementary colors** of each other. The complementary color of red light is cyan light. This is reasonable since cyan light is the combination of blue and green light; and blue and green light when added to red light will produce white light. Thus, red light and cyan light (blue + green) represent a pair of complementary colors; they add together to produce white light. This is illustrated in the equation below:

R + C = R + (B + G) = White

Each primary color of light has a secondary color of light as its complement. The three pairs of complementary colors are listed below.

Complementary Colors of Light

Red and Cyan

Green and Magenta

Blue and Yellow

The production of various colors of light by the mixing of the three primary colors of light is known as **color addition**. color addition to determine why different objects look specific colors when illuminated with various colors of light.

Blue Skies and Red Sunsets

. We will attempt to answer these two questions:

- **Why are the skies blue?**
- **Why are the sunsets red?**

The interaction of sunlight with matter can result in one of three wave behaviors: absorption, transmission, and reflection. The atmosphere is a gaseous sea which contains a variety of types of particles; the two most common types of matter present in the atmosphere are gaseous nitrogen and oxygen. These particles are most effective in scattering the higher frequency and shorter wavelength portions of the visible light spectrum. This scattering process involves the absorption of a light wave by an atom followed by reemission of a light wave in a variety of directions. The amount of multidirectional scattering which occurs is dependent upon the frequency of the light. Atmospheric nitrogen and oxygen scatter violet light most easily, followed by blue light, green light, etc. So as white light (ROYGBIV) from the sun passes through our atmosphere, the high frequencies (BIV) become scattered by atmospheric particles while the lower frequencies (ROY) are most likely to pass through the atmosphere without a significant alteration in their direction. This scattering of the higher frequencies of light illuminates the skies with light on the BIV end of the visible spectrum. Compared to blue light, violet light is most easily scattered by atmospheric particles. However, our eyes are more sensitive to light with blue frequencies. Thus, we view the skies as being blue in color.

Meanwhile, the light that is not scattered is able to pass through our atmosphere and reach our eyes in a rather non-interrupted path. The lower frequencies of sunlight (ROY) tend to reach our eyes as we sight directly at the sun during midday. While sunlight consists of the entire range of frequencies of visible light, not all frequencies are equally intense. In fact, sunlight tends to be most rich with yellow light frequencies. For these reasons, the sun appears yellow during midday due to the direct passage of dominant amounts of yellow frequencies through our atmosphere and to our eyes.

The appearance of the sun changes with the time of day. While it may be yellow during midday, it is often found to gradually turn color as it approaches sunset. This can be explained by light scattering. As the sun approaches the horizon line, sunlight must traverse a greater distance through our atmosphere

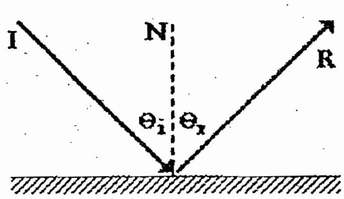
As the path which sunlight takes through our atmosphere increases in length, ROYGBIV encounters more and more atmospheric particles. This results in the scattering of greater and greater amounts of yellow light. During sunset hours, the light passing through our atmosphere to our eyes tends to be most concentrated with red and orange frequencies of light. For this reason, the sunsets have a reddish-orange hue. The affect of a red sunset becomes more pronounced if the atmosphere contains more and more particles. The presence of sulfur aerosols (emitted as an industrial pollutant and by volcanic activity) in our atmosphere contributes to some magnificent sunsets (and some very serious environmental problems).

The objects which we see can be placed into one of two categories: luminous objects and illuminated objects. **Luminous objects** are objects which generate their own light. **Illuminated objects** are objects which are capable of reflecting light to our eyes. The sun is an example of a luminous object, while the moon is an illuminated object.

None of us are light-generating objects. We are not brilliant objects like the sun; rather, we are illuminated objects like the moon. We make our presence visibly known by reflecting light to the eyes of those who look our way. It is only by reflection that we, as well as most of the other objects in our physical world, can be seen.

The Law of Reflection

Light is known to behave in a very predictable manner. If a ray of light could be observed approaching and reflecting off of a flat mirror, then the behavior of the light as it reflects would follow a predictable *law* known as the **law of reflection**. The diagram below illustrates the law of reflection.

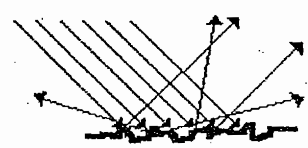


In the diagram, the ray of light approaching the mirror is known as the **incident ray** (labeled **I** in the diagram). The ray of light which leaves the mirror is known as the **reflected ray** (labeled R in the diagram). At the point of incidence where the ray strikes the mirror, a line can be drawn perpendicular to the surface of the mirror. This line is known as a **normal line** (labeled **N** in the diagram). The normal line divides the angle between the incident ray and the reflected ray into two equal angles. The angle between the incident ray and the normal is known as the **angle of incidence**. The angle between the reflected ray and the normal is known as the **angle of reflection**. (These two angles are labeled with the Greek letter "theta" accompanied by a subscript; read as "theta-i" for angle of incidence and "theta-r" for angle of reflection.) The law of reflection states that when a ray of light reflects off a surface, the angle of incidence is equal to the angle of reflection.

Specular vs. Diffuse Reflection

Reflection off of smooth surfaces such as mirrors or a calm body of water leads to a type of reflection known as **specular reflection**. Reflection off of rough surfaces such as clothing, paper, and the asphalt roadway leads to a type of reflection known as **diffuse reflection**. Whether the surface is microscopically rough or smooth has a tremendous impact upon the subsequent reflection of a beam of light. The diagram below depicts two beams of light incident upon a rough and a smooth surface.

Specular Reflection (smooth surfaces)

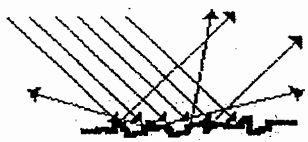


Diffuse Reflection (rough surfaces)

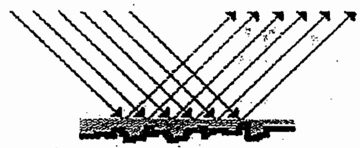
A light beam can be thought of as a bundle of individual light rays which are traveling parallel to each other. Each individual light ray of the bundle follows the law of reflection. If the bundle of light rays is incident upon a smooth surface, then the light rays reflect and remain concentrated in a bundle upon leaving the surface. On the other hand, if the surface is microscopically rough, the light rays will reflect and diffuse in many different directions.

Applications of Specular and Diffuse Reflection

There are several interesting applications of this distinction between specular and diffuse reflection. **One** application pertains to the relative difficulty of night driving on a wet asphalt roadway compared to a dry asphalt roadway. Most drivers are aware of the fact that driving at night on a wet roadway results in an annoying glare from oncoming headlights. The glare is the result of the specular reflection of the beam of light from an oncoming car. Normally a roadway would cause diffuse reflection due to its rough surface. But if the surface is wet, water can fill in the crevices and smooth out the surface. Rays of light from the beam of an oncoming car, hit this smooth surface, undergo specular reflection and remain concentrated in a beam. The driver perceives an annoying glare caused by this concentrated beam of reflected light.



A dry asphalt roadway diffuses incident light.



When wet, water fills in the crevices, resulting in specular reflection and a glare.

A **second** application of the distinction between diffuse and specular reflection pertains to the field of photography. Many people have witnessed in person or have seen a photograph of a beautiful nature scene captured by a photographer who set up the shot with a calm body of water in the foreground. The water (if calm) provides for the specular reflection of light from the subject of the photograph. Light from the subject can reach the camera lens directly or it can take a longer path in which it reflects off the water before traveling to the lens. Since the light reflecting off the water undergoes specular reflection, the incident rays remain concentrated (instead of diffusing). The light is thus able to travel together to the lens of the camera and produce an image (an exact replica) of the subject which is strong enough to perceive in the photograph. An example of such a photograph is shown below.

Right Angle Mirrors

there are optical systems which consist of two or more mirrors. One such system which is often found in homes is a pair of plane mirrors adjoined at right angles to each other. Such a system is called a **right angle mirror**.

If you have a chance to look carefully at the images formed by right angle mirrors, then you will notice that right angle mirrors produce three images. Interestingly, a single mirror produces a single image; another single mirror produces a second image; but when you put the two single mirrors together at right angles, there are three images.

A Pair of Parallel Mirrors

When the two mirrors are aligned at a 0-degree angle with each other (i.e., a parallel mirror system), there are an infinite number of images. Each image is the result of an *image of an image*, or *an image of an image of an image* or *an image of an image of*... .

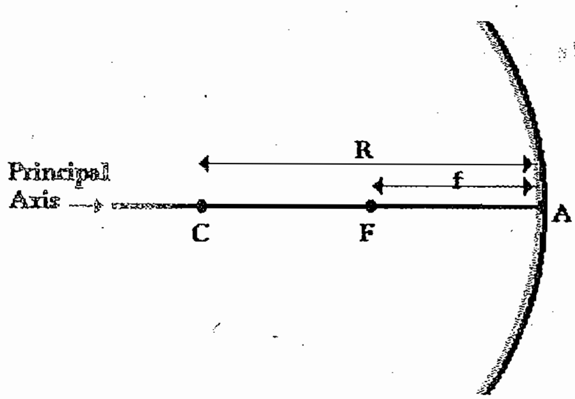
Curved Mirror

we will turn our attention to the topic of curved mirrors, and specifically curved mirrors which have a *spherical* shape. Such mirrors are called **spherical mirrors.** Spherical mirrors can be thought of as a portion of a sphere which was sliced away and then silvered on one of the sides to form a reflecting surface. **Concave mirrors** were silvered on the inside of the sphere and **convex mirrors** were silvered on the outside of the sphere.

Beginning a study of spherical mirrors demands that you first become acquainted with some terminology which will be periodically used..

Principal axis	Center of Curvature	Vertex
Focal Point	Radius of Curvature	Focal Length

If a concave mirror is thought of as being a slice of a sphere, then there would be a line passing through the center of the sphere and attaching to the mirror in the exact center of the mirror. This line is known as the **principal axis**. The point in the center of the sphere from which the mirror was sliced is known as the **center of curvature** and is denoted by the letter **C** in the diagram below. The point on the mirror's surface where the principal axis meets the mirror is known as the **vertex** and is denoted by the letter **A** in the diagram below. The vertex is the geometric center of the mirror. Midway between the vertex and the center of curvature is a point known as the **focal point**; the focal point is denoted by the letter **F** in the diagram below. The distance from the vertex to the center of curvature is known as the **radius of curvature** (represented by **R**). The radius of curvature is the radius of the sphere from which the mirror was cut. Finally, the distance from the mirror to the focal point is known as the **focal length** (represented by **f**). Since the focal point is the midpoint of the line segment adjoining the vertex and the center of curvature, the focal length would be one-half the radius of curvature.



The Mirror Equation

To obtain the numerical information, it is necessary to use the **Mirror Equation** and the **Magnification Equation.** The mirror equation expresses the quantitative relationship between the object distance (d_o), the image distance (d_i), and the focal length (f). The equation is stated as follows:

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

The magnification equation relates the ratio of the image distance and object distance to the ratio of the image height (h_i) and object height (h_o). The magnification equation is stated as follows:

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

These two equations can be combined to yield information about the image distance and image height if the object distance, object height, and focal length are known.

Refraction

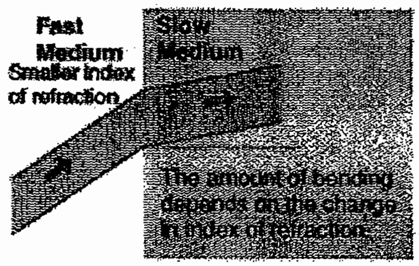
Refraction is the bending of a wave when it enters a medium where it's speed is different. The refraction of light when it passes from a fast medium to a slow medium bends the light ray toward the normal to the boundary between the two media. The amount of bending depends on the indices of refraction of the two media and is described quantitatively by Snell's Law.

Refraction is responsible for image formation by lenses and the eye.

As the speed of light is reduced in the slower medium, the wavelength is shortened proportionately. **The frequency is unchanged; it is a characteristic of the source of the light and unaffected by medium changes.**

Index of Refraction

The index of refraction is defined as the speed of light in vacuum divided by the speed of light in the medium.



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

The indices of refraction of some common substances are given below with a more complete description of the indices for optical glasses given elsewhere. The values given are approximate and do not account for the small variation of index with light wavelength which is called dispersion.

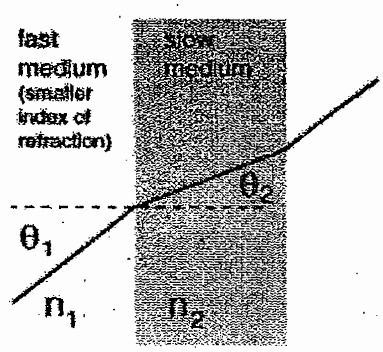
Vacuum	1.000	Ethyl alcohol	1.362
Air	1.000277	Glycerine	1.473
Water	4/3	Ice	1.31
Carbon disulfide	1.63	Polystyrene	1.59
Methylene iodide	1.74	Crown glass	1.50-1.62
Diamond	2.417	Flint glass	1.57-1.75

Snell's Law

Snell's Law relates the indices of refraction n of the two media to the directions of propagation in terms of the angles to the normal.

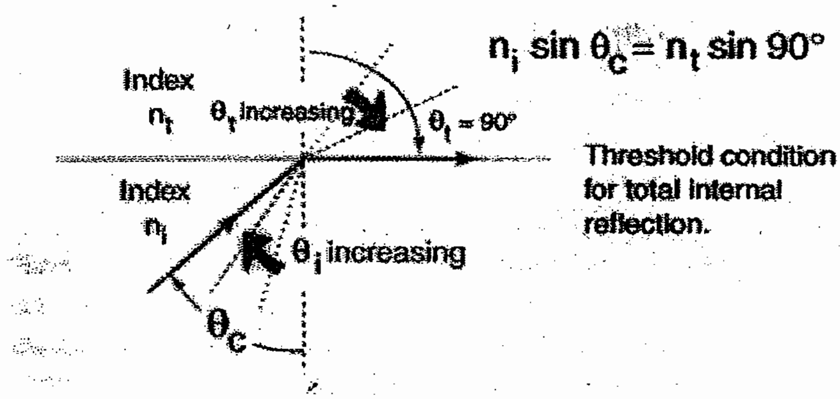
Snell's Law

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



Total Internal Reflection

When light is incident upon a medium of lesser index of refraction, the ray is bent away from the normal, so the exit angle is greater than the incident angle. Such reflection is commonly called "internal reflection". The exit angle will then approach 90° for some critical incident angle θ_c , and for incident angles greater than the critical angle there will be total internal reflection.

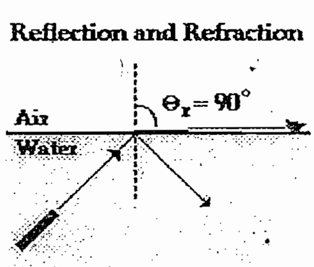


The Critical Angle

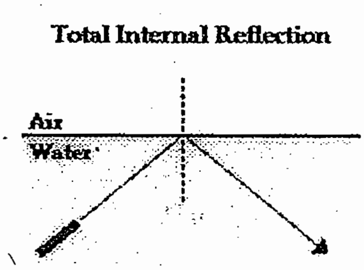
Total internal reflection (TIR) is the phenomenon which involves the reflection of all the incident light off the boundary. TIR only takes place when both of the following two conditions are met:

- a light ray is in the more dense medium and approaching the less dense medium.
- the angle of incidence for the light ray is greater than the so-called critical angle.

. When the angle of incidence in water reaches a certain critical value, the refracted ray lies along the boundary, having an angle of refraction of 90-degrees. **This angle of incidence is known as the critical angle; it is the largest angle of incidence for which refraction can still occur.** For any angle of incidence greater than the critical angle, light will undergo total internal reflection.



When the angle of incidence equal the critical angle, the angle of refraction is 90-degrees.



When the angle of incidence is greater than the critical angle, all the light undergoes reflection.

So the critical angle is defined as the angle of incidence which provides an angle of refraction of 90-degrees

TIR and the Sparkle of Diamonds

Relatively speaking, the critical angle for the diamond-air boundary is an extremely small number. Of all the possible combinations of materials which could interface to form a boundary, the combination of diamond and air provides one of the largest difference in the index of refraction values. This means that there will be a very small n_r/n_i ratio and subsequently a small critical angle. This peculiarity about the diamond-air boundary plays an important role in the brilliance of a diamond gemstone. Having a small critical angle, light has the tendency to become "trapped" inside of a diamond once it enters. A light ray will typically undergo TIR several times before finally refracting out of the diamond. Because the diamond-air boundary has such a small critical angle (due to diamond's large index of refraction), most rays approach the diamond at angles of incidence greater than the critical angle. This gives diamond a tendency to sparkle. The effect can be enhanced by the cutting of a diamond gemstone with a strategically planned shape

mirage

A **mirage** is an optical phenomenon which creates the illusion of water and results from **the refraction** of light through a nonuniform medium. Mirages are most commonly observed on sunny days when driving down a roadway.

The Eye

The power of a lens is measured by opticians in a unit known as a diopter. A **diopter** is the reciprocal of the focal length.

diopters = 1/(focal length)

The maximum variation in the power of the eye is called the **Power of Accommodation**. If an eye has the ability to assume a focal length of 1.80 cm (56 diopters) to view objects many miles away as well as the ability to assume a 1.68 cm focal length to view an object 0.25 meters away (60 diopters), then its Power of Accommodation would be measured as 4 diopters (60 diopters - 56 diopters).

The healthy eye of a young adult has a Power of Accommodation of approximately 4 diopters. As a person grows older, the Power of Accommodation typically decreases as a person becomes less able to view nearby objects. This failure to view nearby objects leads to the need for corrective lenses.

Farsightedness and its Correction

Farsightedness or **hyperopia** is the inability of the eye to focus on nearby objects. The farsighted eye has no difficulty viewing distant objects. But the ability to view nearby objects requires a different lens shape - a shape which the farsighted eye is unable to assume. Subsequently, the farsighted eye is unable to focus on nearby objects. The problem most frequently arises during latter stages in life, as a result of the weakening of the ciliary muscles and/or the decreased flexibility of the lens. These two potential causes leads to the result that the lens of the eye can no longer assume the high curvature which is required to view nearby objects. The lens' power to refract light has diminished and the images of nearby objects are focused at a location behind the retina. On the retinal surface, where the light-detecting nerve cells are located, the image is not focused. These nerve cells thus detect a blurry image of nearby objects.

Thus, the farsighted eye is assisted by the use of a converging lens(double convex lens). This converging lens will refract light before it enters the eye and subsequently decreases the image distance. By beginning the refraction process prior to light reaching the eye, the image of nearby objects is once again focused upon the retinal surface.

Nearsightedness and its Correction

Nearsightedness or **myopia** is the inability of the eye to focus on distant objects. The nearsighted eye has no difficulty viewing nearby objects. But the ability to view distant objects requires that the light be refracted less. Nearsightedness will result if the light from distant objects is refracted more than is necessary. The problem is most common as a youth, and is usually the result of a bulging cornea or an elongated eyeball. If the cornea bulges more than its customary curvature, then it tends to refract light more than usual. This tends to cause the images of distant objects to form at locations in front of the retina. If the eyeball is elongated in the horizontal direction, then the retina is placed at a further distance from the cornea-lens system. Subsequently the images of distant objects form in front of the retina. On the retinal surface, where the light-detecting nerve cells are located, the image is not focused. These nerve cells thus detect a blurry image of distant objects.

The cure for the nearsighted eye is to equip it with a diverging lens (double concave lenses). Since the nature of the problem of nearsightedness is that the light is focused in front of the retina, a diverging lens will serve to diverge light before it reaches the eye. This light will then be converged by the cornea and lens to produce an image on the retina.

Presbyopia

The power of accommodation of the eye usually decreases with ageing. For most people, the near point gradually recedes away. They find it difficult to see nearby objects comfortably and distinctly without corrective eye-glasses. This defect is called Presbyopia. It arises due to the gradual weakening of the ciliary muscles and diminishing flexibility of the eye lens. Sometimes, a person may suffer from both myopia and hypermetropia. Such people often require bifocal lenses. A common type of bi-focal lenses consists of both concave and convex lenses. The upper portion consists of a concave lens. It facilitates distant vision. The lower part is a convex lens. It facilitates near vision. These days, it is possible to correct the refractive defects with contact lenses or through surgical interventions.

Uses of concave mirrors

Concave mirrors are commonly used in torches, search-lights and vehicles headlights to get powerful parallel beams of light. They are often used as shaving mirrors to see a larger image of the face. The dentists use concave mirrors to see large images of the teeth of patients. Large concave mirrors are used to concentrate sunlight to produce heat in solar furnaces.

Uses of convex mirrors

Convex mirrors are commonly used as rear-view (wing) mirrors in vehicles. These mirrors are fitted on the sides of the vehicle, enabling the driver to see traffic behind him/her to facilitate safe driving. Convex mirrors are preferred because they always give an erect, though diminished, image. Also, they have a wider field of view as they are curved outwards. Thus, convex mirrors enable the driver to view much larger area than would be possible with a plane mirror.

11. HEAT AND THERMODYNAMICS

Heat and Thermal Energy

When scientists originally studied thermodynamics, they were really studying heat and thermal energy. Heat can do anything: move from one area to another, get atoms excited, and even increase energy. When you increase the heat in a system, you are really increasing the amount of energy in the system. Now that you understand that fact, you can see that the study of thermodynamics is the study of the amount of energy moving in and out of systems.

Heat of Atoms

Now all of this energy is moving around the world. You need to remember that it all happens on a really small scale. Energy that is transferred is at an atomic level. Atoms and molecules are transmitting these tiny amounts of energy. When heat moves from one area to another, it's because millions of atoms and molecules are working together. Those millions of pieces become the energy flow throughout the entire planet.

Energy Movement

Energy moves from one system to another because of differences in the systems. If you have two identical systems with equal amounts of energy, there will be no flow of energy. When you have two systems with different amounts of energy (maybe different temperatures) the energy will start to flow. Air mass of high pressure forces large numbers of molecules into areas of low pressure. Areas of high temperature give off energy to areas with lower temperature. There is a constant flow of energy throughout the universe. Heat is only one type of that energy.

Increasing Energy and Entropy

Another big idea in thermodynamics is the concept of energy that excites molecules. Atoms have a specific amount of energy when they are at a certain temperature. When you change the system by increasing pressure of temperature, the atoms can get more excited. That increase in excitement is called **entropy**. Atoms move around more and there is more activity. That increase in activity is an increase in entropy.

Energy Likes to Move

If there is a temperature difference in a system, heat will naturally move from high to low temperatures. The place you find the higher temperature is the heat source. The area where the temperature is lower is the heat sink. When examining systems, scientists measure a number called the temperature gradient. The gradient is the change in temperature divided by the distance. The units are degrees per centimeter. If the temperature drops over a specific distance, the gradient is a negative value. If the temperature goes up, the gradient has a positive value.

Ever Hear of Convection Ovens?

Convection is the way heat is transferred from one area to another when there is a "bulk movement of matter." It is the movement of huge amounts of an object, taking the heat from one area and placing it in another. Warm air rises and cold air replaces it. The heat has moved. It is the transfer of heat by motion of objects. Convection occurs when an area of hot water rises to the top of a pot and gives off energy. Another example is warm air in the atmosphere rising and giving off energy. They are all examples of convection. The thing to remember is that the object moves.

Radiating Energy

When the transfer of energy happens by radiation, a temperature gradient exists and there is no conductive medium. That lack of medium means there is no matter there for the heat to pass through. Radiation is the energy carried by electromagnetic waves (light). Those waves could be radio waves, infrared, visible light, UV, or Gamma rays. Radiation is usually found in the infrared sections of the EM spectrum. If the temperature of an object doubles (in Kelvin), the thermal radiation increases 16 times. Therefore, if it goes up four times, it increases to 32 times the original level.

Scientists have also discovered that objects that are good at giving off thermal radiation are also good at absorbing the same energy. Usually the amount of radiation given off by an object depends on the temperature. The rate at which you absorb the energy depends on the energy of the objects and molecules surrounding you.

Conducting Energy and Heat

Conduction is a situation where the heat source and heat sink are connected. As we discussed before, the heat flows from the source down the temperature gradient to the sink. It is different from convection because there is no movement of large amounts of matter. The source and the sink are connected.

Conduction is special in that it needs more free energy than the other ways of transferring thermal energy. If you touch an ice cream cone, the ice cream heats up because you are a warmer body. If you lie on a hot sidewalk, the energy moves directly to your body by conduction. When scientists studied good thermal radiators, they discovered that good thermal conductors are also good at conducting electricity. So when you think of a good thermal conductor, think about copper, silver, gold, and platinum.

Getting Hotter = Getting Bigger

The idea behind thermal expansion is that gases expand as the temperature increases. If you have a balloon and you heat up the contents, the balloon will get larger. Scientists use the term ideal gas law to describe this activity.

Liquids expand and contract, too, but there is a lot less change in their volume compared to gases. Scientists say they have a smaller thermal expansion coefficient. As you can probably figure out, solids expand and contract the least of all the states of matter.

Things Shrink When They get Cold

The opposite of expansion is contraction. If things expand with the addition of energy it makes sense that they contract when energy is removed. If you remove enough energy from a gas it will become a liquid. Liquids can turn into solids. What happens when you remove almost all of the energy from a system? Scientists use the terms absolute zero to describe a system that has no energy. When there is no energy in a system, all molecular motion stops. It seems that even the atoms begin to merge at these low temperatures. Physicists have recently created the Bose-Einstein state of matter that has a small group of atoms with nearly all of the energy taken out of the system

Making Heat

How do you make heat? You could burn things, there could be chemical reactions, or you could rub things together and create heat from friction. When you burn things, thermal energy is released. Thermal energy is measured in calories. For example, when you burn wood, you release 3000 calories for each gram of wood. When you burn an apple, it creates only 600 calories. The amount of energy released is directly related to the amount of energy stored up in the chemical bonds. If you use that idea, there is more energy stored in the bonds of a piece of wood than in the bonds of an apple.

Losing Energy

We just talked about friction. Heat is also created because of inefficiency. When a car engine runs, a lot of heat is given off. Much of that heat is the result of the friction and inefficiency in the running motor. When you lift something and your muscle contracts, you are only 25% efficient. Seventy-five percent of the energy is lost to heat.

More Transfer of Energy

Heat is the thermal energy transported from one system to another because of a temperature difference. The transfer of that energy stops when the temperature balances out in the entire environment. Scientists use the unit of a calorie to measure heat. You might be saying, "I've heard of calories. Are those like the ones in food?" The answer is "Yes." One calorie is measured as the amount of energy needed to raise the temperature of one gram of water, one degree Celsius. When you are burning calories you are actually using the energy stored in your food.

Specific Heat Capacity

There is also something totally important called specific heat capacity. Remember that we just talked about one calorie? Specific heat works the same way. It is the amount of energy required to raise the temperature of one gram of substance one degree Celsius. So the specific heat capacity for water is one. As we said, heat is a form of thermal energy. Because it's energy, scientists also use the units of Joules to measure the energy. One calorie equals 4.186 Joules which also equals 4.186 Watts seconds (Ws). Does that mean you can measure the amount of energy you make in you body in terms of an electric value (Watts)? Yes, your energy can be converted into electrical work.

Three Big Temperature Scales

Since we're going to be talking about heat, temperatures, and energy, we wanted to introduce you to how temperature is measured. **The big three are Fahrenheit, Celsius and Kelvin.** Even though scientists may use only a few scales to measure temperature, there are dozens of types of devices that measure temperatures. All of these devices are called thermometers because they measure temperature. There are thermometers to measure your body temperature, the temperature in your oven, and even the temperature of liquid oxygen.

Fahrenheit is the Classic

Fahrenheit is the classic English system of measuring temperatures. Water freezes at 32 degrees Fahrenheit and boils at 212 degrees. The scale was created by Gabriel Daniel Fahrenheit in 1724 and divides the difference between the boiling point and freezing point of water into 180 equal degrees. You will probably be asked to convert temperatures back and forth from Fahrenheit to Celsius. Here's the formula: (Fahrenheit-32)*5/9=Celsius.

Celsius Based on Water

Celsius is the modern system of measuring temperature. It fits in with much of the metric system and has nice round numbers. Water freezes at 0 degrees Celsius and boils at 100 degrees. The scale used to be known as centigrade but the name was changed several years ago. Both Celsius and Fahrenheit are used when discussing our day-to-day weather temperatures.

Kelvin to Absolute Zero

Kelvin is an important scale used in most of science. The big thing to remember is that this is a scale with no units. It offers more than just giving you degree amounts. The scale begins at 0 (absolute zero) and just goes up from there. Water freezes at the value 273.15 and boils at 373.15 Kelvin. The word "Kelvin" comes from the guy Lord Kelvin who did a lot of work with temperatures.

Thermodynamic Laws that Explain Systems

A thermodynamic system is one that interacts and exchanges energy with the area around it. The exchange and transfer need to happen in at least two ways. At least one way must be the transfer of heat. If the thermodynamic system is "in equilibrium," it can't change its state or status without interacting with its environment. Simply put, if you're in equilibrium, you're a "happy system," just minding your own business. You can't really do anything. If you do, you have to interact with the world around you.

A Zeroth Law?

The zeroth law of thermodynamics will be our starting point. We're not really sure why this law is the zeroth. We think scientists had "first" and "second" for a long time, but this new one was so important it should come before the others. Here's what it says: When two systems are sitting in equilibrium with a third system, they are also in thermal equilibrium with each other.

A First Law

The first law of thermodynamics is a little more simple. The first law states that when heat is added to a system, some of that energy stays in the system and some leaves the system. The energy that leaves does work on the area around it. Energy that stays in the system creates an increase in the internal energy of the system. you have a pot of water at room temperature. You add some heat to the system. First, the temperature and energy of the water increases. Second, the system releases some energy and it works on the environment (maybe heating the air around the water, making the air rise).

A Second Law

The second law of thermodynamics explains that it is impossible to have a cyclic process that converts heat completely into work. It is also impossible to have a process that transfers heat from cool objects to warm objects without using work.

first part of the law says no reaction is 100% efficient. Some amount of energy in a reaction is always lost to heat. Also, a system can not convert all of its energy to working energy.

The second part of the law is more obvious. A cold body can't heat up a warm body. Heat naturally wants to flow from warmer to cooler areas. Energy wants to flow and spread out to areas with less energy. If heat is going to move from cooler to warmer areas, the system must put in some work for it to happen.

A Closer Look at the First Law

Remember the first law of thermodynamics? It described the conservation of energy. When you have a system and it changes, there are four ways it can change its energy. We'll talk about those four ways of changing energy in this section.

Four Thermodynamic Systems

Adiabatic describes a system that changes with no transfer of heat in or out. If a system expands adiabatically, then the internal energy of the system usually decreases. It's as if you have a cup of water just out of the tap. You let the cup sit and the water settles down. The big idea to remember is that there is less energy and no transfer of heat.

The second type of system is isovolumic. You can probably see the term 'volum' in there. Iso usually stands for constant. Put them together and you get a system that changes, but the volume stays constant. These types of changes do not produce any work on the environment. The amount of energy changes (an increase or decrease), but the heat just stays inside the system because the volume of the system stays the same.

The third type of system is isobaric. You've seen the prefix iso before, and the suffix baric refers to pressure. This system changes but keeps a constant pressure. All of the change is in the volume of gas in the system. As you blow air into a balloon, the volume may change but the pressure will stay the same.

The fourth type of system is isothermal. One last iso prefix, and the suffix is now thermal. We're talking about systems that change in every way but their temperature. You would say that these systems are in thermal equilibrium. You would see that the pressure and volume change. As energy is put in the system, pressure or volume increase (or both), but there is no increase in temperature.

A Closer Look at the Second Law

We're going to talk about the second law of thermodynamics here. Scientists use a word called entropy to describe the energy in a system. Remember, there are two words in thermodynamics: entropy, which talks about randomness, and enthalpy, which is a measure of the total energy in a system. Big difference.

Heat flows from hot areas to cold, not the other way. If its energy is to flow from cold to hot, it needs additional energy. Heat is also conserved when energy transfer occurs. That conservation means that when you look at the energy of both systems, at the beginning of the reaction and at the end, the total energy amounts are equal. Energy has moved from one area to another, but the total remains the same.

The second law also considers the entropy of a system. Entropy is a measure of the amount of disorder (chaos) in a system. A good rule of thumb is the more disorder you have, the more energy you have.

Forward and Backward

You might hear the term reversibility. Scientists use the term reversibility to describe systems that are in equilibrium with themselves and the environment around them. When a system is in equilibrium, reversibility explains how some reactions move forward and others move in the opposite direction. Overall, their effect and change on the system are zero.

Even at Equilibrium

So you've got a system at equilibrium. Look closely and you'll find certain qualities. You'll find that in these systems the heat transfer is due to temperature differences. Heat is neither created nor passed on; it's all averaged out. You'll also discover that wild changes do not happen in the system. To get big changes, you need energy. When you're at equilibrium, there is no creation of new energy. Lastly, you'll see that there is no friction in the reactions. If friction occurred, heat would be created and work would be needed to overcome the friction. That work would take energy out of the system.

Energy and Enthalpy

Enthalpy is a measure of heat and energy in the system. Scientists figure out the mass of a substance when it is under a constant pressure. Once they figure out the mass, they measure the internal energy of the system. All together, that energy is the enthalpy. They use the formula $H = U + PV$. H is the enthalpy value, U is the amount of internal energy, and P and V are pressure and volume of the system. This system works really well for gases.

Affecting Enthalpy

There are factors that affect the level of enthalpy in a system. The enthalpy is directly proportional to the amount of substance you have. Chances are if you have more of a substance, you have more energy. More energy means higher enthalpy. If you visualize on a large scale, you can compare the enthalpy in a glass of water to the enthalpy in the ocean. The ocean has more total energy.

The second thing to remember is that the value for H (enthalpy) changes sign when the reactions or values are reversed. When a reaction moves in one direction, the sign is positive. When a reaction moves in the opposite direction, the value is negative. When a system is in equilibrium the number of forward reactions equals the number of reverse reactions.

The third idea to remember is called Hess's Law. If a process happens in stages or steps, the enthalpic change for the overall system can be figured out by adding the changes in enthalpy for each step. Many reactions occur in steps. Only after looking at each step are you able to understand and measure the entire process

Energy and Entropy

Entropy is a measure of the random activity in a system. The entropy of a system depends on your observations at one moment. How the system gets to that point doesn't matter at all. If it took a billion years and a million different reactions doesn't matter. Here and now is all that matters in entropy measurements.

When we say random, we mean energy that can't be used for any work. It's wild and untamed. Scientists use the formula (delta)S = (delta)Q / T. S is the entropy value, Q is the measure of heat, and T is the temperature of the system measured in Kelvin. When we use the symbol delta, it stands for the change. Delta T would be the change in temperature (the final temperature subtracted from the original).

Affecting Entropy

Several factors affect the amount of entropy in a system. If you increase temperature, you increase entropy.

(1) More energy put into a system excites the molecules and the amount of random activity.

(2) As a gas expands in a system, entropy increases. This one is also easy to visualize. If an atom has more space to bounce around, it will bounce more. Gases and plasmas have large amounts of entropy when compared to liquids and solids.

(3) When a solid becomes a liquid, its entropy increases.

(4) When a liquid becomes a gas, its entropy increases. We just talked about this idea. If you give atoms more room to move around, they will move. You can also think about it in terms of energy put into a system. If you add energy to a solid, it can become a liquid. Liquids have more energy and entropy than solids.

(5) Any chemical reaction that increases the number of gas molecules also increases entropy. A chemical reaction that increases the number of gas molecules would be a reaction that pours energy into a system. More energy gives you greater entropy and randomness of the atoms.

Heat Engine

Heat engine is defined as *a device that converts heat energy into mechanical energy* or more exactly *a system which operates continuously and only heat and work may pass across its boundaries.* The operation of a heat engine can best be represented by a thermodynamic cycle. Some examples are: Otto, Diesel, Brayton, Stirling and Rankine cycles.

Forward Heat Engine

A forward heat engine has a positive work output such as Rankine or Brayton cycle.

Reverse Heat Engine

A reverse heat engine has a positive work input such as heat pump and refrigerator.

12. Fluid Mechanics

Fluids and Solids

A fluid is a collection of molecules that are randomly arranged and held together by weak cohesive forces and by forces exerted by the walls of the container. A fluid can flow continuously under the application of a force. However, the solid substance does not deform continuously under the application of force. If the solid is deformed then it may come back to its original shape when the applied deforming force is removed or it may not be able to regain its original shape and size. In either of the case, the deformation is not continuous rather it takes place in a discrete manner. All liquids and gases are fluids. It is worth noting that the fluids are subset of the phases of matter including liquids, gases, plasmas, and to some extent plastic solids.

- A solid has a definite volume and shape where as a fluid does not.
- The fluids have the ability to flow unlike solids.
- The fluids form a free surface unlike the solids that form rigid surfaces.
- The fluids satisfy the conservation laws including the conservation of mass, linear momentum, angular momentum, and conservation of energy. The solids may or may not satisfy these conservation laws.

Pressure and Density:

Pressure in general is the force exerted per unit area. When a solid material is merged in a fluid, the force (F) exerted perpendicularly on the surface per unit area of the solid substance is called pressure (P):

$$P \equiv F/A$$

where A is the surface area of the solid material placed in the fluid. The unit of pressure is Pascal.

Density in general is defined as mass per unit volume of the substance: $\rho = M/V$, where ρ is the density of the considered object, M is the mass of the substance and V is its volume. The unit of density is kg/m3.

- Density explains how tightly the molecules of a material are packed. However, it has nothing to do with the hardness of a substance.
- For an incompressible fluid the density is always constant. Water may be considered as an incompressible fluid at times.

Variation of Pressure in a Fluid at Rest

When a fluid is at rest, then all points at the same depth must be at same pressure. That is the pressure at the same dept of a fluid at rest must be same. However, it varies with depth since it will have weight of the fluid on the top of it.

P_o is the atmospheric pressure = 1.00 atm = 1.013 × 10^5 Pa
g is the acceleration due to gravity
ρ is the density of the fluid
h is the depth of the point at which the pressure P is to be calculated
A is the cross sectional area
Since the fluid is at rest the net force is zero:

$$PA - mg - P_oA = 0$$

However Mass (M) = Density (ρ) × Volume (V) = Density × Area × Height = ρAh. Thus, we can write:

$$PA - P_oA - \rho Ahg = 0$$

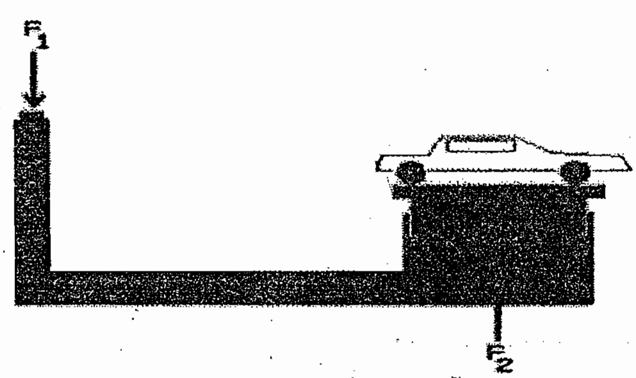
On simplifying we get:

$$P = P_o + \rho gh$$

Hence, the pressure P at a depth h below the surface of a fluid open to the atmosphere is greater than the atmospheric pressure by an amount ρgh. The difference in pressure between two points of unequal depth causes buoyant force.

Pascal's Principle:

A change in the pressure applied to a fluid is transmitted undiminished to every point of the fluid and to the walls of the container. In simpler words it can be stated as "the pressure applied to an enclosed fluid is transmitted equally to all points of the fluid and therefore to all walls of the vessel containing the fluid. Hydraulic press is a very good obvious example for this law/ principle. It is shown below:



Since the pressure must be same everywhere:

$$\mathbf{Pat1 = Pat2}$$

Since pressure = force / area, thus, F1/A1 = F2/A2 or F2 = (F1/A1) × A2. Therefore, the force at the outlet (2) is augmented by the size of the area of the outlet!

Archimedes's Principle

When an object is partly or wholly immersed in a fluid, it is exerted by an upward force called buoyant force. The magnitude of the buoyant force is equal to the weight of the fluid displaced by the object. This is called Archimedes's principle. It can be noted that the buoyant force acting on the object is always in the vertically upward direction and through the center of gravity of the displaced fluid. And, this principle is valid as long as the surface tension on the body is neglected.

• The weight of the fluid displaced is directly proportional to the volume of the displaced fluid. Thus, among objects with equal masses, the one with greater volume has greater buoyancy.

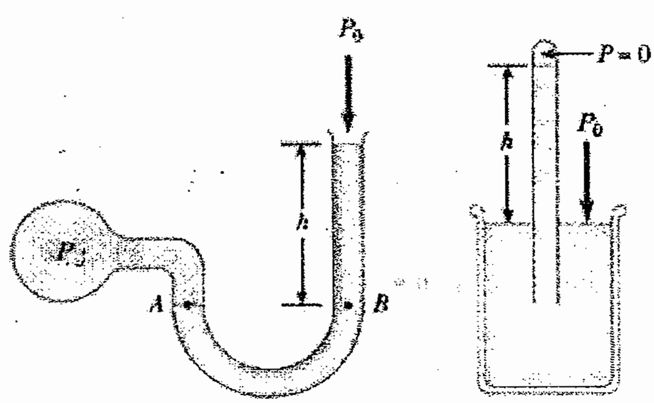
• If the density of an object is greater than the density of the fluid, then the upward buoyant force is less than the downward force of gravity and the unsupported object sinks.

• At neutral buoyancy the buoyant force is balanced by its weight.

• An object's buoyancy reduces with the compression of the fluid and increases with the expansion of the fluid.

Measurement of Pressure:

The fluid pressure can be measured by open-tube monometer or with the help of mercury barometer. One end of the U-shaped tube containing a liquid (figure a) is open to the atmosphere while the other end is connected to a system of unknown pressure P. The difference in pressure P – Po is ρgh. Hence P = Po + ρgh. The pressure P is called absolute pressure and the difference P – Po is the gauge pressure. The later one is usually measured through gauge scale.

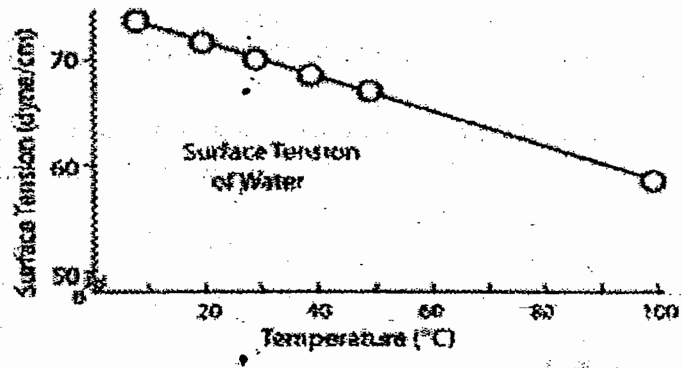


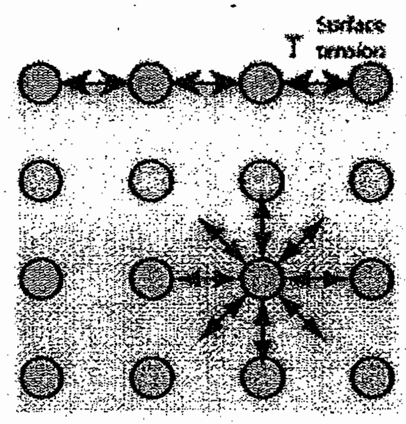
(a) (b)

Another type of instrument used to measure the pressure is called barometer (figure b). This instrument follows the rule Po = ρgh; h is the height of the mercury column.

Surface Tension:

Surface tension is defined as the force experienced (F) by a molecule present on a line (l) of the considered fluid. This happens because of the cohesive force between the liking molecules in a fluid.





The cohesive forces between molecules are shared with the neighboring molecules. Those on the surface have no neighboring molecules above and exhibit stronger attractive forces upon the nearest neighbors on the surface. This enhancement of the intermolecular attractive forces at the surface is called surface tension. Surface tension of water at 25oC is 72 dynes/cm. The surface tension of water decreases with increase in temperature.

- Hot water is a better cleaning agent since it has lower surface tension.
- Small insects can walk on the water surface since they have very less weight.
- Soaps and detergents help in lowering the surface tension so that the washing of clothes are possible in better way.

General Concepts of Fluid Flow

When a fluid flows its movement can be characterized in one of the two types: steady or laminar and turbulent.

A fluid flow is laminar if each particle of the fluid follows a smooth path such that the paths of different particles never cross each other. And in the steady flow the velocity of the fluid at any point remains constant.

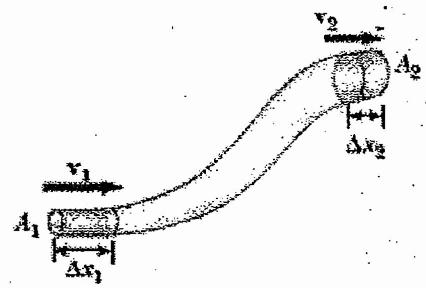
A fluid flow is turbulent after certain limit of speed so that the flow becomes irregular characterized by small whirls.

- To characterize the degree of internal friction of the fluid the term viscosity is used. Due to the viscosity, a part of the kinetic energy of the fluid is converted to internal energy.
- An ideal fluid can be considered to be non-viscous, incompressible with steady and ir-rotational flow.
- In the ir-rotational flow the fluid has no angular momentum about any point.
- The density is constant for an incompressible fluid.
- The velocity in a steady flow is constant at each point of the fluid.
- An object moving through a non-viscous fluid experiences zero viscosity.

Streamlines and Equation of Continuity:

The path taken by a fluid particle under steady flow is called a streamline. The velocity of the particle in the streamline is always tangent to the streamline. In such a motion the fluid particles cannot flow into or out of the tube of flow. If they do so, then the streamlines cross each other. Let us consider a non uniform pipe in which an ideal fluid is flowing as shown in the figure. The particles in the fluid move along streamline in steady flow. In the time t, the fluid at the bottom end of the pipe moves a distance Δx1=v1t. If A1 is the cross-sectional area in this region, then the mass of the fluid contained in the left shaded region in the figure is m1=ρA1Δx1=ρA1v1t, where ρ is the non- changing density of the ideal fluid. Similarly, for the fluid that moves at the upper end of the pipe in time t has a mass m2=ρA2v2t. Since the mass is conserved, we can write:

A1v1 = A2v2 = constant

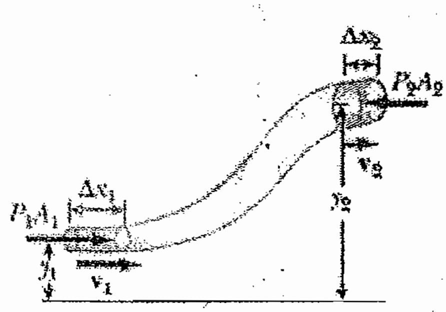


This is called equation of continuity. It implies that the product of area and fluid speed at all points along the pipe is a constant for an incompressible fluid.

Bernoulli's Equation:

The relationship between fluid speed, pressure and elevation for the flow of an ideal fluid through a non-uniform pipe is called Bernoulli's Equation. For a non-uniform pipe as shown below the equation can be written as follows:

$$P_1 + \frac{1}{2}\rho v_1^2 + \rho g y_1 = P_2 + \frac{1}{2}\rho v_2^2 + \rho g y_2$$



Thus, we can generalize this as follows:

$$P + \frac{1}{2}\rho v^2 + \rho g y = \text{constant}$$

This expression specifies that, in laminar flow, the sum of the pressure (P), kinetic energy per unit volume (0.5ρv2) and gravitational potential energy per unit volume (ρgy) has the same value at all points along a streamline.

Application of Bernoulli's Equation

Some of the applications of Bernoulli Equation and Equation of continuity are given as follows:

(1) The lift on an aircraft wing can be explained with the help of Bernoulli Effect.

(2) A golf ball is made to spin when struck by the club. The spinning ball experiences a lifting force that allows it to travel much farther than it would if it were not spinning. This can be explained by the Bernoulli Equation.

(3) As the water flows from a faucet, the stream of water becomes narrower as it descends since the speed increases. This can be explained by the equation of continuity.

Fields of Flow:

The fields of flow are considered as the speed and direction of flow of the fluids like air, water etc. The molecular motion is important in all these fluids.

Viscosity, Turbulence and Chaotic flows:

Viscosity is the characteristic of the fluid which arises as there is a resistance force coming into play in between two layers of fluid which move in a relative motion with each other. It characterizes the degree of the internal friction in the fluid. It can be noted that the viscosity causes part of the kinetic energy of a fluid to be converted to internal energy. This is similar to the mechanism of the object sliding on a rough horizontal surface, which loses kinetic energy.

When the particles in the fluid move in a smooth path and constant reasonable speed the flow is usually called steady or laminar flow. And if the fluid flows in a speed just above a critical speed, then the flow is turbulent. The turbulent flow is irregular and is characterized by small whirlpool like regions. These regions are called eddies. These eddies can vary in size with the extent of turbulence present in the fluid.

The flow becomes chaotic if the motion of the fluid becomes very much disorder or irregular even more as that of the turbulent flow.

Gases: Boyle's Law and Charles's Law

For most gases and under a wide range of conditions, the ratio of volume to temperature, for a gas at constant pressure, is constant; V/T = constant. This is known as **Charles' Law.**

For most gases and under a wide range of conditions, the product of pressure and volume, for a constant temperature, is constant; PV= constant. This is known as **Boyle's Law.**

Charles' and Boyle's Law may be combined as PV/T = constant or PV/T = P_oV_o/T_o.

For **constant volume:**

$$\frac{P}{T} = \text{constant}$$

$$\frac{P}{T} = \frac{P_o}{T_o}$$

For **constant temperature:**

$$PV = \text{constant}$$

$$PV = P_oV_o$$

This is known as **Boyle's Law.**

For **constant pressure:**

$$\frac{V}{T} = \text{constant}$$

$$\frac{V}{T} = \frac{V_o}{T_o}$$

This is known as **Charles' Law.**

Combining these, we have

$$\frac{PV}{T} = \text{constant}$$

$$\frac{PV}{T} = \frac{P_o V_o}{T_o}$$

$$PV = [\text{constant}]\, T$$

$$PV = n\,R\,T$$

This is known as the **ideal gas law.**

n = number of moles

A mole of gas molecules is Avagadro's number N_A of molecules;

$N_A = 6.02 \times 10^{23}$

R = universal gas constant

R = 8.314 J/mole-K

Pressure is caused by the constant bombardment of the many individual molecules of a gas.

The ideal gas law can be explained by the constant bombardment of the many individual molecules of a gas.