SRIRAM'S IAS

GENERAL STUDIES

PHYSICS

11A/22; 1st Floor; Old Rajender Nagar;New Delhi -60
ph. 011-25825591; 42437002; 9958671553
73-75; 1st Floor; Ring Road ;Beside GTB Metro Station
Kingsway Camp;New Delhi.
Ph. 08447273027

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1.One Dimensional Motion

Physics concerns itself with a variety of broad topics. One such topic is **mechanics** - the study of the motion of objects

Kinematics is the science of describing the motion of objects using words, diagrams, numbers, graphs, and equations. Kinematics is a branch of mechanics. The goal of any study of kinematics is to develop sophisticated mental models which serve to describe (and ultimately, explain) the motion of real-world objects.

Scalars and Vectors

- **Scalars** are quantities which are fully described by a magnitude (or numerical value) alone.
- **Vectors** are quantities which are fully described by both a magnitude and a direction.

Distance and Displacement

Distance and displacement are two quantities which may seem to mean the same thing yet have distinctly different definitions and meanings.

- **Distance** is a scalar quantity which refers to "how much ground an object has covered" during its motion.
- **Displacement** is a vector quantity which refers to "how far out of place an object is"; it is the object's overall change in position.

Speed and Velocity

Speed is a scalar quantity which refers to "how fast an object is moving." Speed can be thought of as the rate at which an object covers distance.

Velocity is a vector quantity which refers to "the rate at which an object changes its position." velocity is *direction aware*. When evaluating the velocity of an object, one must keep track of direction.

Calculating Average Speed and Average Velocity

The average speed during the course of a motion is often computed using the following formula:

$$\text{Average Speed} = \frac{\text{Distance Traveled}}{\text{Time of Travel}}$$

Meanwhile, the average velocity is often computed using the equation

$$\text{Average Velocity} = \frac{\Delta\,\text{position}}{\text{time}} = \frac{\text{displacement}}{\text{time}}$$

Average Speed versus Instantaneous Speed

Since a moving object often changes its speed during its motion, it is common to distinguish between the average speed and the instantaneous speed. The distinction is as follows.

Instantaneous Speed - the speed at any given instant in time.

Average Speed - the average of all instantaneous speeds; found simply by a distance/time ratio.

one might think of the instantaneous speed as the speed which the speedometer reads at any given instant in time and the average speed as the average of all the speedometer readings during the course of the trip.

Acceleration

Acceleration is a vector quantity which is defined as the rate at which an object changes its velocity. An object is accelerating if it is changing its velocity.

The Meaning of Constant Acceleration

Sometimes an accelerating object will change its velocity by the same amount each second.. This is referred to as a **constant acceleration** since the velocity is changing by a constant amount each second.

Calculating the Average Acceleration

The average acceleration (**a**) of any object over a given interval of time (**t**) can be calculated using the equation

$$\text{Ave. acceleration} = \frac{\Delta\text{velocity}}{\text{time}} = \frac{v_f - v_i}{t}$$

Acceleration values are expressed in units of velocity/time. Typical acceleration units include the following:

m/s/s

mi/hr/s

km/hr/s

m/s²

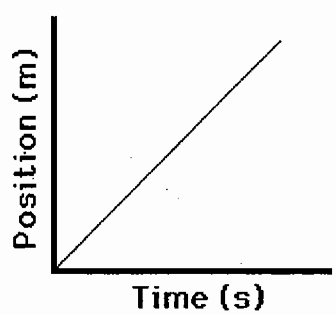
The Direction of the Acceleration Vector

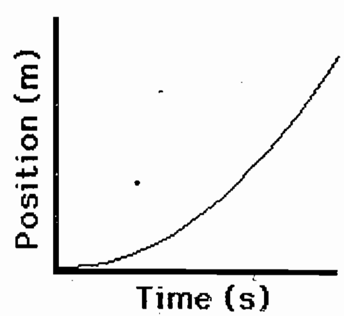
Since acceleration is a vector quantity, it has a direction associated with it. The direction of the acceleration vector depends on two things:

- whether the object is speeding up or slowing down
- whether the object is moving in the + or - direction

Describing Motion with Position vs. Time Graphs

The Meaning of Shape for a p-t Graph





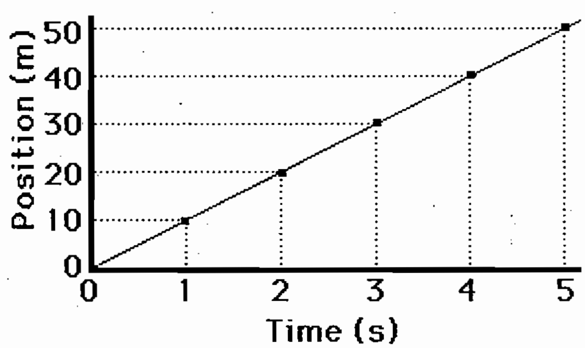
The shapes of the position versus time graphs for these two basic types of motion - constant velocity motion and accelerated motion (i.e., changing velocity) - reveal an important principle. The principle is that the slope of the line on a position-time graph reveals useful information about the velocity of the object. It is often said, "As the slope goes, so goes the velocity." Whatever characteristics the velocity has, the slope will exhibit the same (and vice versa). If the velocity is constant, then the slope is constant (i.e., a straight line). If the velocity is changing, then the slope is changing (i.e., a curved line). If the velocity is positive, then the slope is positive (i.e., moving upwards and to the right). This very principle can be extended to any motion conceivable.

The Meaning of Slope for a p-t Graph

The slope of a position vs. time graph reveals pertinent information about an object's velocity. For example, a small slope means a small velocity; a negative slope means a negative velocity; a constant slope (straight line) means a constant velocity; a changing slope (curved line) means a changing velocity. Thus the shape of the line on the graph (straight, curving, steeply sloped, mildly sloped, etc.) is descriptive of the object's motion.

Determining the Slope on a p-t Graph

Let's begin by considering the position versus time graph below.



The line is sloping upwards to the right. But mathematically, by how much does it slope upwards for every 1 second along the horizontal (time) axis? To answer this question we must use the slope equation.

$$\text{Slope} = \frac{\Delta y}{\Delta x} = \frac{y_2 - y_1}{x_2 - x_1} = \frac{\text{rise}}{\text{run}}$$

The slope equation says that the slope of a line is found by determining the amount of *rise* of the line between any two points divided by the amount of *run* of the line between the same two points. In other words,

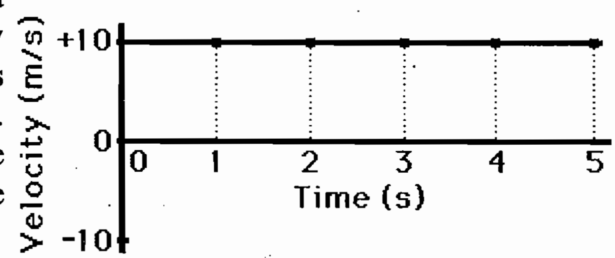
- Pick two points on the line and determine their coordinates.
- Determine the difference in y-coordinates of these two points (*rise*).
- Determine the difference in x-coordinates for these two points (*run*).
- Divide the difference in y-coordinates by the difference in x-coordinates (rise/run or slope).

The Meaning of Shape for a v-t Graph

The specific features of the motion of objects are demonstrated by the shape and the slope of the lines on a velocity vs. time graph.

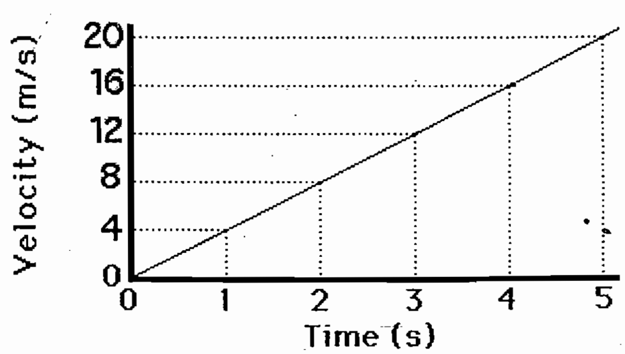
Consider a car moving with a **constant, rightward (+) velocity** - say of +10 m/s. As learned in an earlier, a car moving with a constant velocity is a car with zero acceleration.

If the velocity-time data for such a car were graphed, then the resulting graph would look like the graph at the right. Note that a motion described as a constant, positive velocity results in a line of zero slope **(a horizontal line has zero slope)** when plotted as a velocity-time graph. Furthermore, only positive velocity values are plotted, corresponding to a motion with positive velocity.



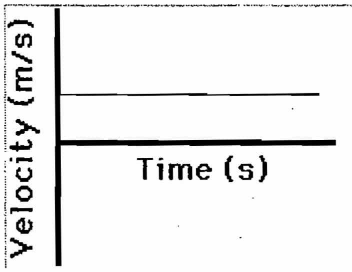
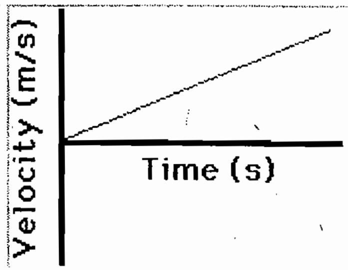
Now consider a car moving with a **rightward (+), changing velocity** - that is, a car that is moving rightward but speeding up or *accelerating*. Since the car is moving in the positive direction and speeding up, the car is said to have a *positive* acceleration.

If the velocity-time data for such a car were graphed, then the resulting graph would look like the graph at the right. Note that a motion described as a changing, positive velocity results in a sloped line when plotted as a velocity-time graph. The slope of the line is



positive, corresponding to the positive acceleration. Furthermore, only positive velocity values are plotted, corresponding to a motion with positive velocity.

The velocity vs. time graphs for the two types of motion - constant velocity and changing velocity (acceleration) - can be summarized as follows.

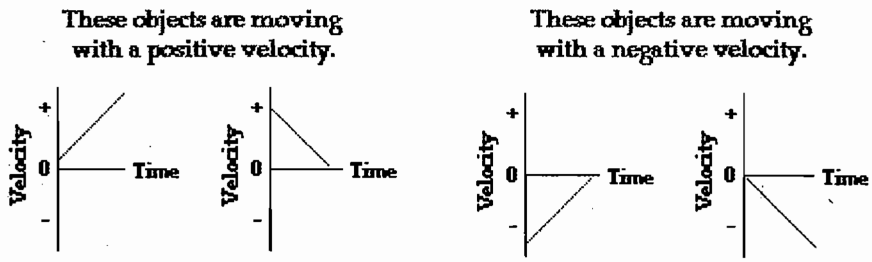
Positive Velocity **Zero Acceleration**	**Positive Velocity** **Positive Acceleration**
	

The Importance of Slope

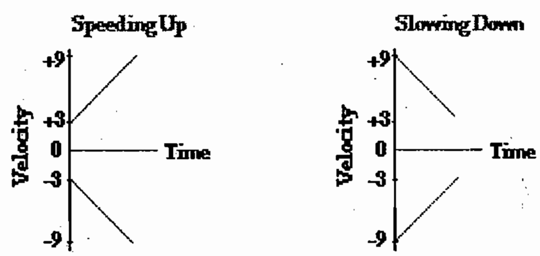
The shapes of the velocity vs. time graphs for these two basic types of motion - constant velocity motion and accelerated motion (i.e., changing velocity) - reveal an important principle. The principle is that **the slope of the line on a velocity-time graph reveals useful information about the acceleration of the object**. If the acceleration is zero, then the slope is zero (i.e., a horizontal line). If the acceleration is positive, then the slope is positive (i.e., an upward sloping line). If the acceleration is negative, then the slope is negative (i.e., a downward sloping line). This very principle can be extended to any conceivable motion.

The slope of a velocity-time graph reveals information about an object's acceleration. But how can one tell whether the object is moving in the positive direction (i.e., positive velocity) or in the negative direction (i.e., negative velocity)? And how can one tell if the object is speeding up or slowing down?

The answers to these questions hinge on one's ability to read a graph. Since the graph is a velocity-time graph, the velocity would be positive whenever the line lies in the positive region (above the x-axis) of the graph. Similarly, the velocity would be negative whenever the line lies in the negative region (below the x-axis) of the graph., a positive velocity means the object is moving in the positive direction; and a negative velocity means the object is moving in the negative direction. So one knows an object is moving in the positive direction if the line is located in the positive region of the graph (whether it is sloping up or sloping down). And one knows that an object is moving in the negative direction if the line is located in the negative region of the graph (whether it is sloping up or sloping down). And finally, if a line crosses over the x-axis from the positive region to the negative region of the graph (or vice versa), then the object has changed directions.



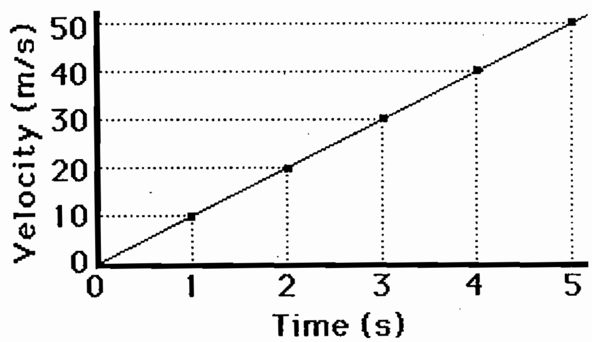
Now how can one tell if the object is speeding up or slowing down? Speeding up means that the magnitude (or numerical value) of the velocity is getting large. For instance, an object with a velocity changing from +3 m/s to + 9 m/s is speeding up. Similarly, an object with a velocity changing from -3 m/s to -9 m/s is also speeding up. In each case, the magnitude of the velocity (the number itself, not the sign or direction) is increasing; the speed is getting bigger. Given this fact, one would believe that an object is speeding up if the line on a velocity-time graph is changing from near the 0-velocity point to a location further away from the 0-velocity point. That is, if the line is getting further away from the x-axis (the 0-velocity point), then the object is speeding up. And conversely, if the line is approaching the x-axis, then the object is slowing down.



Determining the Slope on a v-t Graph

The slope of the line on a velocity versus time graph is equal to the acceleration of the object. If the object is moving with an acceleration of +4 m/s/s (i.e., changing its velocity by 4 m/s per second), then the slope of the line will be +4 m/s/s. If the object is moving with an acceleration of -8 m/s/s, then the slope of the line will be -8 m/s/s. If the object has a velocity of 0 m/s, then the slope of the line will be 0 m/s. Because of its importance, a student of physics must have a good understanding of how to calculate the slope of a line. In this part of the lesson, the method for determining the slope of a line on a velocity-time graph will be discussed.

Let's begin by considering the velocity versus time graph below.



The line is sloping upwards to the right. But mathematically, by how much does it slope upwards for every 1 second along the horizontal (time) axis? To answer this question we must use the slope equation.

$$\text{Slope} = \frac{\Delta y}{\Delta x} = \frac{y_2 - y_1}{x_2 - x_1} = \frac{\text{rise}}{\text{run}}$$

The slope equation says that the slope of a line is found by determining the amount of *rise* of the line between any two points divided by the amount of *run* of the line between the same two points. A method for carrying out the calculation is

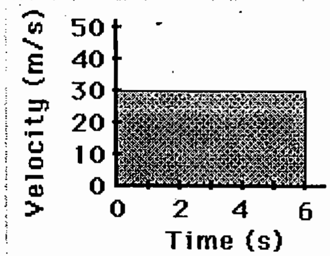
1. Pick two points on the line and determine their coordinates.
2. Determine the difference in y-coordinates for these two points (*rise*).
3. Determine the difference in x-coordinates for these two points (*run*).
4. Divide the difference in y-coordinates by the difference in x-coordinates (rise/run or slope).

Determining the Area on a v-t Graph

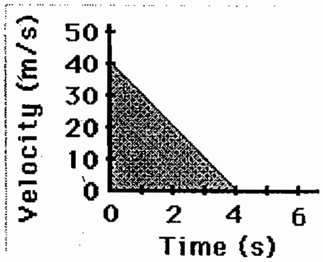
As learned in an earlier part , a plot of velocity-time can be used to determine the acceleration of an object (the slope). In this part, we will learn how a plot of velocity versus time can also be used to determine the displacement of an object. For velocity versus time graphs, the area bound by the line and the axes represents

the displacement. The diagram below shows three different velocity-time graphs; the shaded regions between the line and the time-axis represents the displacement during the stated time interval.

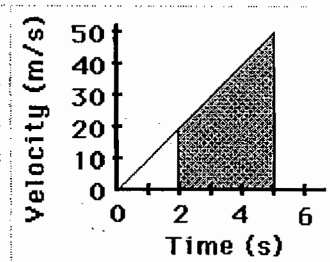
The shaded area is representative of the displacement during from 0 seconds to 6 seconds. This area takes on the shape of a **rectangle** can be calculated using the appropriate equation.



The shaded area is representative of the displacement during from 0 seconds to 4 seconds. This area takes on the shape of a **triangle** can be calculated using the appropriate equation.



The shaded area is representative of the displacement during from 2 seconds to 5 seconds. This area takes on the shape of a **trapezoid** can be calculated using the appropriate equation.



The method used to find the area under a line on a velocity-time graph depends upon whether the section bound by the line and the axes is a rectangle, a triangle or a trapezoid. Area formulas for each shape are given below.

Rectangle

$$\text{Area} = b \times h$$

Triangle

$$\text{Area} = \frac{1}{2} \times b \times h$$

Trapezoid

$$\text{Area} = \frac{1}{2} \times b \times (h_1 + h_2)$$

Introduction to Free Fall

A free-falling object is an object which is falling under the sole influence of gravity. Any object which is being acted upon only be the force of gravity is said to be in a state of **free fall**. There are two important motion characteristics which are true of free-falling objects:

- Free-falling objects do not encounter air resistance.
- All free-falling objects (on Earth) accelerate downwards at a rate of 9.8 m/s/s (often approximated as 10 m/s/s for *back-of-the-envelope* calculations)

The Acceleration of Gravity

It was learned in the previous part of this lesson that a free-falling object is an object which is falling under the sole influence of gravity. A free-falling object has an acceleration of 9.8 m/s/s, downward (on Earth). This numerical value for the acceleration of a free-falling object is such an important value that it is given a special name. It is known as the **acceleration of gravity** - the acceleration for any object moving under the sole influence of gravity. A matter of fact, this quantity known as the acceleration of gravity is such an important quantity that physicists have a special symbol to denote it - the symbol **g**. The numerical value for the acceleration of gravity is most accurately known as 9.8 m/s/s. There are slight variations in this numerical value (to the second decimal place) **which are dependent primarily upon on altitude**. We occasionally use the approximated value of 10 m/s/s in The Physics Classroom Tutorial in order to reduce the complexity of the many mathematical tasks

g = 9.8 m/s/s, downward

(~ 10 m/s/s, downward)

The Big Misconception

we have learnt that that the acceleration of a free-falling object (on earth) is 9.8 m/s/s. This value (known as the acceleration of gravity) is the same for all free-falling objects regardless of how long they have been falling, or whether they were initially dropped from rest or thrown up into the air. Yet the questions are often asked "doesn't a more massive object accelerate at a greater rate than a less massive object?" "Wouldn't an elephant free-fall faster than a mouse?" This question is a reasonable inquiry that is probably based in part upon personal observations made of falling objects in the physical world. After all, nearly everyone has observed the difference in the rate of fall of a single piece of paper (or similar object) and a textbook. The two objects clearly travel to the ground at different rates - with the more massive book falling faster.

The answer to the question (doesn't a more massive object accelerate at a greater rate than a less-massive object?) is absolutely not! That is, absolutely not if we are considering the specific type of falling motion known as free-fall. Free-fall is the motion of objects which move under the sole influence of gravity; **free-falling objects do not encounter air resistance.** More massive objects will only fall faster if there is an appreciable amount of air resistance present.

The actual explanation of why all objects accelerate at the same rate involves the concepts of force and mass. The details will be discussed later. At that time, you will learn that **the acceleration of an object is directly proportional to force and inversely proportional to mass**. Increasing force tends to increase acceleration while increasing mass tends to decrease acceleration. Thus, the greater force on more massive objects is offset by the inverse influence of greater mass. **Subsequently, all objects free fall at the same rate of acceleration, regardless of their mass**

The Kinematic Equations

$$d = v_i*t + \frac{1}{2}*a*t^2 \qquad v_f^2 = v_i^2 + 2*a*d$$

$$v_f = v_i + a*t \qquad d = \frac{v_i + v_f}{2} * t$$

There are a variety of symbols used in the above equations. Each symbol has its own specific meaning. The symbol **d** stands for the **displacement** of the object. The symbol **t** stands for the **time** for which the object moved. The symbol **a** stands for the **acceleration** of the object. And the symbol **v** stands for the velocity of the object; a subscript of i after the v (as in $\mathbf{v_i}$) indicates that the velocity value is the **initial velocity** value and a subscript of f (as in $\mathbf{v_f}$) indicates that the velocity value is the **final velocity** value.

Each of these four equations appropriately describe the mathematical relationship between the parameters of an object's motion. As such, they can be used to predict unknown information about an object's motion if other information is known.

Kinematic Equations and Free Fall

As mentioned, a free-falling object is an object which is falling under the sole influence of gravity. That is to say that any object which is moving and being acted upon only be the force of gravity is said to be "in a state of **free fall**." Such an object will experience a downward acceleration of 9.8 m/s/s. Whether the object is falling downward or rising upward towards its peak, if it is under the sole influence of gravity, then its acceleration value is 9.8 m/s/s.

Like any moving object, the motion of an object in free fall can be described by four kinematic equations. The kinematic equations which describe any object's motion are:

The Kinematic Equations

$$d = v_i * t + \frac{1}{2} * a * t^2 \qquad v_f^2 = v_i^2 + 2 * a * d$$

$$v_f = v_i + a * t \qquad d = \frac{v_i + v_f}{2} * t$$

The symbols in the above equation have a specific meaning: the symbol **d** stands for the **displacement**; the symbol **t** stands for the **time**; the symbol **a** stands for the **acceleration** of the object; the symbol $\mathbf{v_i}$ stands for the **initial velocity** value; and the symbol $\mathbf{v_f}$ stands for the **final velocity**.

There are a few conceptual characteristics of free fall motion which will be of value when using the equations to analyze free fall motion. These concepts are described as follows:

- An object in free fall experiences an acceleration of -9.8 m/s/s. (The - sign indicates a downward acceleration.) Whether explicitly stated or not, the value of the acceleration in the kinematic equations is -9.8 m/s/s for any freely falling object.
- If an object is merely dropped (as opposed to being thrown) from an elevated height, then the initial velocity of the object is 0 m/s.
- If an object is projected upwards in a perfectly vertical direction, then it will slow down as it rises upward. The instant at which it reaches the peak of its trajectory, its velocity is 0 m/s. This value can be used as one of the motion parameters in the kinematic equations; for example, the final velocity ($\mathbf{v_f}$) after traveling to the peak would be assigned a value of 0 m/s.
- If an object is projected upwards in a perfectly vertical direction, then the velocity at which it is projected is equal in magnitude and opposite in sign to the velocity which it has when it returns to the same height. These four principles and the four kinematic equations can be combined to solve problems involving the motion of free falling objects.

2. Newton's Laws of Motion

The focus here is Newton's first law of motion - sometimes referred to as the law of inertia.

Newton's first law of motion is often stated as:

An object at rest tends to stay at rest and an object in motion tends to stay in motion with the same speed and in the same direction **unless acted upon by an unbalanced force.**

Everyday Applications of Newton's First Law

There are many applications of Newton's first law of motion. Several applications are listed below. Perhaps you could think about the law of inertia and provide explanations for each application.

- Blood rushes from your head to your feet while quickly stopping when riding on a descending elevator.
- The head of a hammer can be tightened onto the wooden handle by banging the bottom of the handle against a hard surface.
- A brick is painlessly broken over the hand of a physics teacher by slamming it with a hammer.
- To dislodge ketchup from the bottom of a ketchup bottle, it is often turned upside down and thrusted downward at high speeds and then abruptly halted.
- Headrests are placed in cars to prevent whiplash injuries during rear-end collisions.
- While riding a skateboard (or wagon or bicycle), you fly forward off the board when hitting a curb or rock or other object which abruptly halts the motion of the skateboard.

Inertia and Mass

Newton's first law of motion states that "An object at rest tends to stay at rest and an object in motion tends to stay in motion with the same speed and in the same direction unless acted upon by an unbalanced force." Objects tend to "keep on doing what they're doing." In fact, it is the natural tendency of objects to resist changes in their state of motion. This tendency to resist changes in their state of motion is described as **inertia**.

Galileo and the Concept of Inertia

Galileo, a premier scientist in the seventeenth century, developed the concept of inertia. Galileo reasoned that moving objects eventually stop because of a force called friction.

Mass as a Measure of the Amount of Inertia

All objects resist changes in their state of motion. All objects have this tendency - they have inertia. But do some objects have more of a tendency to resist changes than others? Absolutely yes! The tendency of an object to resist changes in its state of motion varies with mass. Mass is that quantity which is solely dependent upon the inertia of an object. The more inertia which an object has, the more mass it has. A more massive object has a greater tendency to resist changes in its state of motion.

Force and Its Representation

The Meaning of Force

A **force** is a push or pull upon an object resulting from the object's *interaction* with another object. Whenever there is an *interaction* between two objects, there is a force upon each of the objects. When the *interaction* ceases, the two objects no longer experience the force. Forces only exist as a result of an interaction.

For simplicity sake, all forces (interactions) between objects can be placed into two broad categories:

- contact forces, and
- forces resulting from action-at-a-distance

Contact forces are those types of forces which result when the two interacting objects are perceived to be physically contacting each other. Examples of contact forces include frictional forces, tensional forces, normal forces, air resistance forces, and applied forces..

Action-at-a-distance forces are those types of forces which result even when the two interacting objects are not in physical contact with each other, yet are able to exert a push or pull despite their physical separation. Examples of action-at-a-distance forces include gravitational forces. For example, the sun and planets exert a gravitational pull on each other despite their large spatial separation. Even when your feet leave the earth and you are no longer in physical contact with the earth, there is a gravitational pull between you and the Earth. Electric forces are action-at-a-distance forces. For example, the protons in the nucleus of an atom and the electrons outside the nucleus experience an electrical pull towards each other .

despite their small spatial separation. And magnetic forces are action-at-a-distance forces. For example, two magnets can exert a magnetic pull on each other even when separated by a distance of a few centimeters.

Examples of contact and action-at-distance forces are listed in the table below.

Contact Forces	**Action-at-a-Distance Forces**
Frictional Force	Gravitational Force
Tension Force	Electrical Force
Normal Force	Magnetic Force
Air Resistance Force	
Applied Force	
Spring Force	

Force is a quantity which is measured using the standard metric unit known as the **Newton**. A Newton is abbreviated by a "N." To say "10.0 N" means 10.0 Newtons of force. One Newton is the amount of force required to give a 1-kg mass an acceleration of 1 m/s/s. Thus, the following unit equivalency can be stated:

$$1\ \text{Newton} = 1\ \text{kg} * \frac{\text{m}}{\text{s}^2}$$

A force is a vector quantity.

Newton's Second Law of Motion

The acceleration of an object as produced by a net force is directly proportional to the magnitude of the net force, in the same direction as the net force, and inversely proportional to the mass of the object.

The net force is equated to the product of the mass times the acceleration.

$$\mathbf{F_{net} = m * a}$$

Newton's Third Law

Formally stated, Newton's third law is:

For every action, there is an equal and opposite reaction.

The statement means that in every interaction, there is a pair of forces acting on the two interacting objects. The size of the forces on the first object equals the size of the force on the second object. The direction of the force on the first object is opposite to the direction of the force on the second object. Forces always come in pairs - equal and opposite action-reaction force pairs.

Projectile Motion

What is a Projectile?

The most common example of an object which is moving in *two dimensions* is a projectile.

A projectile is an object upon which the only force acting is gravity. There are a variety of examples of projectiles. An object dropped from rest is a projectile (provided that the influence of air resistance is negligible). An object which is thrown vertically upward is also a projectile (provided that the influence of air resistance is negligible). And an object is which thrown upward at an angle to the horizontal is also a projectile (provided that the influence of air resistance is negligible). A projectile is any object which once *projected* or dropped continues in motion by its own inertia and is influenced only by the downward force of gravity.

By definition, a projectile has only one force acting upon it - the force of gravity. If there was any other force acting upon an object, then that object would not be a projectile.

3. Momentum and Its Conservation

Momentum refers to the quantity of motion that an object has.

Momentum can be defined as "mass in motion." All objects have mass; so if an object is moving, then it has momentum - it has its mass in motion. The amount of momentum which an object has is dependent upon two variables: how much *stuff* is moving and how fast the *stuff* is moving. Momentum depends upon the variables mass and velocity. In terms of an equation, the momentum of an object is equal to the mass of the object times the velocity of the object.

Momentum = mass • velocity

In physics, the symbol for the quantity momentum is the lower case "p". Thus, the above equation can be rewritten as

$p = m \bullet v$

where **m** is the mass and **v** is the velocity. The equation illustrates that momentum is directly proportional to an object's mass and directly proportional to the object's velocity.

The units for momentum would be mass units times velocity units. The standard metric unit of momentum is the kg•m/s.

Momentum is a **vector quantity**

Momentum and Impulse Connection:

These concepts are merely an outgrowth of Newton's second law .Newton's second law ($F_{net} = m \bullet a$) stated that the acceleration of an object is directly proportional to the net force acting upon the object and inversely proportional to the mass of the object. When combined with the definition of acceleration (a = change in velocity / time), the following equalities result.

$$F = m * a = m * \frac{\Delta v}{t}$$

or

$$F = m * \frac{\Delta v}{t}$$

If both sides of the above equation are multiplied by the quantity t, a new equation results.

$$F * t = m * \Delta v$$

To truly understand the equation, it is important to understand its meaning in words. In words, it could be said that **the force times the time** equals **the mass times the change in velocity.** In physics, the quantity Force • time is known as **impulse**. And since the quantity m•v is the momentum, the quantity m•ΔV

must be the **change in momentum**. The equation really says that the

Impulse = Change in momentum

The physics of collisions are governed by the laws of momentum.

In a collision, an object experiences a force for a specific amount of time which results in a change in momentum. The result of the force acting for the given amount of time is that the object's mass either speeds up or slows down (or changes direction). The impulse experienced by the object equals the change in momentum of the object. In equation form, F • t = m • Δ v.

Momentum Conservation Principle

One of the most powerful laws in physics is the law of momentum conservation. The law of momentum conservation can be stated as follows.

For a collision occurring between object 1 and object 2 in an **isolated system,** the total momentum of the two objects before the collision is equal to the total momentum of the two objects after the collision. That is, the momentum lost by object 1 is equal to the momentum gained by object 2.

The above statement tells us that the total momentum of a collection of objects (a *system*) is *conserved* - that is, the total amount of momentum is a constant or unchanging value..

Isolated Systems

Total system momentum is conserved for collisions occurring in isolated systems. But what makes a system of objects an isolated system? And is momentum conserved if the system is not isolated?

A system is a collection of two or more objects. An isolated system is a system which is free from the influence of a net external force which alters the momentum of the system. There are two criteria for the presence of a net external force; it must be...

- a force which originates from a source other than the two objects of the system
- a force that is not balanced by other forces.

A system in which the only forces which contribute to the momentum change of an individual object are the forces acting between the objects themselves can be considered an isolated system.

If a system is not isolated, then the total system momentum is not conserved. Because of the inevitability of friction and air resistance in any real collision, one might conclude that no system is ever perfectly isolated. The reasoning would be that there will always be a resistance force of some kind robbing the system of its momentum

Momentum Conservation in Explosions

For collisions occurring in isolated systems, there are no exceptions to this law. This same principle of momentum conservation can be applied to explosions. In an explosion, an internal impulse acts in order to propel the parts of a system (often a single object) into a variety of directions. After the explosion, the individual parts of the system (which is often a collection of fragments from the original object) have momentum. If the vector sum of all individual parts of the system could be added together to determine the total momentum after the explosion, then it should be the same as the total momentum before the explosion. Just like in collisions, total system momentum is conserved.

4. Work ,Energy and Power

When a force acts upon an object to cause a displacement of the object, it is said that **work** was done upon the object. **There are three key *ingredients* to work - force, displacement, and cause. In order for a force to qualify as having done *work* on an object, there must be a displacement and the force must *cause* the displacement**.

Read the following five statements to understand the concept of work.

Statement	Answer with Explanation
A teacher applies a force to a wall and becomes exhausted.	**No.** This is not an example of work. The wall is not displaced. A force must cause a displacement in order for work to be done
A book falls off a table and free falls to the ground.	**Yes.** This is an example of work. There is a force (gravity) which acts on the book which causes it to be displaced in a downward direction (i.e., "fall").
A waiter carries a tray full of meals above his head by one arm straight across the room at constant speed.	**No.** This is not an example of work. There is a force (the waiter pushes up on the tray) and there is a displacement (the tray is moved horizontally across the room). Yet the force does not cause the displacement. To cause a displacement, there must be a component of force in the direction of the displacement.
A rocket accelerates through space.	**Yes.** This is an example of work. There is a force (the expelled gases push on the rocket) which causes the rocket to be displaced through space.

Mathematically, work can be expressed by the following equation.

$$W = F * d * \cos \Theta$$

where F **is the force,** d **is the displacement, and the angle** (theta) **is defined as the angle between the force and the displacement vector.**

The Meaning of Negative Work

On occasion, a force acts upon a moving object to hinder a displacement. Examples might include a car skidding to a stop on a roadway surface or a baseball runner sliding to a stop on the infield dirt. In such instances, the force acts in the direction opposite the objects motion in order to slow it down. The force doesn't cause the displacement but rather *hinders* it. These situations involve what is commonly called *negative work.* The *negative* of negative work refers to the numerical value which results when values of F, d and theta are substituted into the work equation.

Units of Work Whenever a new quantity is introduced in physics, the standard metric units associated with that quantity are discussed. In the case of work (and also energy), the standard metric unit is the **Joule** (abbreviated **J**). One Joule is equivalent to one Newton of force causing a displacement of one meter. In other words,

The Joule is the unit of work.

1 Joule = 1 Newton * 1 meter

Potential Energy

Potential energy is the stored energy of position possessed by an object.

Gravitational potential energy is the energy stored in an object as the result of its vertical position or height. The energy is stored as the result of the gravitational attraction of the Earth for the object. The gravitational potential energy of the massive ball of a demolition machine is dependent on two variables - the mass of the ball and the height to which it is raised. There is a direct relation between gravitational potential energy and the mass of an object. More massive objects have greater gravitational potential energy. There is also a direct relation between gravitational potential energy and the height of an object. The higher that an object is elevated, the greater the gravitational potential energy. These relationships are expressed by the equation:

$$PE_{grav} = mass * g * height$$

$$PE_{grav} = m * g * h$$

Elastic potential energy is the energy stored in elastic materials as the result of their stretching or compressing. Elastic potential energy can be stored in rubber bands, bungee chords, trampolines, springs, an arrow drawn into a bow, etc. The amount of elastic potential energy stored in such a device is related to the amount of stretch of the device - the more stretch, the more stored energy.

Springs are a special instance of a device which can store elastic potential energy due to either compression or stretching. A force is required to compress a spring; the more compression there is, the more force which is required to compress it further. For certain springs, the amount of force is directly proportional to the amount of stretch or compression (x); the constant of proportionality is known as the spring constant (k).

$$F_{spring} = k * x$$

Such springs are said to follow Hooke's Law. If a spring is not stretched or compressed, then there is no elastic potential energy stored in it. The spring is said to be at its *equilibrium position.* The equilibrium position is the position that the spring naturally assumes when there is no force applied to it. In terms of potential energy, the equilibrium position could be called the zero-potential energy position. There is a special equation for springs which relates the amount of elastic potential energy to the amount of stretch (or compression) and the spring constant. The equation is

$$PE_{spring} = \frac{1}{2} * k * x^2$$

where k= spring constant
x= amount of compression
(relative to equilibrium pos'n)

Kinetic energy is the energy of motion. An object which has motion - whether it be vertical or horizontal motion - has kinetic energy. The following equation is used to represent the kinetic energy (KE) of an object.

$$KE = \frac{1}{2} * m * v^2$$

where **m** = mass of object.

v = speed of object

Kinetic energy is a scalar quantity; it does not have a direction.

$$1\ \text{Joule} = 1\ \text{kg} * \frac{m^2}{s^2}$$

The Total Mechanical Energy

The mechanical energy of an object can be the result of its motion (i.e., kinetic energy) and/or the result of its stored energy of position (i.e., potential energy). The total amount of mechanical energy is merely the sum of the potential energy and the kinetic energy. This sum is simply referred to as the total mechanical energy (abbreviated TME).

TME = PE + KE

Power

Power is the rate at which work is done. It is the work/time ratio. Mathematically, it is computed using the following equation.

$$\text{Power} = \frac{\text{Work}}{\text{time}}$$

The standard metric unit of power is the **Watt**.. Thus, a Watt is equivalent to a Joule/second. **For historical reasons, the *horsepower* is occasionally used to describe the power delivered by a machine. One horsepower is equivalent to approximately 750 Watts.**

5. Circular Motion and Planetary Motion

Suppose that you were driving a car with the steering wheel turned in such a manner that your car followed the path of a perfect circle with a constant radius. And suppose that as you drove, your speedometer maintained a constant reading of 10 mi/hr. In such a situation as this, the motion of your car could be described as experiencing uniform circular motion. **Uniform circular motion** is the motion of an object in a circle with a constant or uniform speed.

Calculation of the Average Speed

$$\text{Average Speed} = \frac{\text{distance}}{\text{time}} = \frac{\text{circumference}}{\text{time}}$$

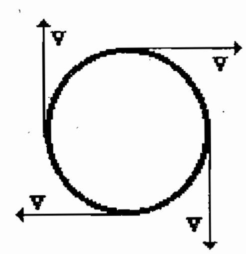
The circumference of any circle can be computed using from the radius according to the equation

Circumference = 2*pi*Radius

Combining these two equations above will lead to a new equation relating the speed of an object moving in uniform circular motion to the radius of the circle and the time to make one cycle around the circle (**period**).

$$\text{Average Speed} = \frac{2 * \pi * R}{T}$$

The Direction of the Velocity Vector As the object *rounds* the circle, the direction of the velocity vector is different than it was the instant before. So while the magnitude of the velocity vector may be constant, the direction of the velocity vector is changing. The best word that can be used to describe the direction of the velocity vector is the word **tangential**. The direction of the velocity vector at any instant is in the direction of a tangent line drawn to the circle at the object's location. (A tangent line is a line which touches a circle at one point but does not intersect it.) **The diagram at the right** shows the direction of the velocity vector at four different point for an object moving in a clockwise direction around a circle. While the actual direction of the object (and thus, of the velocity vector) is changing, it's direction is always tangent to the circle.



The direction of the velocity vector at every instant is in a direction tangent to the circle.

Acceleration

An accelerating object is an object which is changing its velocity. And since velocity is a vector which has both magnitude and direction, a change in either the magnitude or the direction constitutes a change in the velocity. **For this reason, it can be safely concluded that an object moving in a circle at constant speed is indeed accelerating. It is accelerating because the direction of the velocity vector is changing**.It is calculated using the following equation:

$$\text{Ave. acceleration} = \frac{\Delta \text{velocity}}{\text{time}} = \frac{v_f - v_i}{t}$$

where $\mathbf{v_i}$ represents the initial velocity and $\mathbf{v_f}$ represents the final velocity after some time of **t**. The numerator of the equation is found by subtracting one vector ($\mathbf{v_i}$) from a second vector ($\mathbf{v_f}$).

The Centripetal Force Requirement

An object moving in a circle experiences an acceleration. Even if moving around the perimeter of the circle with a constant speed, there is still a change in velocity and subsequently an acceleration. This acceleration is directed towards the center of the circle. And in accord with Newton's second law of motion, an object which experiences an acceleration must also be experiencing a net force. The direction of the net force is in the same direction as the acceleration. So for an object moving in a circle, there must be an inward force acting upon it in order to cause its inward acceleration. This is sometimes referred to as the **centripetal force requirement**. The word *centripetal* means center-seeking. For object's moving in circular motion, there is a net force acting towards the center which causes the object to *seek* the center.

Centrifugal force An object traveling in a circle behaves as if it is experiencing an outward force. This force, known as the centrifugal force, depends on the mass of the object, the speed of rotation, and the distance from the center. The more massive the object, the greater the force; the greater the speed of the object, the greater the force; and the greater the distance from the center, the greater the force.

Mathematics of Circular Motion

There are three mathematical quantities which will be of primary interest to us as we analyze the motion of objects in circles. These three quantities are speed, acceleration and force. The speed of an object moving in a circle is given by the following equation.

$$\text{Average Speed} = \frac{\text{distance}}{\text{time}} = \frac{2 * \pi * R}{T}$$

where R represents radius
T represents period

The acceleration of an object moving in a circle can be determined by either two of the following equations.

$$\text{Acceleration} = \frac{v^2}{R} \qquad \text{Acceleration} = \frac{4 * \pi^2 * R}{T^2}$$

where v represents speed
R represents radius
T represents period

The equation on the right (above) is derived from the equation on the left by the substitution of the expression for speed.

The net force (F_{net}) acting upon an object moving in circular motion is directed inwards. While there may by more than one force acting upon the object, the vector sum of all of them should add up to the net force. In general, the inward force is larger than the outward force (if any) such that the outward force cancels and the unbalanced force is in the direction of the center of the circle. The net force is related to the acceleration of the object (as is always the case) and is thus given by the following three equations:

$$F_{net} = m * a \qquad F_{net} = m * \frac{v^2}{R} \qquad F_{net} = m * \frac{4 * \pi^2 * R}{T^2}$$

where m represents mass
v represents speed
R represents radius
T represents period

The equations in the middle (above) and on the right (above) are derived from the equation on the left by the substitution of the expressions for acceleration.

6. Universal Gravitation

Gravity is a force which exists between the Earth and the objects which are near it.. We have become accustomed to calling it the **force of gravity** and have even represented it by the symbol $\mathbf{F_{grav}}$.

Not to be confused with the force of gravity ($\mathbf{F_{grav}}$), the acceleration of gravity (**g**) is the acceleration experienced by an object when the only force acting upon it is the force of gravity. On and near Earth's surface, the value for the acceleration of gravity is approximately 9.8 m/s/s. It is the same acceleration value for all objects, regardless of their mass (and assuming that the only significant force is gravity).

The Apple, the Moon, and the Inverse Square Law

In the early 1600's, German mathematician and astronomer, Johannes Kepler mathematically analyzed known astronomical data in order to develop three **laws to describe the motion of planets about the sun**. Kepler's three laws emerged from the analysis of data carefully collected over a span of several years by his Danish predecessor and teacher, Tycho Brahe. Kepler's three laws of planetary motion can be briefly described as follows:

- The path of the planets about the sun are elliptical in shape, with the center of the sun being located at one focus. (The Law of Ellipses)
- An imaginary line drawn from the center of the sun to the center of the planet will sweep out equal areas in equal intervals of time. (The Law of Equal Areas)
- The ratio of the squares of the periods of any two planets is equal to the ratio of the cubes of their average distances from the sun. (The Law of Harmonies)

While Kepler's laws provided a suitable framework for describing the motion and paths of planets about the sun, there **was no accepted explanation for why such paths existed**. The cause for how the planets moved as they did was never stated. Kepler could only suggest that there was some sort of interaction between the sun and the planets which provided the driving force for the planet's motion. To Kepler, the planets were somehow "magnetically" driven by the sun to orbit in their elliptical trajectories. There was however no interaction between the planets themselves.

Newton was troubled by the lack of explanation for the planet's orbits. To Newton, there must be some cause for such elliptical motion. Even more troubling was the circular motion of the moon about the earth. Newton knew that there must be some sort of force which governed the heavens; for the motion of the moon in a circular path and of the planets in an elliptical path required that there be an inward component of force. Circular and elliptical motion were clearly departures from the inertial paths (straight-line) of objects. And as such, these celestial motions required a cause in the form of an unbalanced force. The nature of such a force - its cause and its origin - bothered Newton for some time and was the fuel for much mental pondering. And according to legend, a breakthrough came at age 24 in an apple orchard in England. Newton never wrote of such an event, yet it is often claimed that the notion of gravity as the cause of all heavenly motion was instigated when he was struck in the head by an apple while lying under a tree in an orchard in England. Whether it is a myth or a reality, the fact is certain that it was Newton's ability to relate the cause for heavenly motion (the orbit of the moon about the earth) to the cause for Earthly motion (the falling of an apple to the Earth) which led him to his notion of **universal gravitation**.

Newton's Law of Universal Gravitation

Isaac Newton compared the acceleration of the moon to the acceleration of objects on earth. Believing that gravitational forces were responsible for each, Newton was able to draw an important conclusion about the dependence of gravity upon distance. This comparison led him to conclude that the force of gravitational attraction between the Earth and other objects is inversely proportional to the distance separating the earth's center from the object's center. But distance is not the only variable affecting the magnitude of a gravitational force. Consider Newton's famous equation

$$\mathbf{F_{net} = m \bullet a}$$

Newton knew that the force which caused the apple's acceleration (gravity) must be dependent upon the mass of the apple. And since the force acting to cause the apple's downward acceleration also causes the earth's upward acceleration (Newton's third law), that force must also depend upon the mass of the earth. So for Newton, the force of gravity acting between the earth and any other object is directly proportional to the mass of the earth, directly proportional to the mass of the object, and inversely proportional to the square of the distance which separates the centers of the earth and the object.

But Newton's law of universal gravitation extends gravity beyond earth. Newton's law of universal gravitation is about the **universality** of gravity. Newton's place in the *Gravity Hall of Fame* is not due to his discovery of gravity, but rather due to his discovery that gravitation is universal. **ALL** objects attract each other with a force of gravitational attraction. Gravity is universal. This force of gravitational attraction is directly dependent upon the masses of both objects and inversely proportional to the square of the distance which separates their centers. Newton's conclusion about the magnitude of gravitational forces is summarized symbolically as

$$F_{grav} \sim \frac{m_1 * m_2}{d^2}$$

where F_{grav} represents the force of gravity between two objects

$\sim$ means "proportional to"

m_1 represents the mass of object 1

m_2 represents the mass of object 2

d represents the distance separating the objects' centers

Since the gravitational force is directly proportional to the mass of both interacting objects, more massive objects will attract each other with a greater gravitational force. So as the mass of either object increases, the force of gravitational attraction between them also increases. If the mass of one of the objects is doubled, then the force of gravity between them is doubled. If the mass of one of the objects is tripled, then the force of gravity between them is tripled. If the mass of both of the objects is doubled, then the force of gravity between them is quadrupled; and so on.

Since gravitational force is inversely proportional to the separation distance between the two interacting objects, more separation distance will result in weaker gravitational forces. So as two objects are separated from each other, the force of gravitational attraction between them also decreases.

Another means of representing the proportionalities is to express the relationships in the form of an equation using a constant of proportionality. This equation is shown below.

$$F_{grav} = \frac{G * m_1 * m_2}{d^2}$$

where G represents the universal gravitation constant

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

The constant of proportionality (G) in the above equation is known as the **universal gravitation constant**. The precise value of G was determined experimentally by Henry Cavendish in the century after Newton's death. The value of G is found to be

$$\mathbf{G = 6.673 \times 10^{-11}\ N\ m^2/kg^2}$$

The units on G may seem rather odd; nonetheless they are sensible. When the units on G are substituted into the equation above and multiplied by $\mathbf{m_1} \cdot \mathbf{m_2}$ units and divided by $\mathbf{d}^2$ units, the result will be Newtons - the unit of force.

Planetary and Satellite Motion

Kepler's Three Laws

In the early 1600s, Johannes Kepler proposed three laws of planetary motion. Kepler was able to summarize the carefully collected data of his mentor - Tycho Brahe - with three statements which described the motion of planets in a sun-centered solar system. Kepler's efforts to explain the underlying reasons for such motions are no longer accepted; nonetheless, the actual laws themselves are still considered an accurate description of the motion of any planet and any satellite.

Kepler's three laws of planetary motion can be described as follows:

- The path of the planets about the sun are elliptical in shape, with the center of the sun being located at one focus. (The Law of Ellipses)
- An imaginary line drawn from the center of the sun to the center of the planet will sweep out equal areas in equal intervals of time. (The Law of Equal Areas)
- The ratio of the squares of the periods of any two planets is equal to the ratio of the cubes of their average distances from the sun. (The Law of Harmonies)

Circular Motion Principles for Satellites

A satellite is any object which is orbiting the earth, sun or other massive body. Satellites can be categorized as **natural satellites** or **man-made satellites**. The moon, the planets and comets are examples of natural satellites. Accompanying the orbit of natural satellites are a host of satellites launched from earth for purposes of communication, scientific research, weather forecasting, intelligence, etc. Whether a moon, a planet, or some man-made satellite, every satellite's motion is governed by the same physics principles and described by the same mathematical equations.

The fundamental principle to be understood concerning satellites is that a satellite is a projectile. That is to say, a satellite is an object upon which the only force is gravity. Once launched into orbit, the only force governing the motion of a satellite is the force of gravity. Newton was the first to theorize that a projectile launched with sufficient speed would actually orbit the earth

So what launch speed does a satellite need in order to orbit the earth? The answer emerges from a basic fact about the curvature of the earth. For every 8000 meters measured along the horizon of the earth, the earth's surface curves downward by approximately 5 meters. So if you were to look out horizontally along the horizon of the Earth for 8000 meters, you would observe that the Earth curves downwards below this straight-line path a distance of 5 meters. For a projectile to orbit the earth, it must travel horizontally a distance of 8000 meters for every 5 meters of vertical fall. It so happens that the vertical distance which a horizontally launched projectile would fall in its first second is approximately 5 meters ($0.5*g*t^2$). For this reason, a projectile launched horizontally with a speed of about 8000 m/s will be capable of orbiting the earth in a circular path. This assumes that it is launched above the surface of the earth and encounters negligible atmospheric drag. As the projectile travels tangentially a distance of 8000 meters in 1 second, it will drop approximately 5 meters towards the earth. Yet, the projectile will remain the same distance above the earth due to the fact that the earth curves at the same rate that the projectile falls. If shot with a speed greater than 8000 m/s, it would orbit the earth in an elliptical path.

Elliptical Orbits of Satellites

Occasionally satellites will orbit in paths which can be described as ellipses. In such cases, the central body is located at one of the foci of the ellipse. Similar motion characteristics apply for satellites moving in elliptical paths. The velocity of the satellite is directed tangent to the ellipse. The acceleration of the satellite is directed towards the focus of the ellipse. And in accord with Newton's second law of motion, the net force acting upon the satellite is directed in the same direction as the acceleration - towards the focus of the ellipse. Once more, this net force is supplied by the force of gravitational attraction between the central body and the orbiting satellite. In the case of elliptical paths, there is a component of force in the same direction as (or opposite direction as) the motion of the object. such a component of force can cause the satellite to either speed up or slow down in addition to changing directions. So unlike uniform circular motion, the elliptical motion of satellites is not characterized by a constant speed.

Meaning and Cause of Weightlessness

Weightlessness is simply a sensation experienced by an individual when there are no external objects touching one's body and exerting a push or pull upon it. Weightless sensations exist when all contact forces are removed. These sensations are common to any situation in which you are momentarily (or perpetually) in a state of free fall. When in free fall, the only force acting upon your body is the force of gravity - a non-contact force. Since the force of gravity cannot be felt without any other opposing forces, you would have no sensation of it. You would feel weightless when in a state of free fall.

These feelings of weightlessness are common at amusement parks for riders of roller coasters and other rides in which riders are momentarily airborne and lifted out of their seats. Suppose that you were lifted in your chair to the top of a very high tower and then your chair was suddenly dropped. As you and your chair fall towards the ground, you both accelerate at the same rate - **g**. Since the chair is unstable, falling at the same rate as you, it is unable to push upon you. Normal forces only result from contact with stable, supporting surfaces. The force of gravity is the only force acting upon your body. There are no external objects touching your body and exerting a force. As such, you would experience a weightless sensation. You would weigh as much as you always do (or as little), yet you would not have any sensation of this weight.

Weightlessness is only a sensation; it is not a reality corresponding to an individual who has lost weight. As you are free-falling on a roller coaster ride (or other amusement park ride), you have not momentarily lost your weight. Weightlessness has very little to do with weight and mostly to do with the presence or absence of contact forces. If by "weight" we are referring to the force of gravitational attraction to the Earth, a free-falling person has not "lost their weight;" they are still experiencing the Earth's gravitational attraction. Unfortunately, the confusion of a person's actual weight with one's feeling of weight is the source of many misconceptions.

Weightlessness in Orbit

Earth-orbiting astronauts are weightless for the same reasons that riders of a free-falling amusement park ride or a free-falling elevator are weightless. They are weightless because there is no external contact force pushing or pulling upon their body. In each case, gravity is the only force acting upon their body. Being an action-at-a-distance force, it cannot be felt and therefore would not provide any sensation of their weight. But for certain, the orbiting astronauts weigh something; that is, there is a force of gravity acting upon their body. In fact, if it were not for the force of gravity, the astronauts would not be orbiting in circular motion. It is the force of gravity which supplies the centripetal force requirement to allow the inward acceleration which is characteristic of circular motion. The force of gravity is the only force acting upon their body. The astronauts are in free-fall. Like the falling amusement park rider and the falling elevator rider, the astronauts and their surroundings are falling towards the Earth under the sole influence of gravity. The astronauts and all their surroundings - the space station with its contents - are falling towards the Earth without colliding into it. Their tangential velocity allows them to remain in orbital motion while the force of gravity pulls them inward.

Many students believe that orbiting astronauts are weightless because they do not experience a force of gravity. So to presume that the absence of gravity is the cause of the weightlessness experienced by orbiting astronauts would be in violation of circular motion principles. If a person believes that the absence of gravity is the cause of their weightlessness, then that person is hard-pressed to come up with a reason for why the astronauts are orbiting in the first place. The fact is that there must be a force of gravity in order for there to be an orbit.

One might respond to this discussion by adhering to a second misconception: the astronauts are weightless because the force of gravity is reduced in space. The reasoning goes as follows: "with less gravity, there would be less weight and thus they would feel less than their normal weight." While this is partly true, it does not explain their sense of weightlessness. The force of gravity acting upon an astronaut on the space station is certainly less than on Earth's surface. But how much less? Is it small enough to account for a significant reduction in weight? Absolutely not! If the space station orbits at an altitude of approximately 400 km above the Earth's surface, then the value of g at that location will be reduced from 9.8 m/s/s (at Earth's surface) to approximately 8.7 m/s/s. This would cause an astronaut weighing 1000 N at Earth's surface to be reduced in weight to approximately 890 N when in orbit. While this is certainly a reduction in weight, it does not account for the absolutely weightless sensations which astronauts experience. Their absolutely weightless sensations are the result of having "the floor pulled out from under them" (so to speak) as they are free-falling towards the Earth.

Still other students believe that weightlessness is due to the absence of air in space. Their misconception lies in the idea that there is no force of gravity when their is no air. According to them, gravity does not exist in a vacuum. But this is not the case. Gravity is a force which acts between the Earth's mass and the mass of other objects which surround it. The force of gravity can act across large distances and its affect can even penetrate across and into the vacuum of outer space. Perhaps students who own this misconception are confusing the force of gravity with air pressure. Air pressure is the result of surrounding air particles pressing upon the surface of an object in equal amounts from all directions. The force of gravity is not affected by air pressure. While air pressure reduces to zero in a location void of air (such as space), the force of gravity does not become 0 N. Indeed the presence of a vacuum results in the absence of air resistance; but this would not account for the weightless sensations. Astronauts merely feel weightless because there is no external contact force pushing or pulling upon their body. They are in a state of free fall.

7.Static Electricity

Charge as a Quantity

Like mass, the charge of an object is a measurable quantity. The charge possessed by an object is often expressed using the scientific unit known as the **Coulomb**. Just as mass is measured in grams or kilograms, charge is measured in units of Coulombs (abbreviated C). Because one Coulomb of charge is an abnormally large quantity of charge, the units of microCoulombs (μC) or nanoCoulombs (nC) are more commonly used as the unit of measurement of charge. To illustrate the magnitude of 1 Coulomb, an object would need an excess of 6.25×10^{18} electrons to have a total charge of -1 C. And of course an object with a shortage of 6.25×10^{18} electrons would have a total charge of +1 C.

The charge on a single electron is -1.6×10^{-19} Coulomb. The charge on a single proton is $+1.6 \times 10^{-19}$ Coulomb.

Charge Interactions

Opposites attract. And likes repel.

These two fundamental principles of charge interactions will be used throughout to explain the vast array of static electricity phenomena. These two types of electrical charges - positive and negative - are said to be opposite types of charge. And consistent with our fundamental principle of charge interaction, a positively charged object will attract a negatively charged object. A positively charged object will exert a repulsive force upon a second positively charged object. This repulsive force will push the two objects apart. Similarly, a negatively charged object will exert a repulsive force upon a second negatively charged object. Objects with like charge repel each other.

Interaction Between Charged and Neutral Objects

The interaction between two like-charged objects is repulsive. The interaction between two oppositely charged objects is attractive. What type of interaction is observed between a charged object and a neutral object? **The answer is quite surprising to many students. Any charged object - whether positively charged or negatively charged - will have an attractive interaction with a neutral object. Positively charged objects and neutral objects attract each other; and negatively charged objects and neutral objects attract each other.**

Conductors and Insulators

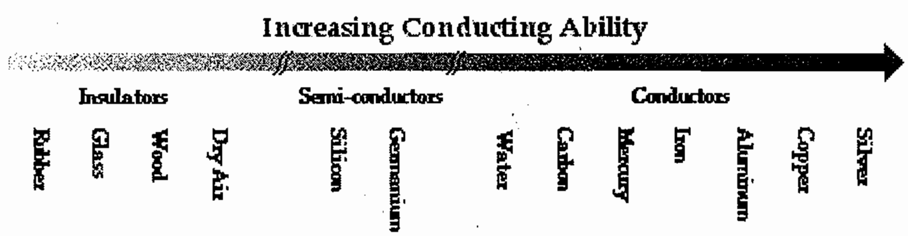
The behavior of an object which has been charged is dependent upon whether the object is made of a conductive or a nonconductive material. **Conductors** are materials which permit electrons to flow freely from atom to atom and molecule to molecule.

In contrast to conductors, **insulators** are materials which impede the free flow of electrons from atom to atom and molecule to molecule. If charge is transferred to an insulator at a given location, the excess charge will remain at the initial location of charging. The particles of the insulator do not permit the free flow of electrons; subsequently charge is seldom distributed evenly across the surface of an insulator.

Examples of conductors include metals, aqueous solutions of salts (i.e., *ionic compounds* dissolved in water), graphite, water and the human body.

Examples of insulators include plastics, Styrofoam, paper, rubber, glass and dry air.

The division of materials into the categories of conductors and insulators is a somewhat artificial division. It is more appropriate to think of materials as being placed somewhere along a continuum. Those materials which are super conductive (known as **superconductors**) would be placed at on end and the least conductive materials (best insulators) would be placed at the other end. Metals would be placed near the most conductive end and glass would be placed on the opposite end of the continuum. The conductivity of a metal might be as much as a million trillion times greater than that of glass.



Along the continuum of conductors and insulators, one might find the human body somewhere towards the conducting side of the middle. When the body acquires a static charge it has a tendency to distribute that charge throughout the surface of the body. Given the size of the human body, relative to the size of typical objects used in electrostatic experiments, it would require an abnormally large quantity of excess charge before its affect is noticeable. When a student places their hand upon the static ball, excess charge from the ball is shared with the human body. Being a conductor, the excess charge could flow to the human body and spread throughout the surface of the body, even onto strands of hair. As the individual strands of hair become charged, they begin to repel each other. Looking to distance themselves from their like-charged neighbors, the strands of hair begin to rise upward and outward - a truly hair-raising experience.

Many are familiar with the impact that **humidity** can have upon static charge buildups. You have likely noticed that bad hair days, doorknob shocks and static clothing are most common during winter months. Winter months tend to be the driest months of the year with humidity levels in the air dropping to lower values. Water, being a conductor, has a tendency to gradually remove excess charge from objects. When the humidity is high, a person acquiring an excess charge will tend to lose that charge to water molecules in the surrounding air. On the other hand, dry air conditions are more conducive to the buildup of static charge and more frequent electric shocks. Since humidity levels tend to vary from day to day and season to season.

Distribution of Charge via Electron Movement

At the location where the charge is imparted, there is an excess of electrons. That is, the multitude of atoms in that region possess more electrons than protons. Of course, there are a number of electrons who could be thought of as being *quite contented* since there is an accompanying positively charged proton to satisfy their attraction for an opposite. However, the so-called excess electrons have a repulsive response to each other and would prefer more space. Electrons, like human beings, wish to manipulate their surroundings in an effort to reduce repulsive affects. Since these excess electrons are present in a conductor, there is little hindrance to their ability to migrate to other parts of the object. And that is exactly what they do. In an effort to reduce the overall repulsive affects within the object, there is a mass migration of excess electrons throughout the entire surface of the object. Excess electrons migrate to distance themselves from their repulsive neighbors. In this sense, it is said that excess negative charge distributes itself throughout the surface of the conductor.

But what happens if the conductor acquires an excess of positive charge? What if electrons are removed from a conductor at a given location, giving the object an overall positive charge? If protons cannot move, then how can the excess of positive charge distribute itself across the surface of the material? While the answers to these questions are not as obvious, it still involves a rather simple explanation which once again relies on the two fundamental rules of charge interaction. Opposites attract and likes repel. Suppose that a conducting metal sphere is charged on its left side and imparted an excess of positive charge. (Of course, this requires that electrons be removed from the object at the location of charging.) A multitude of atoms in the region where the charging occurs have lost one or more electrons and have an excess of protons. The imbalance of charge within these atoms creates affects which can be thought of as disturbing the balance of charge within the entire object. The presence of these excess protons in a given location draws electrons from other atoms. Electrons in other parts of the object can be thought of as being *quite contented* with the balance of charge which they are experiencing. Yet there will always be some electrons who will feel the attraction for the excess protons some distance away. In human terms, we might say these electrons are drawn by curiosity or by the belief that the grass is greener on the other side of the fence. In the language of electrostatics, we simply assert that opposites attract - the excess protons and both the neighboring and distant electrons attract each other. The protons cannot do anything about this attraction since they are bound within the nucleus of their own atoms. Yet, electrons are loosely bound within atoms; and being present in a conductor, they are free to move. These electrons make the move for the excess protons, leaving their own atoms with their own excess of positive charge. This electron migration happens across the entire surface of the object, until the overall sum of repulsive affects between electrons across the whole surface of the object are minimized.

Polarization

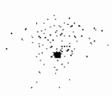
In conducting objects, electrons are so loosely bound that they may be **induced** into moving from one portion of the object to another portion of the object. To get an electron in a conducting object to *get up and go*, all that must be done is to place a charged object nearby the conducting object.

In general terms, polarization means to separate into opposites. In the political world, we often observe that a collection of people becomes polarized over some issue. For instance, we might say that the United States has become polarized over the issue of the death penalty. That is, the citizens of the United States have been separated into opposites - those who are for the death penalty and those who are against the death penalty. In the context of electricity, **polarization** is the process of separating opposite charges within an object. The positive charge becomes separated from the negative charge. By **inducing** the movement of electrons within an object, one side of the object is left with an excess of positive charge and the other side of the object is left with an excess of negative charge. Charge becomes separated into opposites.

How Can an Insulator be Polarized?

The electrons surrounding the nucleus of an atom are believed to be located in regions of space with specific shapes and sizes. The actual size and shape of these regions is determined by the high-powered mathematical equations common to Quantum Mechanics. Rather than being located a specific distance from the nucleus in a fixed orbit, the electrons are simply thought of as being located in regions often referred to as **electron clouds**. At any given moment, the electron is likely to be found at some location within the cloud. The electron clouds have varying density; the density of the cloud is considered to be greatest in the portion of the cloud where the electron has the greatest probability of being found at any given moment. And conversely, the electron cloud density is least in the regions where the electron is least likely to be found. In addition to having varying density, these electron clouds are also highly distortable. The presence of neighboring atoms with high electron affinity can distort the electron clouds around atoms. Rather than being located symmetrically about the positive nucleus, the cloud becomes asymmetrically shaped. As such, there is a polarization of the atom as the centers of positive and negative charge are no longer located in the same location. The atom is still a neutral atom; it has just become polarized.

Electron Cloud Distribution



Uniform distribution of electron cloud about the nucleus.

Non-uniform distribution of electron cloud - separation of + and - charge within atom.

This polarization leaves the molecule with areas which have a concentration of positive charges and other areas with a concentration of negative charges. This principle is utilized in the manufacture of certain commercial products which are used to reduce static cling. The centers of positive and negative charge within the product are drawn to excess charge residing on the clothes. There is a neutralization of the static charge buildup on the clothes, thus reducing their tendency to be attracted to each other. (Other products actually use a different principle. During manufacturing, a thin sheet is soaked in a solution containing positively charged ions. The sheet is tossed into the dryer with the clothes. Being saturated with positive charges, the sheet is capable of attracting excess electrons which are scuffed off of clothes during the drying cycle.)

Polarization is Not Charging

Perhaps the biggest misconception that pertains to polarization is the belief that polarization involves the charging of an object. Polarization is not charging! When an object becomes polarized, there is simply a redistribution of the centers of positive and negative charges within the object. Either by the movement of electrons across the surface of the object (as is the case in conductors) or through the distortion of electron clouds (as is the case in insulators), the centers of positive and negative charges become separated from each other. The atoms at one location on the object possess more protons than electrons and the atoms at another location have more electrons than protons. While there are the same number of protons and electrons within the object, these protons and electrons are not distributed in the same proportion across the object's surface. Yet, there are still equal numbers of positive charges (protons) and negative charges (electrons) within the object. While there is a separation of charge, there is NOT an imbalance of charge. When neutral objects become polarized, they are still neutral objects.

Methods of Charging

1.Charging by Friction

The presence of different atoms in objects provide different objects with different electrical properties. One such property is known as **electron affinity**. Simply put, the property of electron affinity refers to the relative amount of *love* which a material has for electrons. If atoms of a material have a high electron affinity, then that material will have a relatively high love for electrons

How Charging by Friction Works

The frictional charging process results in a transfer of electrons between the two objects which are rubbed together. Rubber has a much greater attraction for electrons than animal fur. As a result, the atoms of rubber pull electrons from the atoms of animal fur, leaving both objects with an imbalance of charge. The rubber balloon has an excess of electrons and the animal fur has a shortage of electrons. Having an excess of electrons, the rubber balloon is charged negatively. Similarly, the shortage of electrons on the animal fur leaves it with a positive charge. The two objects have become charged with opposite types of charges as a result of the transfer of electrons from the least electron-loving material to the most electron-loving material.

As mentioned, different materials have different affinities for electrons. By rubbing a variety of materials against each other and testing their resulting interaction with objects of known charge, the tested materials can be ordered according to their affinity for electrons. Such an ordering of substances is known as a **triboelectric series**. One such ordering for several materials is shown in the table at the right. Materials shown highest on the table tend to have a greater affinity for electrons than those below it. Subsequently, when any two materials in the table are rubbed together, the one which is higher can be expected to pull electrons from the material which is lower. As such, the materials highest on the table will have the greatest tendency to acquire the negative charge. Those below it would become positively charged.

Triboelectric Series

Celluloid
Sulfur
Rubber
Copper, Brass
Amber
Wood
Cotton
Human Skin
Silk
Cat Fur
Wool
Glass
Rabbit Fur
Asbestos

The Law of Conservation of Charge

Whenever a quantity like charge (or momentum or energy or matter) is observed to be the same prior to and after the completion of a given process, we say that the quantity is conserved. **Charge is always conserved**. When all objects involved are considered prior to and after a given process, we notice that the total amount of charge amidst the objects is the same before the process starts as it is after the process ends. This is referred to as the **law of conservation of charge**.

2.Charging by Induction

Induction charging is a method used to charge an object without actually touching the object to any other charged object involving the process of polarization

The fundamental principles principles of Induction charging are:

- The charged object is never touched to the object being charged by induction.
- The charged object does not transfer electrons to or receive electrons from the object being charged.
- The charged object serves to polarize the object being charged.
- The object being charged is touched by a ground; electrons are transferred between the ground and the object being charged (either into the object or out of it).
- The object being charged ultimately receives a charge that is opposite that of the charged object which is used to polarize it.

3.Charging by Conduction

Charging by conduction involves the contact of a charged object to a neutral object.. In contrast to induction, where the charged object is brought near but never contacted to the object being charged, conduction charging involves making the physical connection of the charged object to the neutral object. Because charging by conduction involves contact, it is often called **charging by contact**.

Grounding - the Removal of a Charge

We have discussed the three common methods of charging - charging by friction, charging by induction, and charging by conduction. A discussion of charging would not be complete without a discussion of *uncharging*. Objects with an excess of charge - either positive or negative - can have this charge *removed* by a process known as grounding. **Grounding is the process of *removing* the excess charge on an object by means of the transfer of electrons between it and another**

object of substantial size. When a charged object is grounded, the excess charge is balanced by the transfer of electrons between the charged object and a ground.

A **ground** is simply an object which serves as a seemingly infinite reservoir of electrons; the ground is capable of transferring electrons to or receiving electrons from a charged object in order to neutralize that object.

Any negatively charged object has an excess of electrons. If it is to have its charge removed, then it will have to lose its excess electrons. Once the excess electrons are removed from the object, there will be equal numbers of protons and electrons within the object and it will have a balance of charge. To remove the excess of electrons from a negatively charged electroscope, the electroscope will have to be connected by a conducting pathway to another object which is capable of receiving those electrons. The other object is the ground. In typical electrostatic experiments and demonstrations, this is simply done by touching the electroscope with one's hand. Upon contact, the excess electrons leave the electroscope and enter the person who touches it. These excess electrons subsequently spread about the surface of the person.

The previous discussion describes the grounding of a negatively charged electroscope. Electrons were transferred from the electroscope to the ground. But what if the electroscope is positively charged? How does electron transfer allow an object with an excess of protons to become neutralized? To explore these questions, we will consider the grounding of a positively charged electroscope. A positively charged electroscope must gain electrons in order to acquire an equal number of protons and electrons. By gaining electrons from *the ground*, the electroscope will have a balance of charge and therefore be neutral. Thus, the grounding of a positively charged electroscope involves the transfer of electrons from *the ground* into the electroscope.

Electric Force

Coulomb's Law Equation

The quantitative expression for the affect of these three variables on electric force is known as Coulomb's law. Coulomb's law states that the electrical force between two charged objects is directly proportional to the product of the quantity of charge on the objects and inversely proportional to the square of the separation distance between the two objects. In equation form, Coulomb's law can be stated as

$$F = \frac{k \cdot Q_1 \cdot Q_2}{d^2}$$

where Q_1 represents the quantity of charge on object 1 (in Coulombs), Q_2 represents the quantity of charge on object 2 (in Coulombs), and **d** represents the distance of separation between the two objects (in meters). The symbol **k** is a proportionality constant known as the Coulomb's law constant. **The value of this constant is dependent upon the medium that the charged objects are immersed in.** In the case of air, the value is approximately $9.0 \times 10^9\ N \cdot m^2 / C^2$. If the charged objects are present in water, the value of **k** can be reduced by as much as a factor **of 80**. It is worthwhile to point out that the units on **k** are such that when substituted into the equation the units on charge (Coulombs) and the units on distance (meters) will be canceled, leaving a Newton as the unit of force.

The Coulomb's law equation provides an accurate description of the force between two objects whenever the objects act as **point charges**. A charged conducting sphere interacts with other charged objects as though all of its charge were located at its center. While the charge is uniformly spread across the surface of the sphere, the center of charge can be considered to be the center of the sphere. The sphere acts as a point charge with its excess charge located at its center. Since Coulomb's law applies to point charges, the distance **d** in the equation is the distance between the centers of charge for both objects.

Electric Fields

Action at a Distance

How can an object be charged and what affect does that charge have upon other objects in its vicinity? we will explore this concept of **action-at-a-distance** using a different concept known as the **electric field**.

The Electric Field Concept

Action-at-a-distance forces are sometimes referred to as field forces. . An alternative to describing this action-at-a-distance affect is to simply suggest that there is something rather strange about the space surrounding a charged object. Any other charged object that is in that space feels the affect of the charge. A charged object creates an electric field - an alteration of the space in the region which surrounds it. Other charges in that field would feel the unusual alteration of the space. Whether a charged object enters that space or not, the electric field exists. Space is altered by the presence of a charged object. Other objects in that space experience the strange and mysterious qualities of the space.

A Stinky Analogy

With a concept such as the electric field, analogies are often appropriate and useful. While the following analogy might be a *wee-bit* crude, it certainly proves useful in many respects in describing the nature of an electric field. Anyone who has ever walked into a room of an infant with a soiled diaper (as in a *poopy* diaper) has experienced a *stinky field*. There is something about the space surrounding an infant's soiled diaper which exerts a strange influence upon other people who enter that space. When that *little stinker* needs a diaper change, you can't help but to notice it. When you walk into a room with such a diaper present, your detectors (i.e., the nose) begin to detect the presence of a stinky field. As you move closer and closer to the infant, the stinky field becomes more and more intense. And of course the worse the diaper, the stronger the stinky field becomes. It's not difficult to imagine that a soiled diaper could exert a smelly influence some distance away that would repel any nose that gets in that area. The diaper has altered the nature of the surrounding space and when your nose gets near, you know it. The stinky diaper has created a stinky field.

In the same manner, an electric charge creates an electric field - it has altered the nature of the space surrounding the charge. And if another charge gets near enough, that charge will sense that there is an affect when present in that surrounding space. And electric field is sensed by the detector charge in the same way that a nose senses the stinky field. The strength of the stinky field is dependent upon the distance from the stinky diaper and the amount of *stinky* in the diaper. And in an analogous manner, the strength of the electric field is dependent upon the amount of charge which creates the field and the distance from the charge.

Electric Field Intensity

The Force per Charge Ratio

Electric field strength is a vector quantity; it has both magnitude and direction. The magnitude of the electric field strength is defined in terms of how it is measured. Let's suppose that an electric charge can be denoted by the symbol **Q**. This electric charge creates an electric field; since **Q** is the source of the electric field, we will refer to it as the **source charge**. The strength of the source charge's electric field could be measured by any other charge placed somewhere in its surroundings. The charge that is used to measure the electric field strength is referred to as a **test charge** since it is used to *test* the field strength. The test charge has a quantity of charge denoted by the symbol **q**. When placed within the electric field, the test charge will experience an electric force - either attractive or repulsive. As is usually the case, this force will be denoted by the symbol **F**. The magnitude of the electric field is simply defined as the force per charge on the test charge.

$$\text{Electric Field Strength} = \frac{\text{Force}}{\text{Charge}}$$

If the electric field strength is denoted by the symbol **E**, then the equation can be rewritten in symbolic form as

$$E = \frac{F}{q}$$

The standard metric units on electric field strength arise from its definition. Since electric field is defined as a force per charge, its units would be force units divided by charge units. In this case, the standard metric units are Newton/Coulomb or N/C.

In the above discussion, you will note that two charges are mentioned - the source charge and the test charge. Two charges would always be necessary to encounter a force. In the electric world, it takes two to attract or repel. The equation for electric field strength (**E**) has one of the two charge quantities listed in it. Since there are two charges involved, a student will have to be ultimately careful to use the correct charge quantity when computing the electric field strength. The symbol **q** in the equation is the quantity of charge on the test charge (not the source charge). Recall that the electric field strength is defined in terms of how it is measured or tested; thus, the test charge finds its way into the equation. Electric field is the force per quantity of charge *on the test charge*.

The electric field strength is not dependent upon the quantity of charge on the test charge. If you think about that statement for a little while, you might be bothered by it. After all, the quantity of charge on the test charge (**q**) is in the equation for electric field. So how could electric field strength not be dependent upon **q** if **q** is in the equation? Increasing the quantity of charge on the test charge - say, by a factor of 2 - would increase the denominator of the equation by a factor of 2. But according to Coulomb's law, more charge also means more electric force (**F**). In fact, a twofold increase in **q** would be accompanied by a twofold increase in **F**. So as the denominator in the equation increases by a factor of two (or three or four), the numerator increases by the same factor. These two changes offset each other such that one can safely say that the electric field strength is not dependent upon the quantity of charge on the test charge. So regardless of what test charge is used, the electric field strength at any given location around the source charge **Q** will be measured to be the same.

The Direction of the Electric Field Vector

The precise direction of the force is dependent upon whether the test charge and the source charge have the same type of charge (in which repulsion occurs) or the opposite type of charge (in which attraction occurs). To resolve the dilemma of whether the electric field vector is directed towards or away from the source charge, a convention has been established. The worldwide convention which is used by scientists is to define the direction of the electric field vector as the direction that a **positive test charge** is pushed or pulled when in the presence of the electric field. By using the convention of a positive test charge, everyone can agree upon the direction of **E**.

Given this convention of a positive test charge, several generalities can be made about the direction of the electric field vector. A positive source charge would create an electric field that would exert a repulsive affect upon a positive test charge. Thus, the electric field vector would always be directed away from positively charged objects. On the other hand, a positive test charge would be attracted to a negative source charge. Therefore, electric field vectors are always directed towards negatively charged objects.

Electrostatic equilibrium is the condition established by charged conductors in which the excess charge has optimally distanced itself so as to reduce the total amount of repulsive forces. Once a charged conductor has reached the state of electrostatic equilibrium, there is no further motion of charge about the surface.

Electric Fields Inside of Charged Conductors

Charged conductors which have reached electrostatic equilibrium share a variety of unusual characteristics. One characteristic of a conductor at electrostatic equilibrium is that the electric field anywhere beneath the surface of a charged conductor is zero.

If an electric field did exist beneath the surface of a conductor (and inside of it), then the electric field would exert a force on all electrons that were present there. This net force would begin to accelerate and move these electrons. But objects at electrostatic equilibrium have no further motion of charge about the surface. So if this were to occur, then the original claim that the object was at electrostatic equilibrium would be a false claim. If the electrons within a conductor have assumed an equilibrium state, then the net force upon those electrons is zero. The electric field lines either begin or end upon a charge and in the case of a conductor, the charge exists solely upon its outer surface. The lines extend from this surface outward, not inward. This of course presumes that our conductor does not surround a region of space where there was another charge.

This concept of the electric field being zero inside of a closed conducting surface was first demonstrated by Michael Faraday, a 19th century physicist who promoted the field theory of electricity. Faraday constructed a room within a room, covering the inner room with a metal foil. He sat inside the inner room with an electroscope and charged the surfaces of the outer and inner room using an electrostatic generator. While sparks were seen flying between the walls of the two rooms, there was no detection of an electric field within the inner room. The excess charge on the walls of the inner room resided entirely upon the outer surface of the room.

The inner room with the conducting frame which protected Faraday from the static charge is now referred to as a **Faraday's cage**. The cage serves to shield whomever and whatever is on the inside from the influence of electric fields. Any closed, conducting surface can serve as a Faraday's cage, shielding whatever it surrounds from the potentially damaging affects of electric fields.

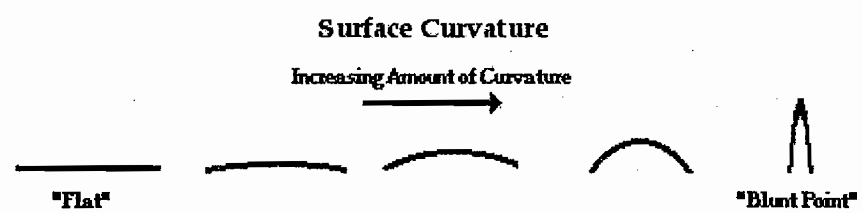
This principle of **shielding** is commonly utilized today as we protect delicate electrical equipment by enclosing them in metal cases. Even delicate computer chips and other components are shipped inside of conducting plastic packaging which shields the chips from potentially damaging affects of electric fields

Electric Fields are Perpendicular to Charged Surfaces

A second characteristic of conductors at electrostatic equilibrium is that the electric field upon the surface of the conductor is directed entirely perpendicular to the surface. There cannot be a component of electric field (or electric force) that is parallel to the surface. If the conducting object is spherical, then this means that the perpendicular electric field vector are aligned with the center of the sphere. If the object is irregularly shaped, then the electric field vector at any location is perpendicular to a tangent line drawn to the surface at that location.

Electric Fields and Surface Curvature

A third characteristic of conducting objects at electrostatic equilibrium is that the electric fields are strongest at locations along the surface where the object is most curved. The curvature of a surface can range from absolute flatness on one extreme to being curved to a *blunt* point on the other extreme.



A flat location has no curvature and is characterized by relatively weak electric fields. On the other hand, a *blunt point* has a high degree of curvature and is characterized by relatively strong electric fields. A sphere is uniformly shaped with the same curvature at every location along its surface. As such, the electric field strength on the surface of a sphere is everywhere the same.

The fact that surfaces which are sharply curved to a blunt edge create strong electric fields is the underlying principle for the use of **lightning rods**.

Lightning

Perhaps the most known and powerful displays of electrostatics in nature is a lightning storm. Lightning storms are inescapable from humankind's attention. They are never invited, never planned and never gone unnoticed. The rage of a lightning strike will wake a person in the middle of the night. They send children rushing into parent's bedrooms, crying for assurance that everything will be safe. The fury of a lightning strike is capable of interrupting midday conversations and activities. They're the frequent cause of canceled ball games and golf outings. Children and adults alike crowd around windows to watch the lightning displays in the sky, standing in awe of the power of static discharges. Indeed, a lightning storm is the most powerful display of electrostatics in nature.

Static Charge Buildup in the Clouds

The precursor of any lightning strike is the polarization of positive and negative charges within a storm cloud. The tops of the storm clouds are known to acquire an excess of positive charge and the bottom of the storm clouds acquire an excess of negative charge. Two mechanisms seem important to the polarization process. One mechanism involves a separation of charge by a process which bears resemblance to frictional charging. Clouds are known to contain countless millions of suspended water droplets and ice particles moving and whirling about in turbulent fashion. Additional water from the ground evaporates, rises upward and forms clusters of droplets as it approaches a cloud. This upwardly rising moisture collides with water droplets within the clouds. In the collisions, electrons are ripped off the rising droplets, causing a separation of negative electrons from a positively charged water droplet or a cluster of droplets.

The second mechanism which contributes to the polarization of a storm cloud involves a freezing process. Rising moisture encounters cooler temperatures at higher altitudes. These cooler temperatures cause the cluster of water droplets to undergo freezing. The frozen particles tend to cluster more tightly together and form the central regions of the cluster of droplets. The frozen portion of the cluster of rising moisture becomes negatively charged and the outer droplets acquire a positive charge. Air currents within the clouds can rip the outer portions off the clusters and carry them upward toward the top of the clouds. The frozen portion of the droplets with their negative charge tend to gravitate towards the bottom of the storm clouds. Thus, the clouds become further polarized.

These two mechanisms are believed to be the primary causes of the polarization of storm clouds. In the end, a storm cloud becomes polarized with positive charges carried to the upper portions of the clouds and negative portions gravitating towards the bottom of the clouds. The polarization of the clouds has an equally important affect on the surface of the Earth. The cloud's electric field stretches through the space surrounding it and induces movement of electrons upon Earth. Electrons on Earth's outer surface are repelled by the negatively charged cloud's bottom surface. This creates an opposite charge on the Earth's surface. Buildings, trees and even people can experience a buildup of static charge as electrons are repelled by the cloud's bottom. With the cloud polarized into opposites and with a positive charge induced upon Earth's surface, the stage is set for Act 2 in the drama of a lightning strike.

The Mechanics of a Lightning Strike

As the static charge buildup in a storm cloud increases, the electric field surrounding the cloud becomes stronger. Normally, the air surrounding a cloud would be a good enough insulator to prevent a discharge of electrons to Earth. Yet, the strong electric fields surrounding a cloud are capable of ionizing the surrounding air and making it more conductive. The ionization involves the shredding of electrons from the outer shells of gas molecules. The gas molecules which compose air are thus turned into a soup of positive ions and free electrons. The insulating air is transformed into a conductive **plasma**. The ability of a storm cloud's electric fields to transform air into a conductor makes charge transfer (in the form of a lightning bolt) from the cloud to the ground (or even to other clouds) possible.

A lightning bolt begins with the development of a **step leader**. Excess electrons on the bottom of the cloud begin a journey through the conducting air to the ground at speeds up to 60 miles per second. These electrons follow zigzag paths towards the ground, branching at various locations. The variables which affect the details of the actual pathway are not well known. It is believed that the presence of impurities or dust particles in various parts of the air might create regions between clouds and earth which are more conductive than other regions. As the step leader grows, it might be illuminated by the purplish glow which is characteristic of ionized air molecules. Nonetheless, the step leader is not the actual lightning strike, it merely provides the roadway between cloud and Earth along which the lightning bolt will eventually travel.

As the electrons of the step leader approach the Earth, there is an additional repulsion of electrons downward from Earth's surface. The quantity of positive charge residing on the Earth's surface becomes even greater. This charge begins to migrate upward through buildings, trees and people into the air. This upward rising positive charge - known as a **streamer** - approaches the step leader in the air above the surface of the Earth. The streamer might meet the leader at an altitude equivalent to the length of a football field. Once contact is made between the streamer and the leader, a complete conducting pathway is mapped out and the lightning begins. The contact point between ground charge and cloud charge rapidly ascends upward at speeds as high as 50 000 miles per second. As many as a billion trillion electrons can transverse this path in less than a millisecond. This initial strike is followed by several secondary strikes or charge surges in rapid succession. These secondary surges are spaced apart so closely in time that may appear as a single strike. The enormous and rapid flow of charge along this pathway between the cloud and Earth heats the surrounding air, causing it to expand violently. The expansion of the air creates a shockwave which we observe as thunder.

Lightning Rods and Other Protective Measures

Tall buildings, farm houses and other structures susceptible to lightning strikes are often equipped with **lightning rods**. The attachment of a grounded lightning rod to a building is a protective measure which is taken to protect the building in the event of a lightning strike. The concept of a lightning rod was originally developed by Ben Franklin. Franklin proposed that lightning rods should consist of a pointed metal pole which extends upward above the building which it is intended to protect. Franklin suggested that a lightning rod protects a building by one of two methods. First, the rod serves to prevent a charged cloud from releasing a bolt of lightning. And second, the lightning rod serves to safely divert the lightning to the ground in event that the cloud does discharge its lightning via a bolt. Franklin's theories on the operation of lightning rods have endured for a couple of centuries. And not until the most recent decades have scientific studies provided evidence to confirm the manner in which they operate to protect buildings from lightning damage.

8.Current Electricity

Electric Potential Difference

Electric Potential

Moving a positive test charge against the direction of an electric field is like moving a mass upward within Earth's gravitational field. Both movements would be like *going against nature* and would require work by an external force. This work would in turn increase the potential energy of the object. On the other hand, the movement of a positive test charge in the direction of an electric field would be like a mass falling downward within Earth's gravitational field. Both movements would be like *going with nature* and would occur without the need of work by an external force. This motion would result in the loss of potential energy. Potential energy is the stored energy of position of an object and it is related to the location of the object within a field. we will introduce the concept of **electric potential** and relate this concept to the potential energy of a positive test charge at various locations within an electric field.

Electric potential energy is dependent upon at least two types of quantities:

1) Electric charge - a property of the object experiencing the electrical field, and

2) Distance from source - the location within the electric field

While electric potential energy has a dependency upon the charge of the object experiencing the electric field, electric potential is purely location dependent. Electric potential is the potential energy per charge.

$$\text{Electric Potential} = \frac{PE}{Q}$$

The concept of electric potential is used to express the affect of an electric field of a source in terms of the location within the electric field. A test charge with twice the quantity of charge would possess twice the potential energy at a given location; yet its electric potential at that location would be the same as any other test charge. A positive test charge would be at a high electric potential when held close to a positive source charge and at a lower electric potential when held further away. In this sense, electric potential becomes simply a property of the location within an electric field

Electric Potential Difference

Consider the task of moving a positive test charge within a uniform electric field from location A to location B as shown in the diagram at the right. In moving the charge against the electric field from location A to location B, work will have to be done on the charge by an external force. The work done on the charge changes its potential energy to a higher value; and the amount of work which is done is equal to the change in the potential energy. As a result of this change in potential energy, there is also a difference in electric potential between locations A and B. This difference in electric potential is represented by the symbol ΔV and is formally referred to as the **electric potential difference**.

By definition, the electric potential difference is the difference in electric potential (V) between the final and the initial location when work is done upon a charge to change its potential energy. In equation form, the electric potential difference is

$$\Delta V = V_B - V_A = \frac{\text{Work}}{\text{Charge}} = \frac{\Delta \text{PE}}{\text{Charge}}$$

The standard metric unit on electric potential difference is the volt, abbreviated **V** and named in honor of Alessandra Volta. One Volt is equivalent to one Joule per Coulomb.. Because electric potential difference is expressed in units of volts, it is sometimes referred to as the **voltage**.

Electric Current

As a physical quantity, **current** is the rate at which charge flows past a point on a circuit. As depicted in the diagram below, the current in a circuit can be determined if the quantity of charge **Q** passing through a cross section of a wire in a time **t** can be measured. The current is simply the ratio of the quantity of charge and time.

Current is a rate quantity. In every case of a rate quantity, the mathematical equation involves some quantity over time. Thus, current as a rate quantity would be expressed mathematically as

$$\text{Current} = I = \frac{Q}{t}$$

Note that the equation above uses the symbol **I** to represent the quantity current.

The standard metric unit for current is the **ampere**. Ampere is often shortened to *Amp* and is abbreviated by the unit symbol **A**. A current of 1 ampere means that there is 1 coulomb of charge passing through a cross section of a wire every 1 second.

1 ampere = 1 coulomb / 1 second

Conventional Current Direction

The particles which carry charge through wires in a circuit are mobile electrons. The electric field direction within a circuit is by definition the direction which positive test charges are pushed. Thus, these negatively charged electrons move in the direction opposite the electric field. But while electrons are the charge carriers in metal wires, the charge carriers in other circuits can be positive charges, negative charges or both. **In fact, the charge carriers in semiconductors, street lamps and fluorescent lamps are simultaneously both positive and negative charges traveling in opposite directions.**

The **direction of an electric current** is by convention the direction in which a positive charge would move. Thus, the current in the external circuit is directed away from the positive terminal and toward the negative terminal of the battery. Electrons would actually move through the wires in the opposite direction. Knowing that the actual charge carriers in wires are negatively charged electrons may make this convention seem a bit odd and outdated. Nonetheless, it is the convention which is used world wide and one that a student of physics can easily become accustomed to.

The Nature of Charge Flow

Why does the light in a room or in a flashlight light immediately after the switched is turned on? Wouldn't there be a noticeable time delay before a charge carrier moves from the switch to the light bulb filament? The answer is NO! and the explanation of why reveals a significant amount about the nature of charge flow in a circuit.

charge carriers in the wires of electric circuits are electrons. These electrons are simply supplied by the atoms of copper (or whatever material the wire is made of) within the metal wire. Once the switch is turned to *on*, the circuit is closed and there is an electric potential difference is established across the two ends of the external circuit. The electric field signal travels at nearly the speed of light to all mobile electrons within the circuit, ordering them to begin *marching*. As the signal is received, the electrons begin moving along a zigzag path in their usual direction. Thus, the flipping of the switch causes an immediate response throughout every part of the circuit, setting charge carriers everywhere in motion in the same net direction. While the actual motion of charge carriers occurs with a slow speed, the signal which *informs* them to start moving travels at a fraction of the speed of light.

The electrons which light the bulb in a flashlight do not have to first travel from the switch through 10 cm of wire to the filament. Rather, the electrons which light the bulb immediately after the switch is turned to *on* are the electrons which are present in the filament itself. As the switch is flipped, all mobile electrons everywhere begin marching; and it is the mobile electrons present in the filament whose motion are immediately responsible for the lighting of its bulb. As those electrons leave the filament, new electrons enter and become the ones which are responsible for lighting the bulb. The electrons are moving together much like the water in the pipes of a home move. When a faucet is turned *on*, it is the water in the faucet which emerges from the spigot. One does not have to wait a noticeable time for water from the entry point to your home to travel through the pipes to the spigot. The pipes are already filled with water and water everywhere within the water circuit is set in motion at the same time.

Power

Electric circuits are designed to serve a useful function. The mere movement of charge from terminal to terminal is of little use if the electrical energy possessed by the charge is not transformed into another useful form. To equip a circuit with a battery and a wire leading from positive to negative terminal without an electrical device (light bulb, beeper, motor, etc.) would lead to a high rate of charge flow. **Such a circuit is referred to as a *short circuit.*** With charge flowing rapidly between terminals, the rate at which energy would be consumed would be high. Such a circuit would heat the wires to a high temperature and drain the battery of its energy rather quickly. When a circuit is equipped with a light bulb, beeper, or motor, the electrical energy supplied to the charge by the battery is transformed into other forms in the electrical device.

A light bulb, beeper and motor are generally referred to as a **load**. In a light bulb, electrical energy is transformed into useful light energy (and some non-useful thermal energy). In a beeper, electrical energy is transformed into sound energy. And in a motor, electrical energy is transformed into mechanical energy.

Power is the rate at which electrical energy is supplied to a circuit or consumed by a load. The electrical energy is supplied to the load by an energy source such as an electrochemical cell

Like current, power is a rate quantity. Its mathematical formula is expressed on a *per time* basis.

$$\text{Power} = \frac{\text{Work Done on Charge}}{\text{Time}} = \frac{\text{Energy Consumed by Load}}{\text{Time}}$$

Whether the focus is the energy gained by the charge at the energy source or the energy lost by the charge at the load, electrical power refers to the rate at which the charge changes its energy. In an electrochemical cell (or other energy source), the change is a positive change (i.e., a gain in energy) and at the load, the change is a negative change (i.e., a loss in energy). Thus, power is often referred to as the rate of energy change and its equation is expressed as the energy change per time. Like mechanical power, the unit of electrical power is the **watt**, abbreviated **W**. (Quite obviously, it is important that the symbol **W** as the unit of power not be confused with the symbol **W** for the quantity of work done upon a charge by the energy source.) A watt of power is equivalent to the delivery of 1 joule of energy every second. In other words:

1 watt = 1 joule / second

The kilowatt-hour

A kilowatt is a unit of power and an hour is a unit of time. So a kilowatt • hour is a unit of Power • time. If Power = ΔEnergy / time, then Power • time = ΔEnergy. So a unit of power • time is a unit of energy. The kilowatt • hour is a unit of energy. When an electrical utility company charges a household for the electricity which they used, they are charging them for electrical energy.

It is a common misconception that the utility company provides electricity in the form of charge carriers or electrons. The fact is that the mobile electrons which are in the wires of our homes would be there whether there was a utility company or not. The electrons come with the atoms that make up the wires of our household circuits. The utility company simply provides the energy which causes the motion of the charge carriers within the household circuits. And when they charge us for a few hundred kilowatt-hours of electricity, they are providing us with an energy bill.

Calculating Power

The relationship between power, current and electric potential difference can be derived by combining the mathematical definitions of power, electric potential difference and current. Power is the rate at which energy is added to or removed from a circuit by a battery or a load. Current is the rate at which charge moves past a point on a circuit. And the electric potential difference across the two ends of a circuit is the potential energy difference per charge between those two points. In equation form:

$$P = \frac{\Delta V \cdot Q}{t}$$

In the equation above, there is a **Q** in the numerator and a **t** in the denominator. This is simply the current; and as such, the equation can be rewritten as

$$P = \Delta V \cdot I$$

The electrical power is simply the product of the electric potential difference and the current.

Electrical Resistance

Journey of a Typical Electron

An electron's journey through a circuit can be described as a zigzag path which results from countless collisions with the atoms of the conducting wire. Each collision results in the alteration of the path, thus leading to a zigzag type motion. While the electric potential difference across the two ends of a circuit *encourages* the flow of charge, it is the collisions of charge carriers with atoms of the wire that *discourages* the flow of charge. Different types of atoms offer a different degree of hindrance to the flow of the charge carriers which pass through it.

The journey of an electron through an external circuit involves a long and slow zigzag path which is characterized by several successive losses in electric potential. Each loss of potential is referred to as a **voltage drop**. Accompanying this voltage drop is a *voltage boost* occurring within the internal circuit - for instance, within the electrochemical cell.

Resistance

An electron traveling through the wires and loads of the external circuit encounters resistance. **Resistance** is the hindrance to the flow of charge

Variables Affecting Electrical Resistance

The total amount of resistance to charge flow within a wire of an electric circuit is affected by some clearly identifiable variables.

1.the total length of the wires will affect the amount of resistance.

The longer the wire, the more resistance that there will be. There is a direct relationship between the amount of resistance encountered by charge and the length of wire it must traverse. After all, if resistance occurs as the result of collisions between charge carriers and the atoms of the wire, then there is likely to be more collisions in a longer wire. More collisions means more resistance.

2.The cross-sectional area of the wires will affect the amount of resistance.

Wider wires have a greater cross-sectional area. Water will flow through a wider pipe at a higher rate than it will flow through a narrow pipe. This can be attributed to the lower amount of resistance which is present in the wider pipe. In the same manner, the wider the wire, the less resistance that there will be to the flow of electric charge. When all other variables are the same, charge will flow at higher rates through wider wires with greater cross-sectional areas than through thinner wires.

3. the material that a wire is made of.

Not all materials are created equal in terms of their conductive ability. Some materials are better conductors than others and offer less resistance to the flow of charge. Silver is one of the best conductors but is never used in wires of household circuits due to its cost. Copper and aluminum are among the least expensive materials with suitable conducting ability to permit their use in wires of household circuits. The conducting ability of a material is often indicated by its **resistivity**. The resistivity of a material is dependent upon the material's electronic structure and its temperature. For most (but not all) materials, resistivity increases with increasing temperature. The table below lists resistivity values for various materials at temperatures of 20 degrees Celsius.

Material	Resistivity (ohm•meter)
Silver	1.59×10^{-8}
Copper	1.7×10^{-8}
Gold	2.4×10^{-8}
Aluminum	2.8×10^{-8}
Tungsten	5.6×10^{-8}
Iron	10×10^{-8}
Platinum	11×10^{-8}
Lead	22×10^{-8}
Nichrome	150×10^{-8}
Carbon	3.5×10^{5}
Polystyrene	$10^{7} - 10^{11}$
Polyethylene	$10^{8} - 10^{9}$
Glass	$10^{10} - 10^{14}$
Hard Rubber	10^{13}

As seen in the table, there is a broad range of resistivity values for various materials. Those materials with lower resistivities offer less resistance to the flow of charge; they are better conductors. The materials shown in the last five rows of the above table have such high resistivity that they would not even be considered to be conductors.

Mathematical Nature of Resistance

Resistance is a numerical quantity which can be measured and expressed mathematically. The standard metric unit for resistance is the ohm, represented by the Greek letter omega - Ω. An electrical device having a resistance of 5 ohms would be represented as **R = 5** Ω. The equation representing the dependency of the resistance **(R)** of a cylindrically shaped conductor (e.g., a wire) upon the variables which affect it is

$$R = \rho \frac{L}{A}$$

where **L** represents the length of the wire (in meters), **A** represents the cross-sectional area of the wire (in meters^2), and ρ represents the resistivity of the material (in ohm•meter).

Ohm's Law

The predominant equation which pervades the study of electric circuits is the equation

$$\Delta V = I \bullet R$$

In words, the electric potential difference between two points on a circuit (Δ**V**) is equivalent to the product of the current between those two points (**I**) and the total resistance of all electrical devices present between those two points (**R**). Often referred to as the **Ohm's law** equation, this equation is a powerful predictor of the relationship between potential difference, current and resistance.

Ohm's Law as a Predictor of Current

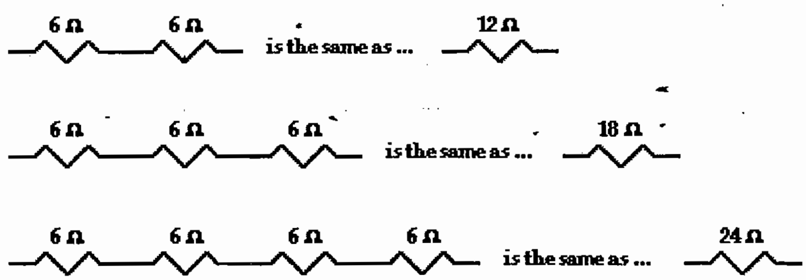
The Ohm's law equation can be rearranged and expressed as

$$I = \frac{\Delta V}{R}$$

The current in a circuit is directly proportional to the electric potential difference impressed across its ends and inversely proportional to the total resistance offered by the external circuit. The greater the battery voltage (i.e., electric potential difference), the greater the current. And the greater the resistance, the less the current. Charge flows at the greatest rates when the battery voltage is increased and the resistance is decreased. In fact, a twofold increase in the battery voltage would lead to a twofold increase in the current (if all other factors are kept equal). And an increase in the resistance of the load by a factor of two would cause the current to decrease by a factor of two to one-half its original value.

Because the current in a circuit is affected by the resistance, resistors are often used in the circuits of electrical appliances to affect the amount of current which is present in its various components. By increasing or decreasing the amount of resistance in a particular *branch* of the circuit, a manufacturer can increase or decrease the amount of current in that *branch*. Kitchen appliances such as electric mixers and light dimmer switches operate by altering the current at the load by increasing or decreasing the resistance of the circuit. Pushing the various buttons on an electric mixer can change the mode from mixing to beating by reducing the resistance and allowing more current to be present in the mixer. Similarly, turning a dial on a dimmer switch can increase the resistance of its built-in resistor and thus reduce the current.

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

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

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

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

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 ($\Delta V = I \bullet R$), 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

$$\mathbf{I_{total} = I_1 + I_2 + I_3 + \ldots}$$

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.

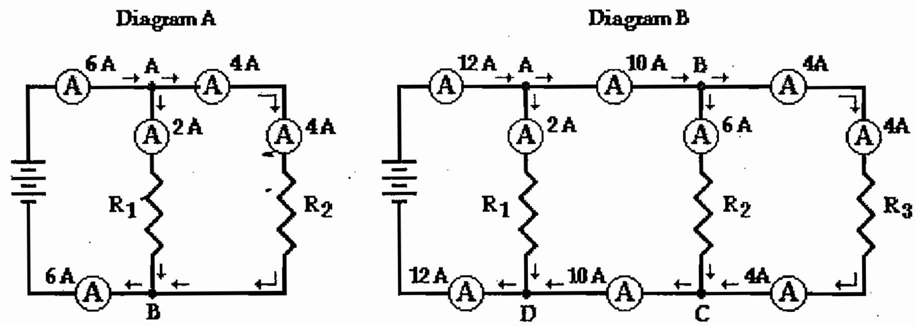


Diagram A displays two resistors in parallel with nodes at point A and point B. Charge flows into point A at a rate of 6 amps and divides into two pathways - one through resistor 1 and the other through resistor 2. The current in the branch with resistor 1 is 2 amps and the current in the branch with 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.

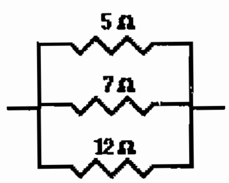
Equivalent Resistance

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

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



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

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

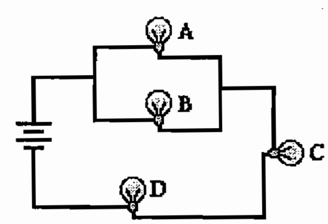
Using a calculator ...

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

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

$R_{eq} = 2.3\ \Omega$

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

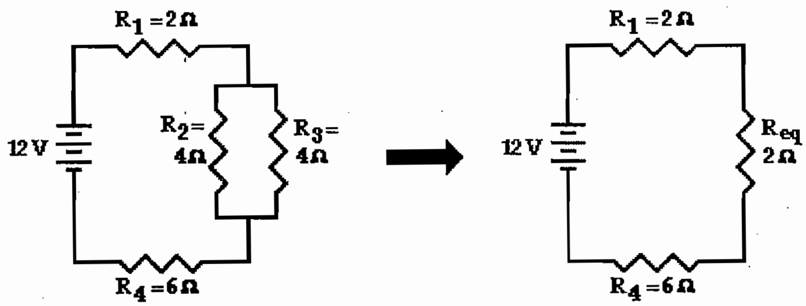
The basic strategy for the analysis of combination circuits involves using the meaning of equivalent resistance for parallel branches to transform the combination circuit into a series circuit. Once transformed into a series circuit, the analysis can be conducted in the usual manner

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

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

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

Diagram A   Diagram B

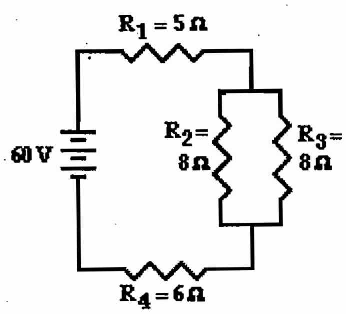


Once the total resistance of the circuit is determined, the analysis continues using Ohm's law and voltage and resistance values to determine current values at various locations.

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,

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

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.

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

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

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

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

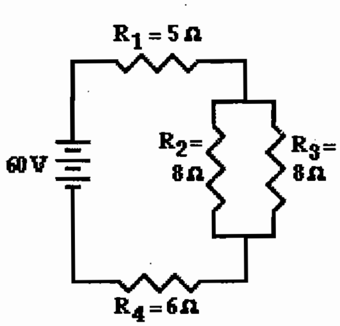
$\Delta V_3 = I_3 \cdot R_3 = (2\ Amp) \cdot (8\ \Omega)$

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

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

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

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.

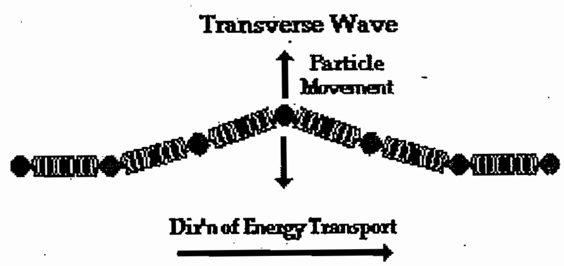
Categories of Waves

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.

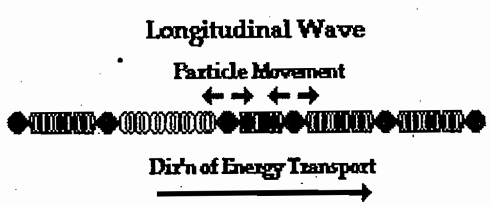
Longitudinal versus Transverse Waves versus Surface Waves

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.



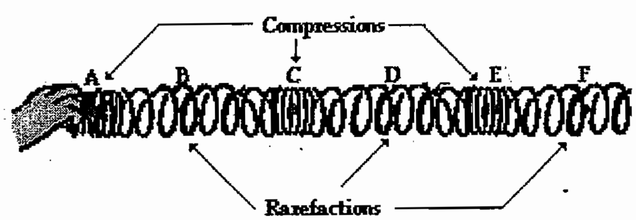
A sound wave traveling through air is a classic example of a longitudinal wave.

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.

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

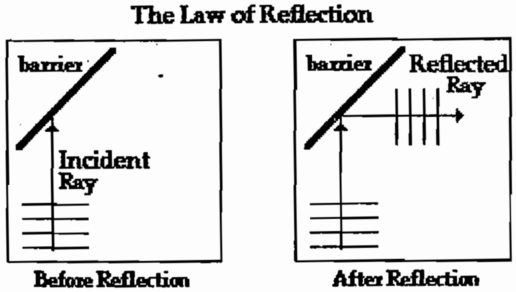
The above equation is known as the wave equation. It states the mathematical relationship between the speed (**v**) of a wave and its wavelength (λ) and frequency (**f**). Using the symbols **v**, λ, and **f**, the equation can be rewritten as

$v = f \cdot \lambda$

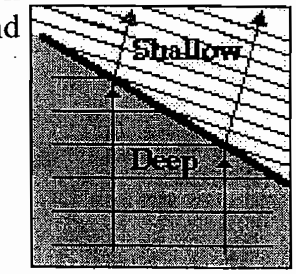
Reflection, Refraction, and Diffraction

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**.

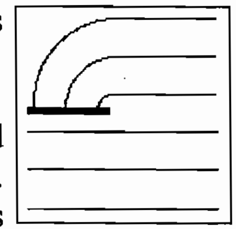
The Law of Reflection



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 Waves

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.

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:

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

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:

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

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

Sulphur dioxide 213

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

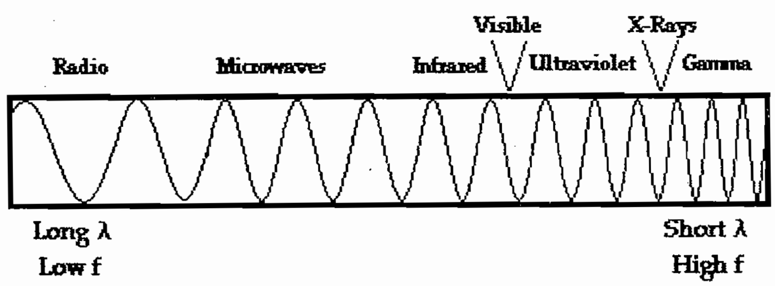
The acronym SONAR stands for Sound Navigation And Ranging. Sonar is a device that uses ultrasonic waves to measure the distance, direction and speed of underwater objects. How does the sonar work? Sonar consists of a transmitter and a detector and is installed in a boat or a ship .The transmitter produces 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

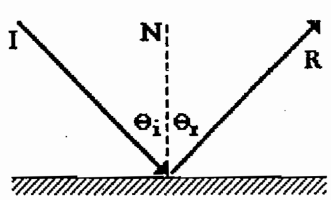
As the path which sunlight takes through our atmosphere increases in length, ROYGBIV encounters more and more atmospheric particles. This results in the scattering of greater and greater amounts of yellow light. During sunset hours, the light passing through our atmosphere to our eyes tends to be most 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

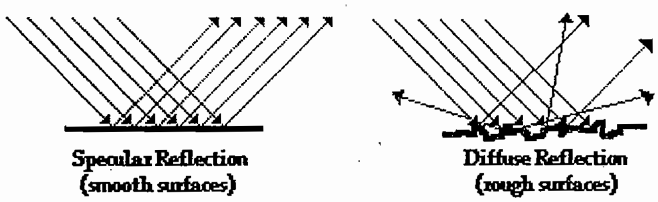
Light is known to behave in a very predictable manner. If a ray of light could be observed approaching and reflecting off of a flat mirror, then the behavior of the light as it reflects would follow a predictable *law* known as the **law of reflection**. The diagram below illustrates the law of reflection.



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

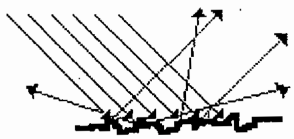
Reflection off of smooth surfaces such as mirrors or a calm body of water leads to a type of reflection known as **specular reflection**. Reflection off of rough surfaces such as clothing, paper, and the asphalt roadway leads to a type of reflection known as **diffuse reflection**. Whether the surface 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.



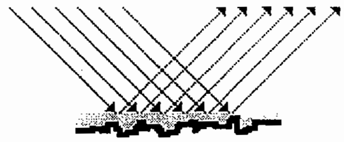
A light beam can be thought of as a bundle of individual light rays which are traveling parallel to each other. Each individual light ray of the bundle follows the law of reflection. If the bundle of light rays is incident upon a smooth surface, then the light rays reflect and remain concentrated in 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....*

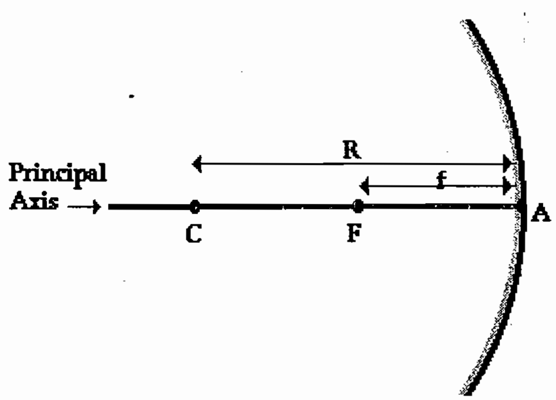
Curved Mirror

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

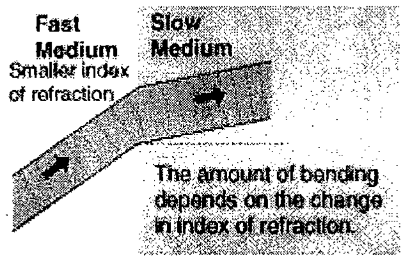
Refraction is the bending of a wave when it enters a medium where it's speed is different. The refraction of light when it passes from a fast medium to a slow medium bends the light ray toward the normal to the boundary between the two media. The amount of bending depends on the indices of refraction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

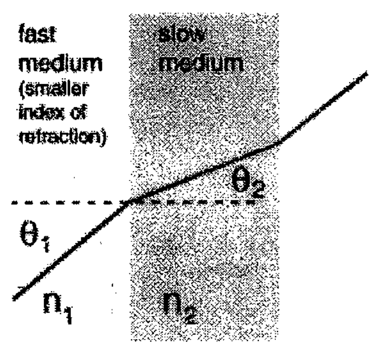
Vacuum	1.000	Ethyl alcohol	1.362
Air	1.000277	Glycerine	1.473
Water	4/3	Ice	1.31
Carbon disulfide	1.63	Polystyrene	1.59
Methylene iodide	1.74	Crown glass	1.50-1.62
Diamond	2.417	Flint glass	1.57-1.75

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.

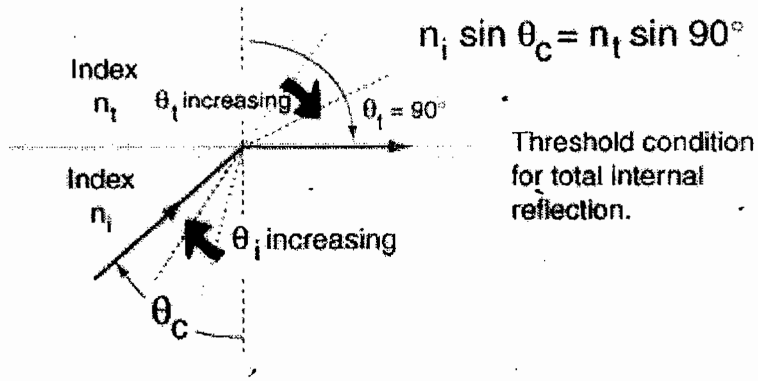
Snell's Law

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



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.

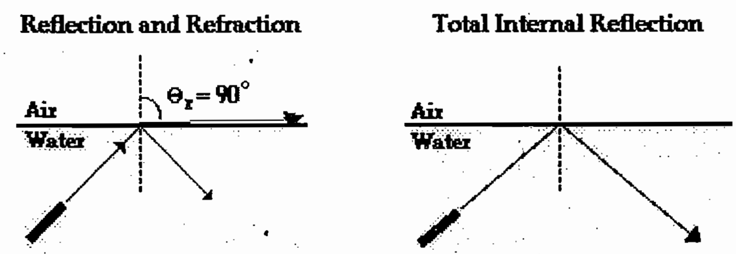


The Critical Angle

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.

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

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

$$\frac{PV}{T} = \frac{P_0V_0}{T_0}$$

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

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

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.