Unit 1: Nature and Process of Science

Chapter 1: About Science

Scientific method Principles and procedures for the systematic pursuit of knowledge involving the recognition and formulation of a problem, the collection of data through observation and experiment, and the formulation and testing of hypotheses.

Scientific attitude The scientific method inclined toward inquiry, integrity, and humility.

Hypothesis An educated guess; a reasonable explanation of an observation or experimental result that is not fully accepted as factual until tested over and over again by experiment.

- Must be falsifiable
- Must be testable

Fact A statement about the world that competent observers who have made a series of observations agree on.

- Observation
- Not open to interpretation or analysis

Law A general hypothesis or statement about the relationship of natural quantities that has been tested over and over again and has not been contradicted. Also known as a *principle*.

- Describes behavior of the natural world

Theory A synthesis of a large body of information that encompasses well-tested and verified hypotheses about certain aspects of the natural world.

- Explains observations

Hypotheses, Law, Theories: must be **testable** and **falsifiable**

New evidence = modifications of scientific ideas

Pseudoscience Fake science that pretends to be real science.

Technology is applied science. Can enhance science.

Limitations of Scientific Inquiry

- Scientific hypotheses need to be **falsifiable**
- Requires **experimentation/evidence**
- Requires **repeatability**
- Cannot address supernatural phenomena
- Cannot address existential or religious issues

Physics

- Concerned with fundamental relationships between forces & energy
- Astrophysics to quantum mechanics
- Focused on the most fundamental questions

Scientific Notation To represent numbers larger than one, write the the number as a decimal, then add the exponent as a power of ten. To write numbers smaller than one, write the number as a decimal to the tenths place, and the exponent as a negative value.

- 700 = 7 * 100 = 7 * 10^2
- 1000 = 1.0 * 10^3
- 0.000372 = 3.72 * 0.001 = 3.72 * 10^-4
- 0.0003 = 3.0 * 10^-4
- On a calculator: Multiply 31,000,000 by 42,500 using scientific notation.
    1. "3.1 EE 7" or "3.1 EXP 7"
    2. " * "
    3. "4.25 EE 4" or "4.25 EXP 4"
    4. " = "
    5. 1,317,500,000,000
        - If your calculator has an "F-E" button, press that to convert the result into scientific notation.
            - 1.3175e + 12 = 1.3175 * 10^12

Unit 2: Classical Physics

Chapter 2: Newton's First Law of Motion—Inertia

Inertia The property of things to resist changes in motion.

Newton's first law of motion (the law of inertia) Every object continues in a state of rest or of uniform speed in a straight line unless acted on by a nonzero net force.

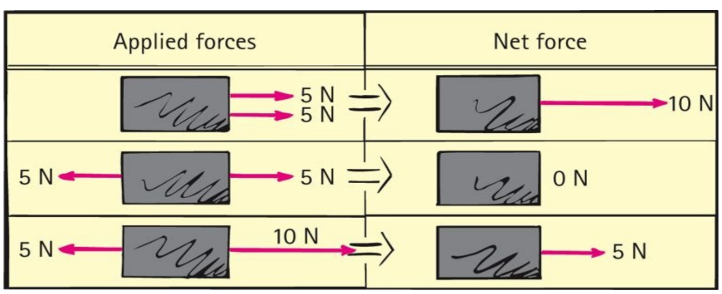
Force In the simplest sense, a push or a pull.

Net force The vector combination (sum) of all forces that act on an object.

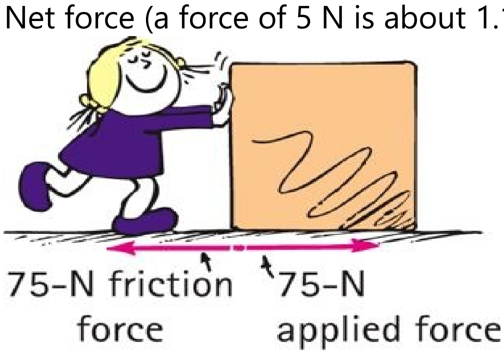
Vector Measurement plus direction.

Mechanical equilibrium The state of an object or system of objects for which there are no changes in motion. In accord with Newton's first law, if at rest, the state of rest persists. If moving, motion continues without change.

Equilibrium rule For any object or system of objects in equilibrium, the sum of the forces acting equals zero. In equation form, $\Sigma \mathbf{F} = 0$.



Net force (a force of 5 N is about 1.1 lb)



When the push on the crate is as great as the force of friction between the crate and the floor, the net force on the crate is zero and it slides at an unchanging speed.

Chapter 3: Linear Motion

Speed How fast something moves; the distance traveled per unit of time.

Instantaneous speed The speed at any instant.

Average speed The total distance traveled divided by the time of travel.

Velocity The **speed** of an object **and** a specification of its **direction** of motion.

Vector quantity Quantity in physics that has both magnitude and direction.

Scalar quantity Quantity that can be described by magnitude without direction.

Acceleration The rate at which velocity changes with time; the change in velocity may be in magnitude, or direction, or both. (i.e. speed up, slow down, or change direction)

Free fall Motion under the influence of gravity only.

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

$$\text{Average speed} = \frac{\text{total distance covered}}{\text{time interval}}$$

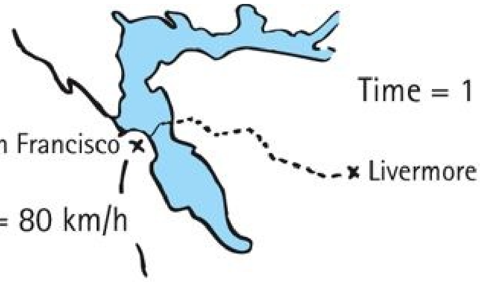
$$\text{Acceleration} = \frac{\text{change of velocity}}{\text{time interval}}$$

$$\text{Acceleration (along a straight line)} = \frac{\text{change in speed}}{\text{time interval}}$$

Velocity acquired in free fall, from rest = acceleration × time (v = gt)

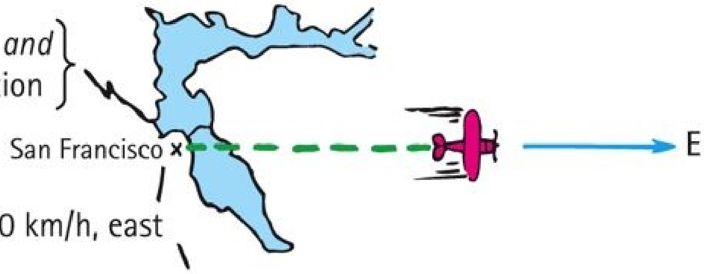
Distance fallen in free fall, from rest = $\frac{1}{2}$ **(acceleration × time^2)** $d = \frac{1}{2}gt^2$

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



$$\text{Speed} = \frac{80 \text{ km}}{1 \text{ h}} = 80 \text{ km/h}$$

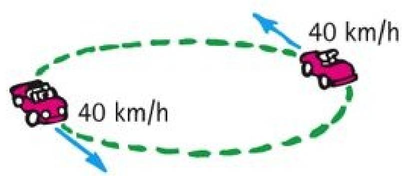
$$\text{Velocity} = \left\{ \begin{matrix} \text{speed } \textit{and} \\ \text{direction} \end{matrix} \right\}$$



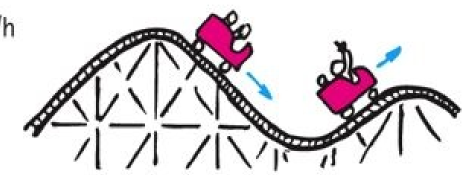
Velocity = 300 km/h, east

$$\text{Acceleration} = \left\{ \begin{matrix} \text{rate of} \\ \text{change in} \\ \text{velocity} \end{matrix} \right\} \textit{ due to } \left\{ \begin{matrix} \text{change in speed} \\ \text{and/or direction} \end{matrix} \right\}$$

Change in speed but *not* direction

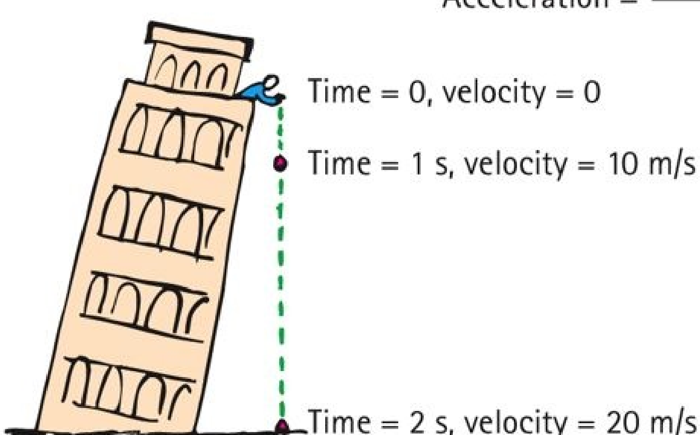


Change in direction but *not* speed



Change in speed *and* direction

$$\text{Acceleration} = \frac{\text{change in velocity}}{\text{time}}$$



$$\text{Acceleration} = \frac{20 \text{ m/s}}{2 \text{ s}}$$

$$a = 10 \frac{\text{m/s}}{\text{s}}$$

$$a = 10 \text{ m/s}\cdot\text{s}$$

$$a = 10 \text{ m/s}^2$$

Chapter 4: Newton’s Second Law of Motion

Force Any influence that can cause an object to be accelerated, measured in newtons (or in pounds, in the British system).

Friction The resistive force that opposes the motion or attempted motion of an object either past another object with which it is in contact or through a fluid.

Mass The quantity of matter in an object. More specifically, it is the measure of the inertia or sluggishness that an object exhibits in response to any effort made to start it, stop it, deflect it, or change in any way its state of motion.

Weight The force due to gravity on an object (*mg*).

Volume The quantity of space an object occupies.

Newton’s second law The acceleration of an object is directly proportional to the net force acting on the object, is in the direction of the net force, and is inversely proportional to the mass of the object.

Newton The SI unit of force. One newton (symbol N) is the force that will give an object of mass 1 kg an acceleration of 1 m/s^2.

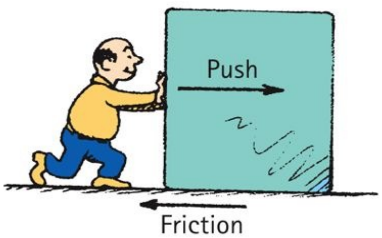
Kilogram The fundamental SI unit of mass. One kilogram (symbol kg) is the mass of 1 liter (1 L) of water at 4 C°.

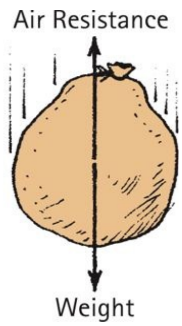
Free fall Motion under the influence of gravitational pull only.

Terminal speed The speed at which the acceleration of a falling object terminates because air resistance balances its weight. When direction is specified, then we speak of **terminal velocity**.

Acceleration ~ net force

The symbol ~ stands for "is directly proportional to." That means, for instance, that if one doubles, the other also doubles.

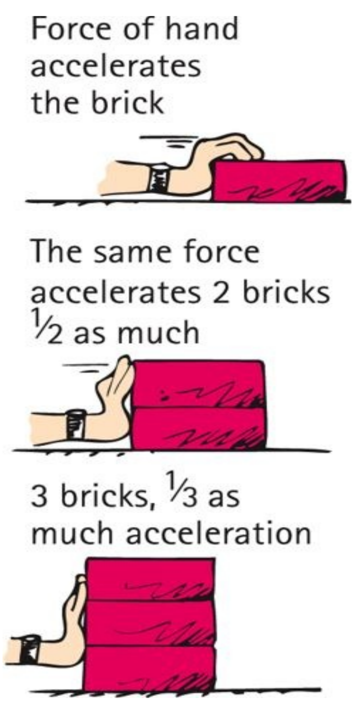




Weight = mg

Force = ma

$$\text{Acceleration} \sim \frac{\text{net force}}{\text{mass}} \qquad a = \frac{F_{\text{net}}}{m}$$



Chapter 5: Newton's Third Law of Motion

Newton's third law Whenever one object exerts a force on a second object, the second object exerts an equal and opposite force on the first.

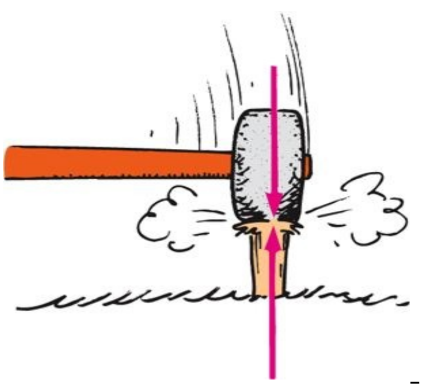
Vector quantity A quantity that has both magnitude and direction. Examples are force, velocity, and acceleration.

Scalar quantity A quantity that has magnitude but not direction. Examples are mass, volume, and speed.

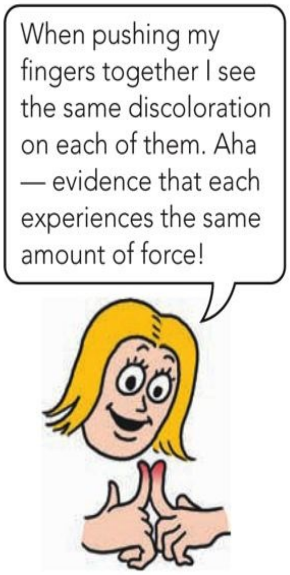
Vector An arrow drawn to scale used to represent a vector quantity.

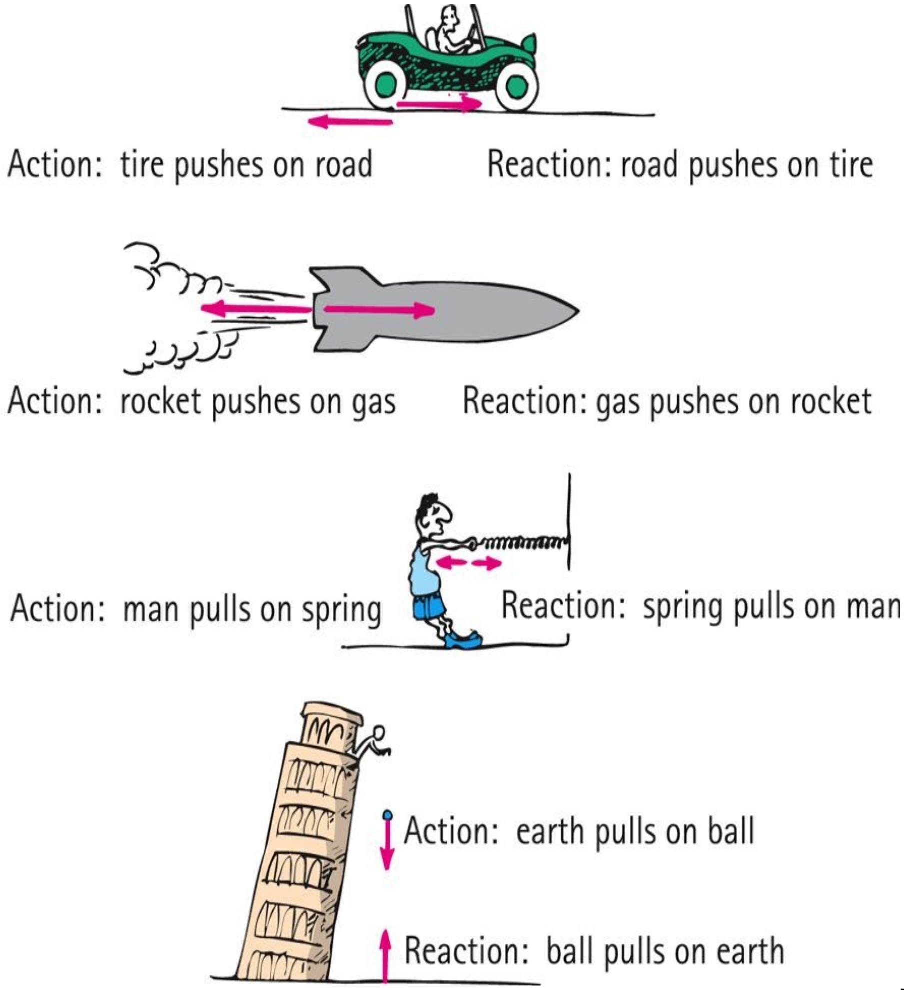
Resultant The net result of a combination of two or more vectors.

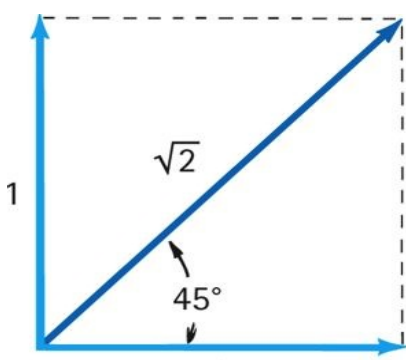
Components Mutually perpendicular vectors, usually horizontal and vertical, whose vector sum is a given vector.



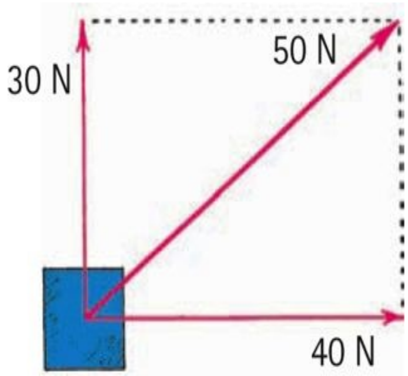
In the interaction between the hammer and the stake, each exerts the same amount of force on the other. We can call one force the *action force* and the other the *reaction force.*



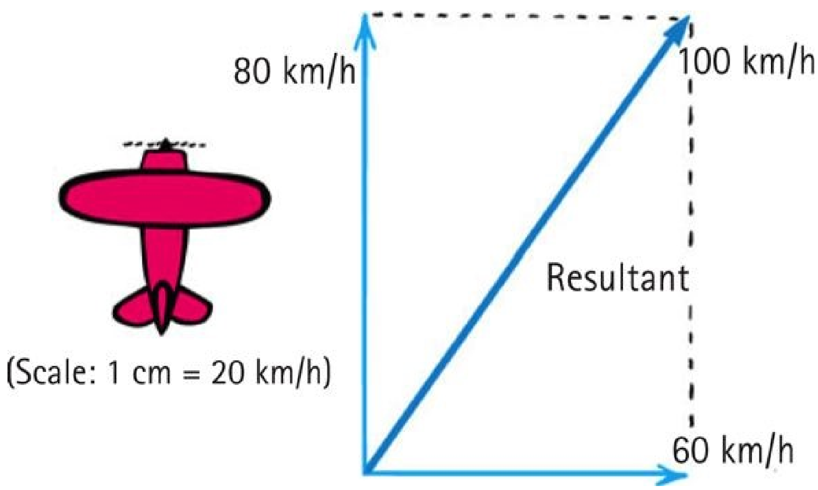




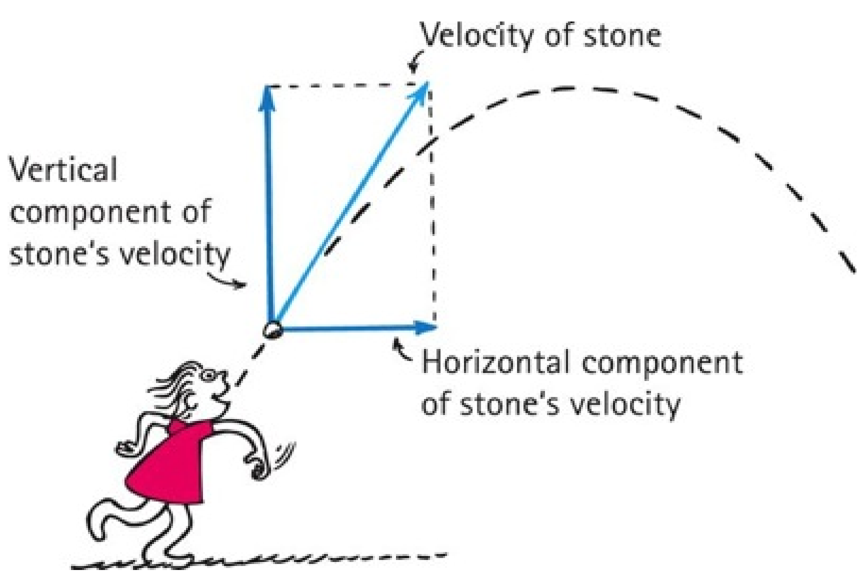
When a pair of equal-length vectors at right angles to each other are added, they form a square. The diagonal of the square is the resultant, $\sqrt{2}$ times the length of either side.



A pair of forces acting on a box. One is 30 newtons and the other is 40 newtons. Simple measurement shows the resultant of this pair of forces is 50 newtons.



The 60-km/h crosswind blows the 80-km/h aircraft off course at 100 km/h.



The horizontal and vertical components of a stone's velocity.

Chapter 6: Momentum

Momentum The product of the mass of an object and its velocity.

Impulse The product of the force acting on an object and the time during which it acts.

Relationship of impulse and momentum Impulse is equal to the change in the momentum of the object that the impulse acts upon. In symbol notation, $Ft = \Delta mv$

Law of conservation of momentum In the absence of an external force, the momentum of a system remains unchanged. Hence, the momentum before an event involving only internal forces is equal to the momentum after the event:

- $mv_{(\text{before event})} = mv_{(\text{after event})}$

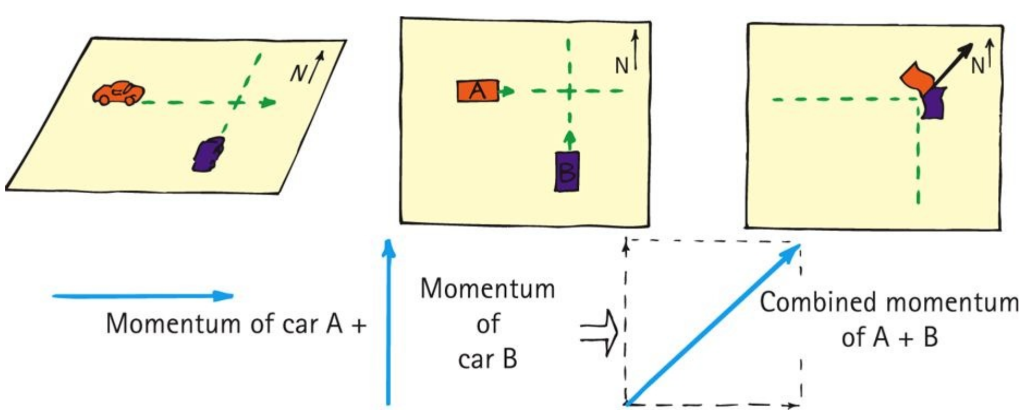
Elastic collision A collision in which colliding objects rebound without lasting deformation or the generation of heat.

Inelastic collision A collision in which the colliding objects become distorted, generate heat, and possibly stick together.

Momentum = mass × velocity (Momentum = mv)

Momentum = mass × speed (When direction is not an important factor)

Impulse = force x time interval (Impulse = Ft)



Chapter 7: Energy

Work The product of the force and the distance moved by the force.

Power The time rate of work.

Energy The property of a system that enables it to do work.

Mechanical energy Energy due to the position of something or the movement of something.

Potential energy The energy that something possesses because of its position.

Kinetic energy Energy of motion, quantified by the relationship.

Work-energy theorem The work done on an object equals the change in kinetic energy of the object. (Work can also transfer other forms of energy to a system.)

Conservation of energy Energy cannot be created or destroyed; it may be transformed from one form into another, but the total amount of energy never changes.

Machine A device, such as a lever or pulley, that increases (or decreases) a force or simply changes the direction of a force.

Conservation of energy for machines The work output of any machine cannot exceed the work input. In an ideal machine, where no energy is transformed into thermal energy, $\text{work}_{\text{input}} = \text{word}_{\text{output}}$; $(Fd)_{\text{input}} = (Fd)_{\text{output}}$.

Lever Simple machine consisting of a rigid rod pivoted at a fixed point called the fulcrum.

Efficiency The percentage of the work put into a machine that is converted into useful work output. (More generally, useful energy output divided by total energy input.)

Work = force × distance (W = fd)

- Measured in joules (J), which is the same as the Newton-meter (N * m)

$$\text{Power} = \frac{\text{work done}}{\text{time interval}} \quad P = \frac{W}{t}$$

- Measured in watts (W), which is the same as joules per second (J / s)

Gravitational potential energy = weight × height (PE = mgh)

$$\text{Kinetic energy} = \frac{1}{2}\text{mass} \times \text{speed}^2$$

$$KE = \frac{1}{2}mv^2$$

- Kinetic Energy is measured in joules (J)

$$\text{Efficiency} = \frac{\text{useful energy output}}{\text{total energy input}}$$

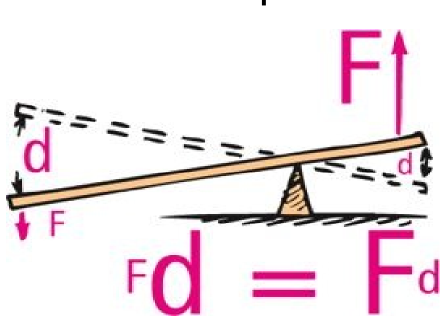
Work energy theorem: Work = ΔKE

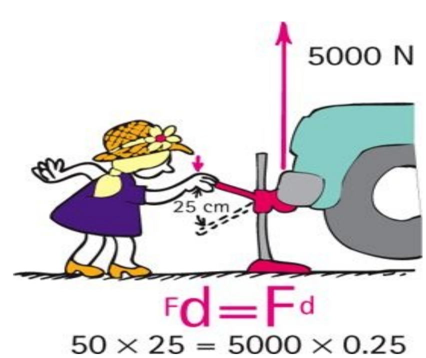
- Δ means "change" or "the change in"

Work input = work output

Applied force × applied distance = output force × output distance

$(\text{Force} \times \text{distance})_{\text{input}} = (\text{force} \times \text{distance})_{\text{output}}$





Chapter 8: Rotational Motion

Tangential speed The linear speed tangent to a curved path, such as in circular motion. (distance traveled / time)

Rotational speed The number of rotations or revolutions per unit of time; often measured in rotations or revolutions per second or per minute. (rotations / time)

Rotational inertia That property of an object that measures its resistance to any change in its state of rotation: if at rest, the body tends to remain at rest; if rotating, it tends to remain rotating and will continue to do so unless acted upon by an external net torque.

Torque The product of force and lever-arm distance, which tends to produce rotation.

- Torque = lever arm × force

Center of mass (CM) The average position of the mass of an object. The CM moves as if all the external forces acted at this point.

Center of gravity (CG) The average position of weight or the single point associated with an object where the force of gravity can be considered to act.

Equilibrium The state of an object in which it is not acted upon by a net force or a net torque.

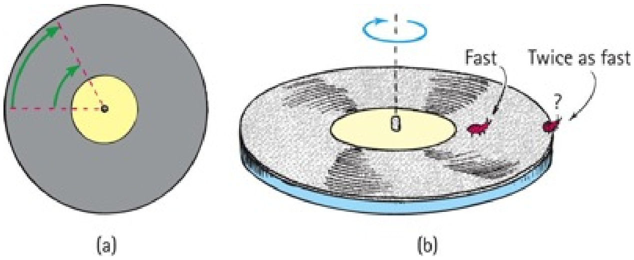
Centripetal force A force directed toward a fixed point, usually the cause of circular motion:

- $F = mv^2/r$

Centrifugal force An outward force apparent in a rotating frame of reference. It is apparent (fictitious) in the sense that it is not part of an interaction but is a result of rotation—with no reaction-force counterpart.

Angular momentum The product of a body's rotational inertia and rotational velocity about a particular axis. For an object that is small compared with the radial distance, it can be expressed as the product of mass, speed, and the radial distance of rotation.

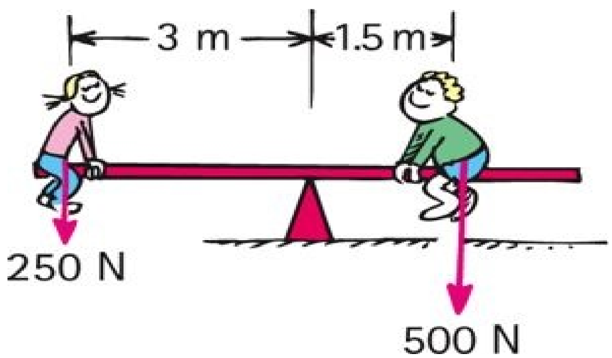
Conservation of angular momentum When no external torque acts on an object or a system of objects, no change of angular momentum can occur. Hence, the angular momentum before an event involving only internal torques or no torques is equal to the angular momentum after the event.



Tangential speed ~ radial distance × rotational speed

- **(v ~ rω)**
- ω (Greek letter omega) is rotational speed

Torque = lever arm × force



Centripetal force:

$$F = \frac{mv^2}{r}$$

Momentum = mass × velocity

Angular Momentum = rotational inertia × rotational velocity **(A = mvr)**

- **mass x velocity x radius**

Chapter 9: Gravity

Law of universal gravitation Every body in the universe attracts every other body with a force that, for two bodies, is directly proportional to the product of their masses and inversely proportional to the square of the distance separating them:

Inverse-square law A law relating the intensity of an effect to the inverse square of the distance from the cause. Gravity follows an inverse-square law, as do the effects of electric, magnetic, light, sound, and radiation phenomena.

Weight The force that an object exerts on a supporting surface (or, if suspended, on a supporting string), which is often, but not always, due to the force of gravity.

Weightless Being without a support force, as in free fall.

Spring tides High or low tides that occur when the Sun, Earth, and the Moon are all lined up so that the tides due to the Sun and the Moon coincide, making the high tides higher than average and the low tides lower than average.

Neap tides Tides that occur when the Moon is midway between new and full, in either direction. Tides due to the Sun and the Moon partly cancel, making the high tides lower than average and the low tides higher than average.

Gravitational field The influence that a massive body extends into the space around itself, producing a force on another massive body. It is measured in newtons per kilogram (N/kg).

Black hole A concentration of mass resulting from gravitational collapse, near which gravity is so intense that not even light can escape.

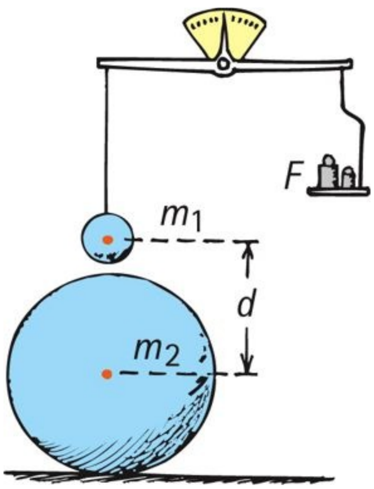
Law of Universal Gravitation:

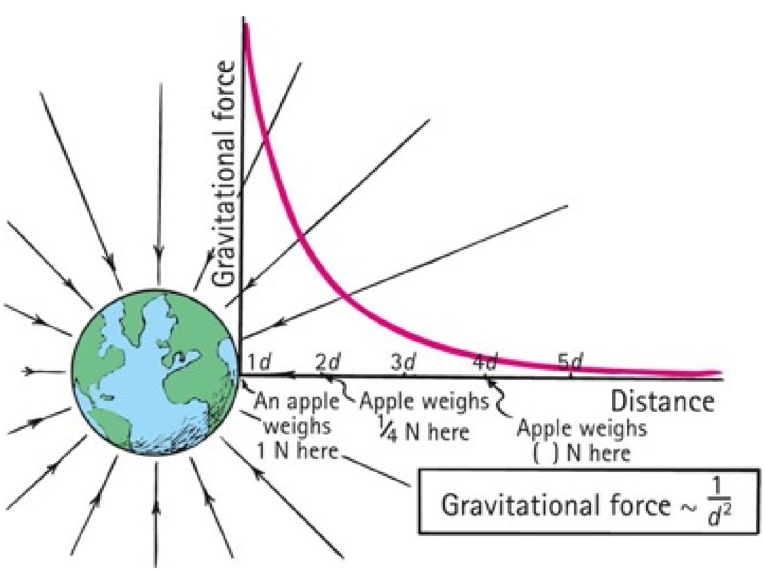
$$\text{Force} \sim \frac{\text{mass}_1 \times \text{mass}_2}{\text{distance}^2} \qquad F \sim \frac{m_1 m_2}{d^2}$$

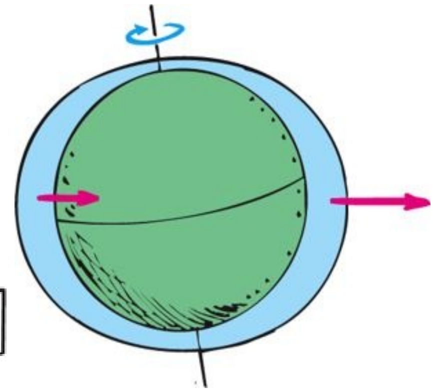
The Universal Gravitational Constant, *G:*

$$F = G\frac{m_1 m_2}{d^2}$$

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







Chapter 10: Projectile and Satellite Motion

Projectile Any object that moves through the air or through space under the influence of gravity.

Parabola The curved path followed by a projectile under the influence only of constant gravity.

Satellite A projectile or small celestial body that orbits a larger celestial body.

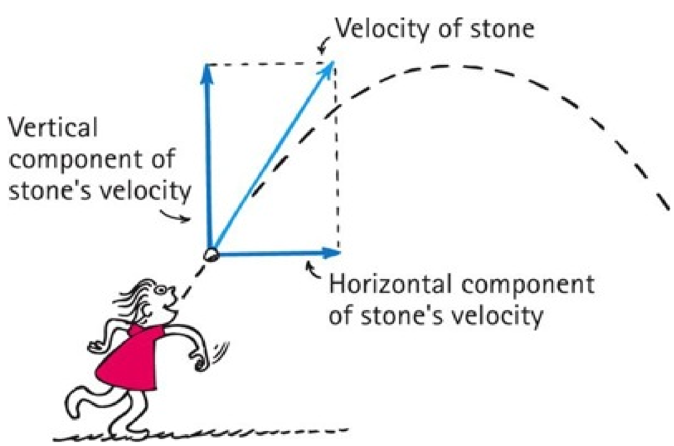
Ellipse The oval path followed by a satellite. The sum of the distances from any point on the path to two points called foci is a constant. When the foci are together at one point, the ellipse is a circle. As the foci get farther apart, the ellipse becomes more "eccentric."

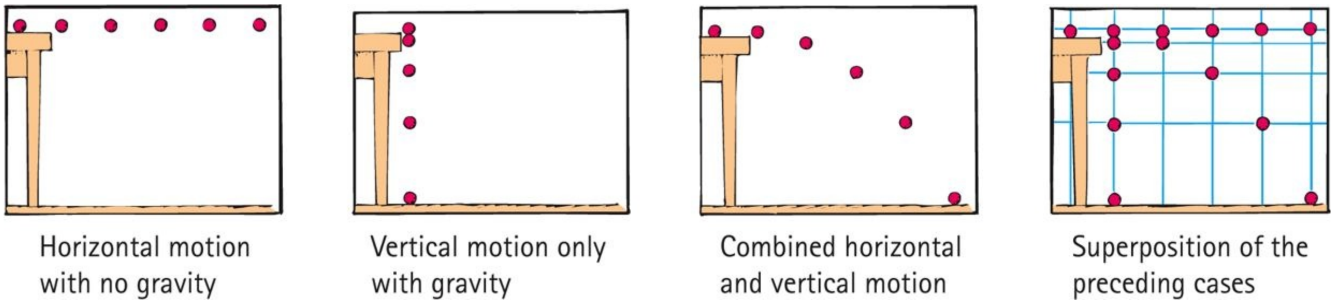
Kepler's laws

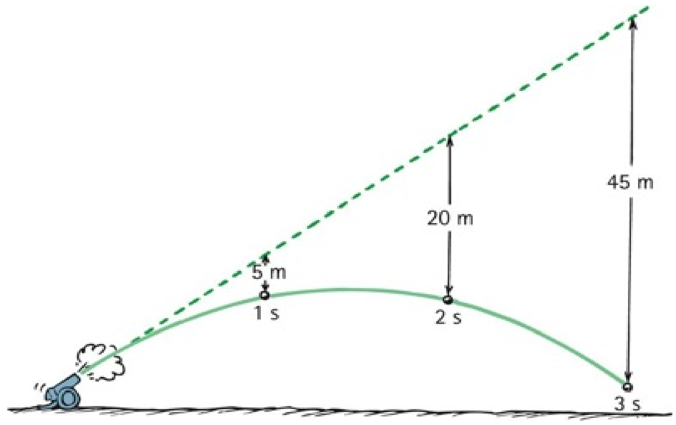
- Law 1: The path of each planet around the Sun is an ellipse with the Sun at one focus.
- Law 2: The line from the Sun to any planet sweeps out equal areas of space in equal time intervals.
- Law 3: The square of the orbital period of a planet is directly proportional to the cube of the average distance of the planet from the Sun ($T^2 \sim r^3$ for all planets).

Escape speed The speed that a projectile, space probe, or similar object must reach to escape the gravitational influence of Earth or of another celestial body to which it is attracted.

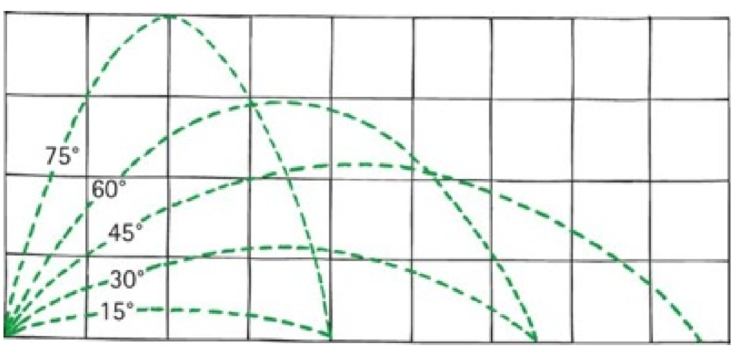
- escape speed from Earth = 11.2 km/s



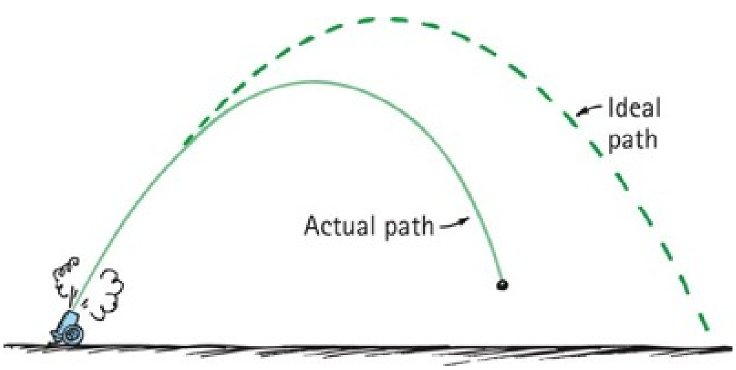




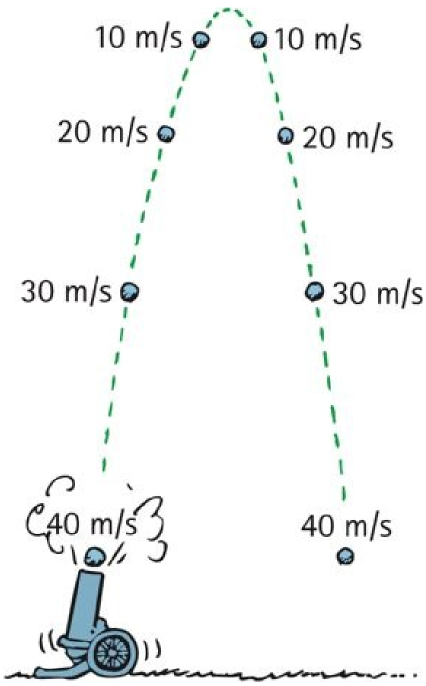
With no gravity, the projectile would follow a straight-line path (dashed line). But, because of gravity, the projectile falls beneath this line the same vertical distance it would fall if it were released from rest.



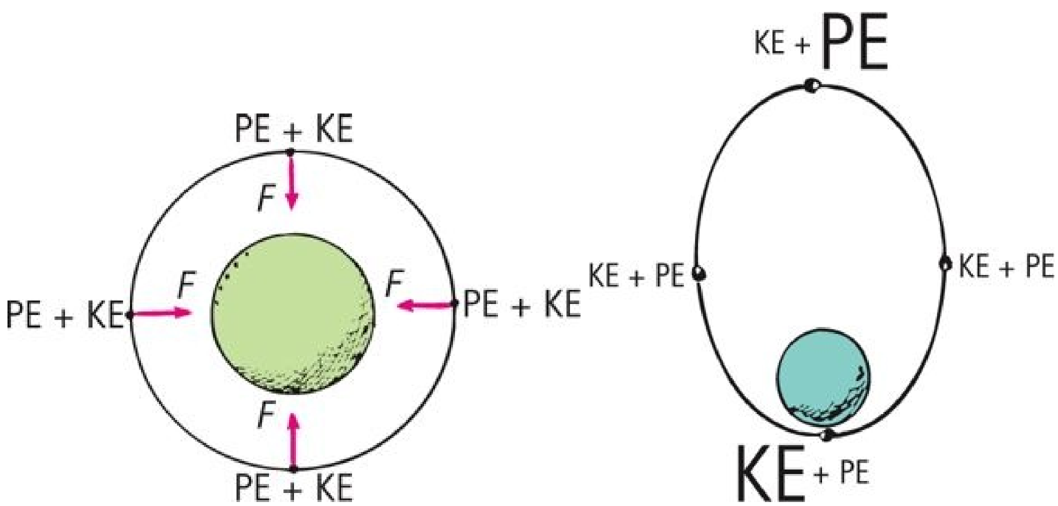
Ranges of a projectile shot at the same speed at different projection angles.



In the presence of air resistance, the trajectory of a high-speed projectile falls short of the idealized parabolic path.



Without air drag, speed lost while going up equals speed gained while coming down: Time going up equals time coming down.



The sum of KE and PE for a satellite is a constant at all points along its orbit.

- KE = kinetic energy
- PE = potential energy

Unit 3: Electricity and Magnetism
Chapter 22: Electrostatics

Electricity General term for electrical phenomena, much like gravity has to do with gravitational phenomena, or sociology with social phenomena.

Electrostatics The study of electric charge at rest (not *in motion,* as in electric currents).

Conservation of charge Electric charge is neither created nor destroyed. The total charge before an interaction equals the total charge after.

Coulomb's law The relationship between electrical force, charge, and distance. If the charges are alike in sign, the force is repulsive; if the charges are unlike, the force is attractive.

Coulomb The SI unit of electrical charge. One coulomb (symbol C) is equal to the total charge of 6.25×10^{18} electrons.

Conductor Any material having free charged particles that easily flow through it when an electric force acts on them.

Insulator A material without free charged particles and through which charge does not easily flow.

Semiconductor A material with properties that fall between a conductor and an insulator and whose resistance can be affected by adding impurities.

Superconductor A material that is a perfect conductor with zero resistance to the flow of electric charge.

Charging by contact Transfer of electric charge between objects by rubbing or simple touching.

Charging by induction Redistribution of electric charges in and on objects caused by the electrical influence of a charged object close by but not in contact.

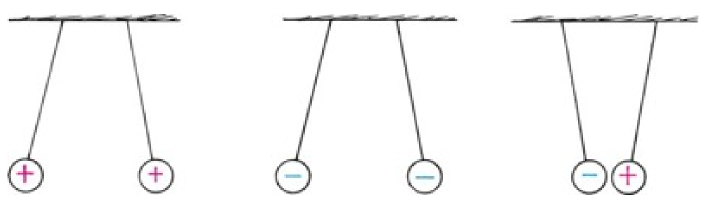
Electrically polarized Term applied to an atom or molecule in which the charges are aligned so that one side has a slight excess of positive charge and the other side a slight excess of negative charge.

Electric field Defined as electric force per unit charge, it can be considered to be an "aura" surrounding charged objects and is a storehouse of electric energy. About a charged 399400point, the field decreases with distance according to the inverse-square law, like a gravitational field. Between oppositely charged parallel plates, the electric field is uniform.

Electric potential energy The energy a charged object possesses by virtue of its location in an electric field.

Electric potential The electric potential energy per unit of charge, measured in volts, and often called *voltage.*

Capacitor An electrical device—in its simplest form, a pair of parallel conducting plates separated by a small distance—that stores electric charge and energy.

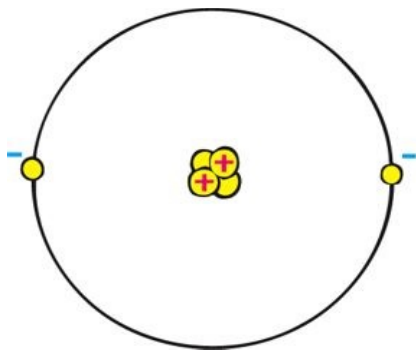


Like charges repel. Unlike charges attract.

Electric Charges

The terms *positive* and *negative* refer to electric *charge,* the fundamental quantity that underlies all electrical phenomena. The positively charged particles in ordinary matter are protons, and the negatively charged particles are electrons. Protons and electrons, with neutral particles called neutrons, make up the atom.

- **1.** Every atom is composed of a positively charged *nucleus* surrounded by negatively charged electrons.
- **2.** The electrons of all atoms are identical. Each has the same quantity of negative charge and the same mass.
- **3.** Protons and neutrons compose the nucleus. (The common form of the hydrogen atom, which has no neutron, is the only exception.) Protons are about 1800 times more massive than electrons, but they carry an amount of positive charge equal to the negative charge of electrons. Neutrons have slightly more mass than protons and have no net charge.
- **4.** Atoms usually have as many electrons as protons, so the atom has zero *net* charge.

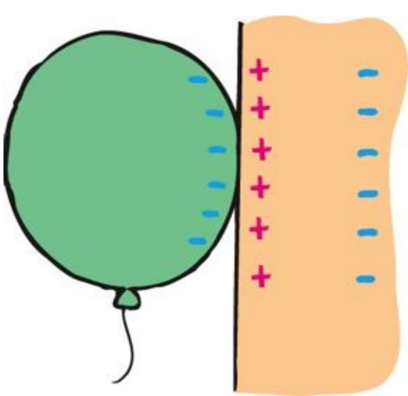


In a neutral atom, there are as many electrons as protons, so there is no net charge. The positive balances the negative exactly. If an electron is removed from an atom, then it is no longer neutral. The atom then has one more positive charge (proton) than negative charge (electron) and is said to be positively charged. A charged atom is called an *ion.* A *positive ion* has a net positive charge.   A *negative ion,* an atom with one or more extra electrons, is negatively charged. Charge is like a baton in a relay race. It can be passed from one object to another but isn't lost.

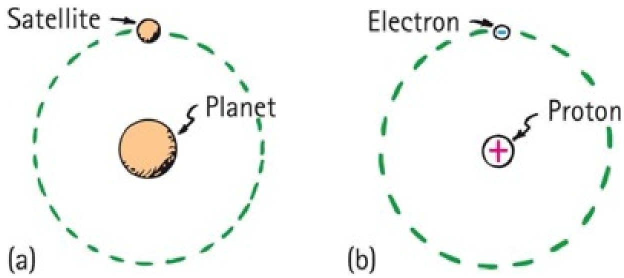
Coulomb's Law

$$F = k\frac{q_1 q_2}{d^2}$$

- d is the distance between the charged particles
- q_1 represents the quantity of charge of one particle
- q_2 represents the quantity of charge of the other particle
- k is the proportionality constant
  - k = 9,000,000,000 N·m^2/C^2



The negatively charged balloon polarizes atoms in the wooden wall and creates a positively charged surface, so the balloon sticks to the wall.

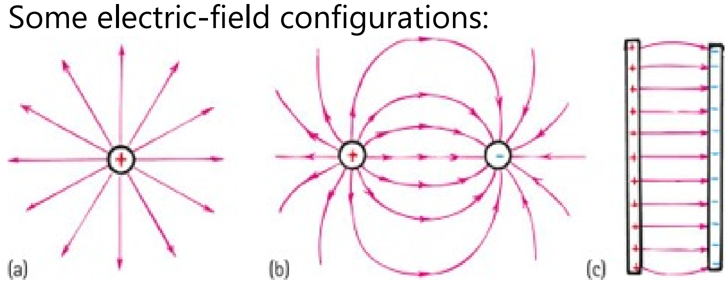


- (a) A gravitational force holds the satellite in orbit about the planet.
- (b) an electrical force holds the electron in orbit about the proton.
- In both cases, there is no contact between the bodies. We say that the orbiting bodies interact with the *force fields* of the planet and proton and are everywhere in contact with these fields. Thus, the force that one electrically charged body exerts on another can be described as the interaction between one body and the field set up by the other. An electric field is nature's storehouse of electrical energy.

An electric field has both magnitude (strength) and direction. The magnitude of the field at any point is simply the force per unit of charge. If a body with charge *q* experiences a force *F* at some point in space, then the electric field *E* at that point is:

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

Some electric-field configurations:



- (a) Lines of force emanating from a single positively charged particle.
- (b) Lines of force for a pair of equal but oppositely charged particles. Note that the lines emanate from the positive particle and terminate on the negative particle.
- (c) Uniform lines of force between two oppositely charged parallel plates.

$$\text{Electric potential} = \frac{\text{electric potential energy}}{\text{charge}} \qquad 1\text{ volt} = 1\,\frac{\text{joule}}{\text{coulomb}}$$

- *electric potential* and *voltage* mean the same thing—electrical potential energy per unit charge—in units of volts.

Chapter 23: Electric Current

Potential difference The difference in electric potential between two points, measured in volts. When two points of different electric potential are connected by a conductor, charge flows so long as a potential difference exists. (Synonymous with *voltage difference.*)

Electric current The flow of electric charge that transports energy from one place to another. Measured in amperes, where 1 A is the flow of 6.25×10^{18} electrons per second, or 1 coulomb per second.

Electrical resistance The property of a material that resists electric current. Measured in ohms (Ω).

Ohm's law The statement that the current in a circuit varies in direct proportion to the potential difference or voltage across the circuit and inversely with the circuit's resistance.

Direct current (dc) Electrically charged particles flowing in one direction only.

Alternating current (ac) Electrically charged particles that repeatedly reverse direction, vibrating about relatively fixed positions. In the United States, the vibrational rate is commonly 60 Hz.

Electric power The rate of energy transfer, or the rate of doing work; the amount of energy per unit time, which electrically can be measured by the product of current and voltage.

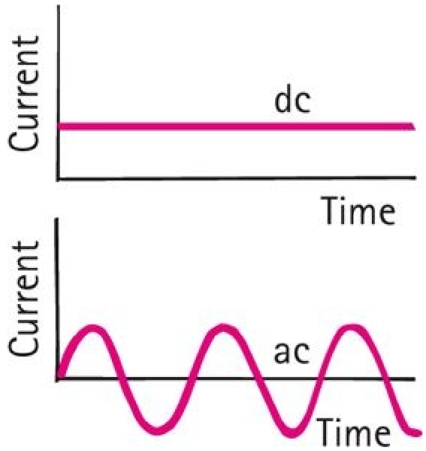
Series circuit An electric circuit in which electrical devices are connected along a single wire such that the same electric current exists in all of them.

Parallel circuit An electric circuit in which electrical devices are connected in such a way that the same voltage acts across each one, and any single one completes the circuit independently of all the others.

Ohm's Law

$$\text{Current} = \frac{\text{voltage}}{\text{resistance}} \quad \text{Amperes} = \frac{\text{volts}}{\text{ohms}}$$

- Current is a flow of charge, pressured into motion by voltage and hampered by resistance.
- A potential difference of 1 V across a resistance of 1 Ω produces a current of 1 A.

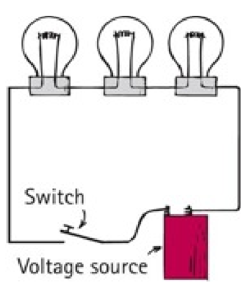


Electric Power

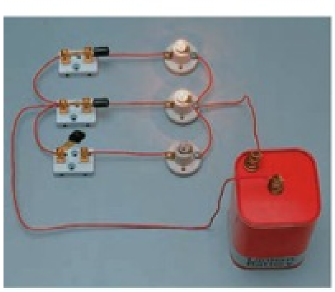
Power = current × voltage (Watts = amperes × volts)

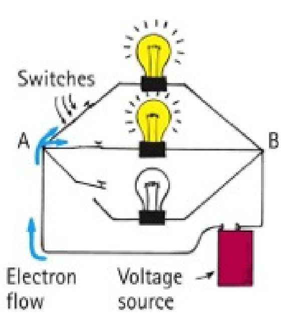
- Electric power is measured in watts (or kilowatts), where 1 W = 1 A × 1 V = 1 J/s.

Series Circuits



Parallel Circuits





Chapter 24: Magnetism

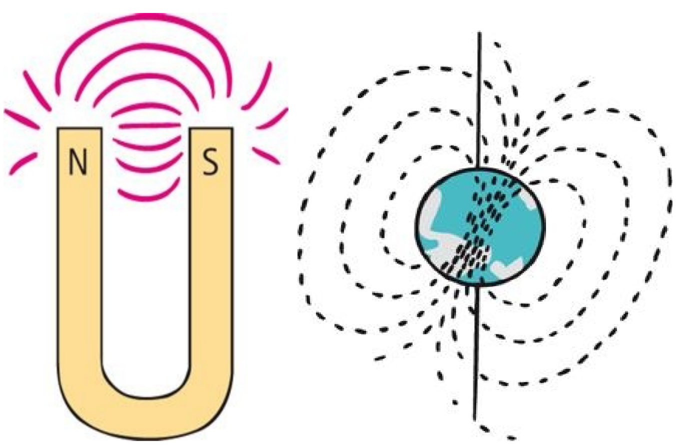
Magnetic force (1) Between magnets, it is the attraction of unlike magnetic poles for each other and the repulsion between like magnetic poles. (2) Between a magnetic field and a moving charged particle, it is a deflecting force due to the motion of the particle: The deflecting force is perpendicular to the velocity of the particle and perpendicular to the magnetic field lines. This force is greatest when the charged particle moves perpendicular to the field lines and is smallest (zero) when it moves parallel to the field lines.

Magnetic field The region of magnetic influence around a magnetic pole or a moving charged particle.

Magnetic domains Clustered regions of aligned magnetic atoms. When these regions themselves are aligned with one another, the substance containing them is a magnet.

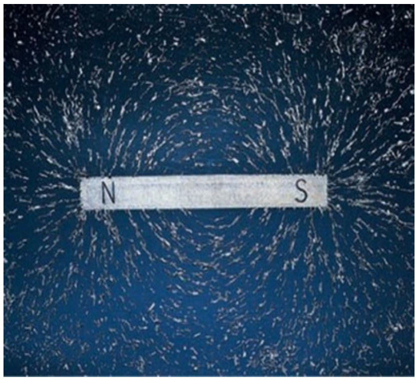
Electromagnet A magnet whose field is produced by an electric current. It is usually in the form of a wire coil with a piece of iron inside the coil.

Cosmic rays Various high-speed particles that travel throughout the universe.

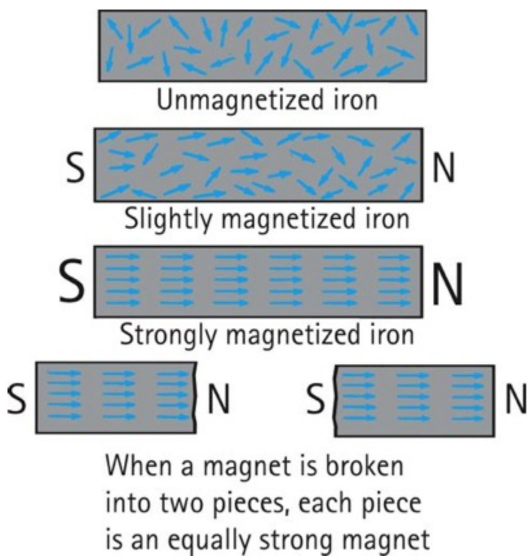


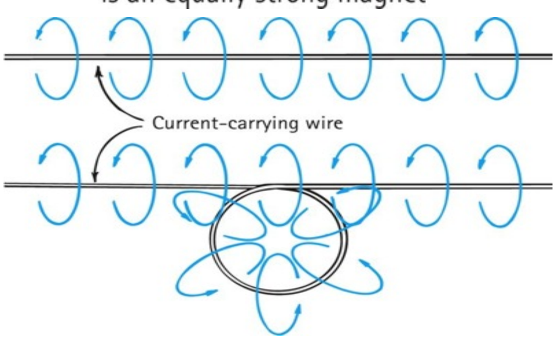
- a) A horseshoe magnet.
- b) Earth is a magnet.

Like poles repel each other; opposite poles attract.

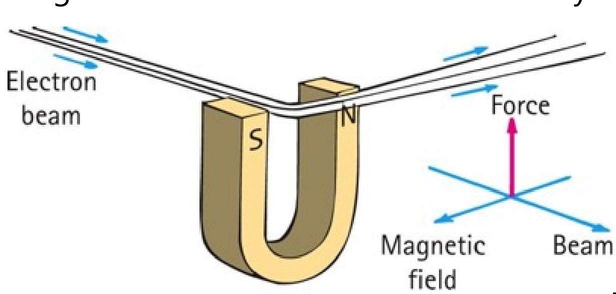


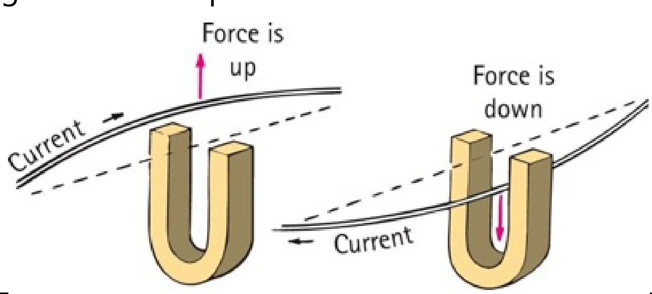
- a) Top view of iron filings sprinkled around a magnet tracing a pattern of magnetic field lines.
- b) A microscopic view of magnetic domains in a crystal of iron. The blue arrows pointing in different directions tell us that these domains are not aligned.





Magnetic field lines about a current-carrying wire crowd up when the wire is bent into a loop.





Chapter 25: Electromagnetic Induction

Electromagnetic induction The induction of voltage when a magnetic field changes with time. If the magnetic field within a closed loop changes in any way, a voltage is induced in the loop. If multiple loops are connected together in a coil, the voltage induced is multiplied by the number of loops. The induction of voltage is actually the result of a more fundamental phenomenon: generally, the induction of an electric *field*.

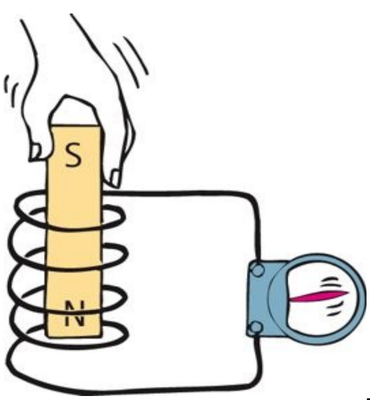
Faraday's law An electric field is created in any region of space in which a magnetic field is changing with time. The magnitude of the induced electric field is proportional to the rate at which the magnetic field changes. The direction of the induced field is at right angles to the changing magnetic field.

Generator An electromagnetic induction device that produces electric current by rotating a coil within a stationary magnetic field. A generator converts mechanical energy to electrical energy.

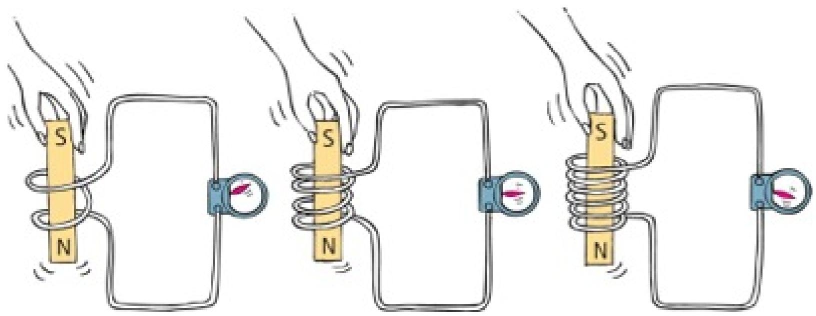
Transformer A device for transferring electric power from one coil of wire to another, by means of electromagnetic induction, for the purpose of transforming one value of voltage to another.

Maxwell's counterpart to Faraday's law A magnetic field is created in any region of space in which an electric field is changing with time. The magnitude of the induced magnetic field is proportional to the rate at which the electric field changes. The direction of the induced magnetic field is at right angles to the changing electric field.

Electromagnetic Induction



When the magnet is plunged into the coil, voltage is induced in the coil and charges in the coil are set in motion.

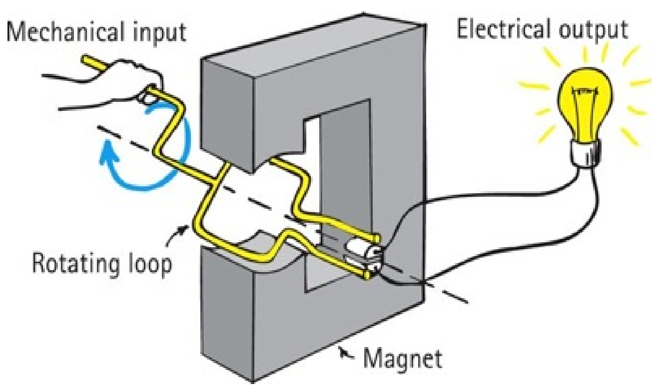


When a magnet is plunged into a coil of twice as many loops as another, twice as much voltage is induced. If the magnet is plunged into a coil with 3 times as many loops, then 3 times as much voltage is induced.

Faraday's Law:

The induced voltage in a coil is proportional to the product of its number of loops, the cross-sectional area of each loop, and the rate at which the magnetic field changes within those loops.

$$\text{Voltage induced} \sim \text{number of loops} \times \text{area of each loop} \times \frac{\Delta\,\text{magnetic field}}{\Delta\,\text{time}}$$

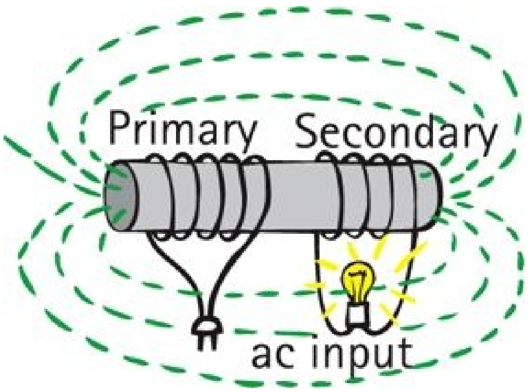


A simple generator. Voltage is induced in the loop when it is rotated in the magnetic field.

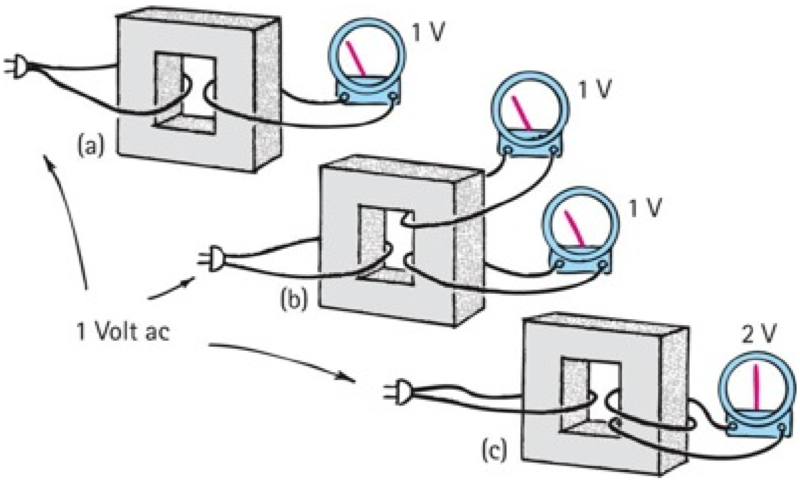
Motor vs Generator = Reversed roles of input and output.

- **Motor = electrical energy to mechanical energy**
- **Generator = mechanical energy to electrical energy**

Transformers



A simple transformer.



$$\frac{\text{Primary voltage}}{\text{Number of primary turns}} = \frac{\text{secondary voltage}}{\text{number of secondary turns}}$$

(voltage × current)$_{\text{primary}}$ = (voltage × current)$_{\text{secondary}}$

Faraday's law:
An electric field is induced in any region of space in which a magnetic field is changing with time.

Maxwell's counterpart to Faraday's law:
A magnetic field is induced in any region of space in which an electric field is changing with time.

Unit 4: Wave Physics

Chapter 19: Vibrations and Waves

Sine curve The waveform traced by simple harmonic motion, which can be made visible on a moving conveyor belt by a pendulum swinging at right angles above the moving belt.

Amplitude For a wave or vibration, the maximum displacement on either side of the equilibrium (midpoint) position.

Wavelength The distance between successive crests, troughs, or identical parts of a wave.

Frequency For a vibrating body or medium, the number of vibrations per unit time. For a wave, the number of crests that pass a particular point per unit time.

Hertz The SI unit of frequency. One hertz (symbol Hz) equals one vibration per second.

Period The time in which a vibration is completed. The period of a wave equals the period of the source and is equal to 1/frequency.

Wave speed The speed with which waves pass a particular point:

- Wave speed = frequency × wavelength

Transverse wave A wave in which the medium vibrates in a direction perpendicular (transverse) to the direction in which the wave travels. Light waves and water waves are transverse.

Longitudinal wave A wave in which the medium vibrates in a direction parallel (longitudinal) to the direction in which the wave travels. Sound waves are longitudinal.

Wave interference Phenomenon that occurs when two waves meet while traveling along the same medium.

Interference pattern The pattern formed by superposition of different sets of waves that produces reinforcement in some places and cancellation in others.

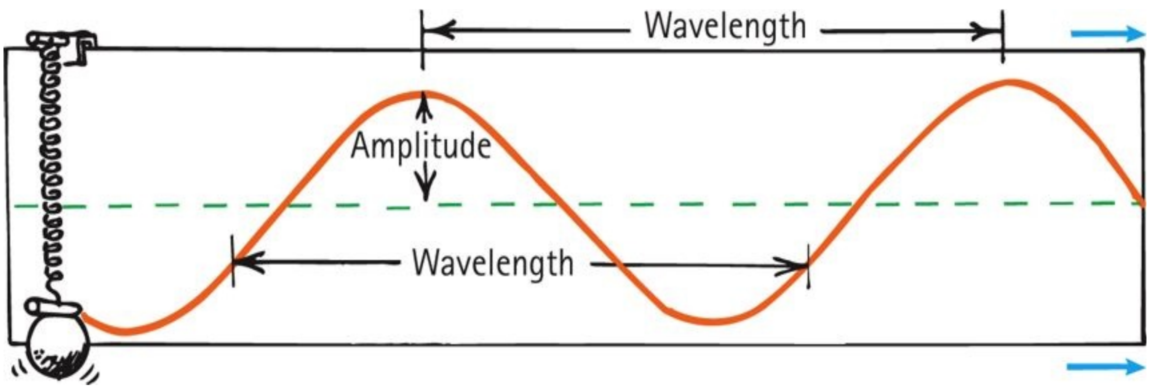
Standing wave A stationary wave pattern formed in a medium when two sets of identical waves pass through the medium in opposite directions.

Doppler effect The shift in received frequency due to motion of a vibrating source toward or away from a receiver.

Bow wave The V-shaped disturbance created by an object moving across a liquid surface at a speed greater than the wave speed.

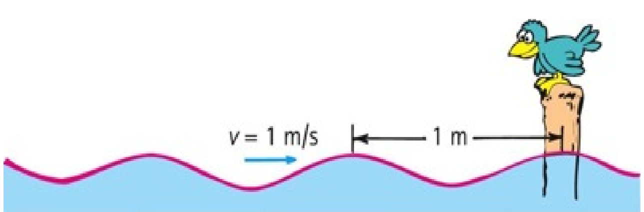
Shock wave The cone-shaped disturbance created by an object moving at supersonic speed through a fluid.

Sonic boom The loud sound resulting from the incidence of a shock wave.

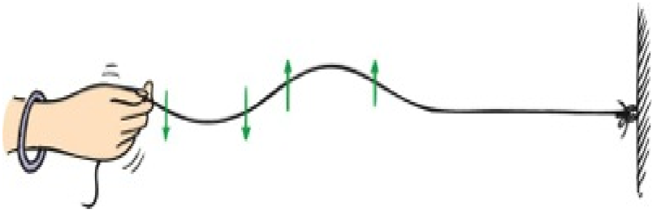


$$\text{Frequency} = \frac{1}{\text{period}} \quad \text{or} \quad \text{Period} = \frac{1}{\text{frequency}}$$

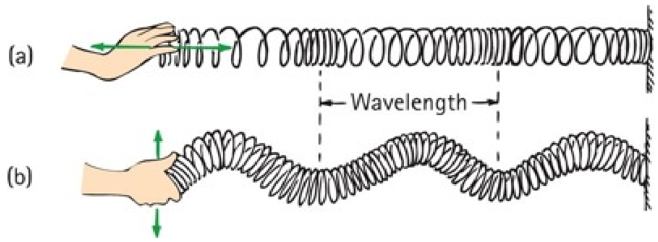
Wave speed = frequency × wavelength



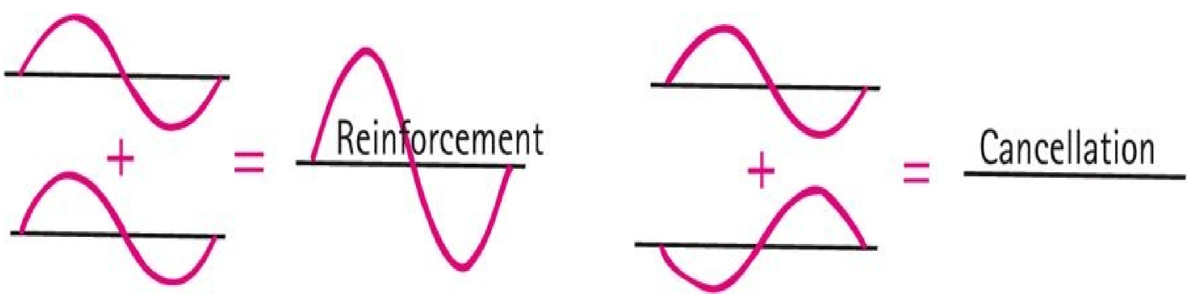
If the wavelength is 1 m, and one wavelength per second passes the pole, then the speed of the wave is 1 m/s.



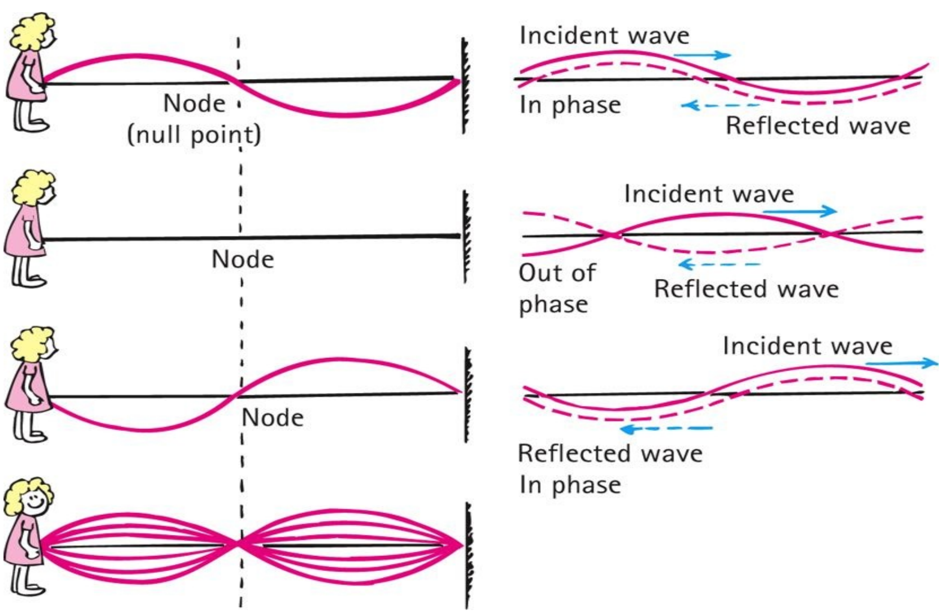
A transverse wave.



- (a) When the end of the Slinky is pushed and pulled rapidly along its length, a longitudinal wave is produced.
- (b) When it's shaken from side to side, a transverse wave is produced.



Constructive and destructive interference in a transverse wave.



The incident and reflected waves interfere to produce a standing wave.

Chapter 20: Sound

Pitch The highness or lowness of a tone related to wave frequency.

Infrasonic Describes a sound that has a frequency too low to be heard by the normal human ear.

Ultrasonic Describes a sound that has a frequency too high to be heard by the normal human ear.

Compression Condensed region of the medium through which a longitudinal wave travels.

Rarefaction Rarefied region (of reduced pressure) of the medium through which a longitudinal wave travels.

Reverberation Persistence of sound, as in an echo, due to multiple reflections.

Refraction Bending of sound or any wave caused by a difference in wave speeds.

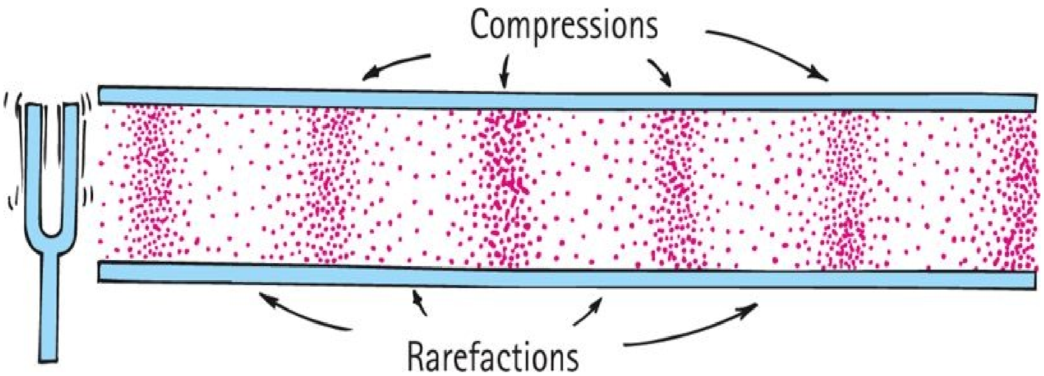
Forced vibration The setting up of vibrations in an object by a vibrating force.

Natural frequency A frequency at which an elastic object naturally tends to vibrate if it is disturbed and the disturbing force is removed.

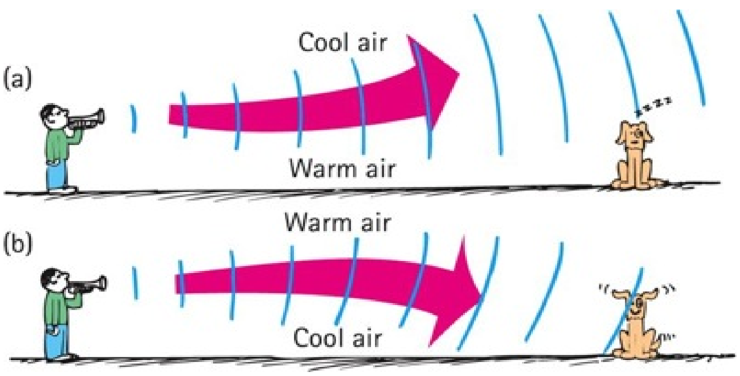
Resonance The response of a body when a forcing frequency matches its natural frequency.

Interference A result of superposing different waves, often of the same wavelength. Constructive interference results from crest-to-crest reinforcement; destructive interference results from crest-to-trough cancellation.

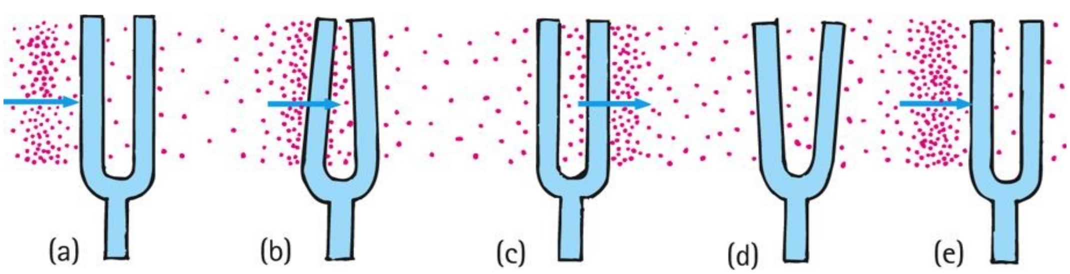
Beats A series of alternate reinforcements and cancellations produced by the interference of two waves of slightly different frequencies, heard as a throbbing effect in sound waves.



Compressions and rarefactions travel (both at the same speed in the same direction) from the tuning fork through the air in the tube.

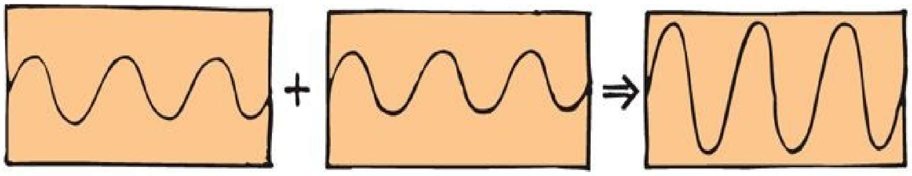


Sound waves are bent in air of uneven temperatures.

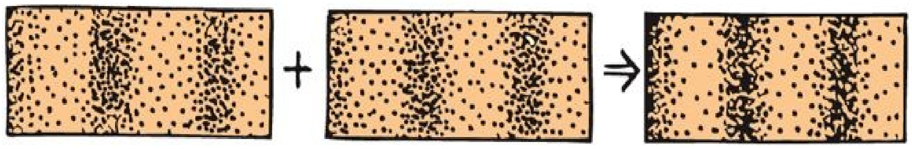


Stages of resonance (blue arrows indicate sound waves traveling to the right):

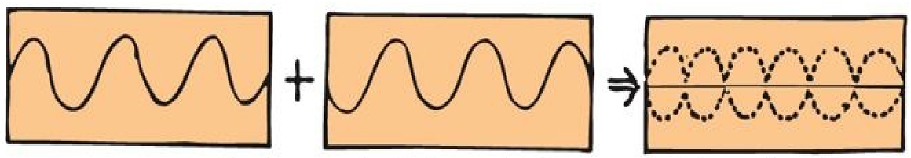
- (a) The first compression meets the tuning fork and gives it a tiny and momentary push.
- (b) The fork bends and then
- (c) returns to its initial position just at the time a rarefaction arrives and
- (d) overshoots in the opposite direction. Just when the fork returns to its initial position
- (e), the next compression arrives to repeat the cycle. Now it bends farther because it is moving.

(a) 

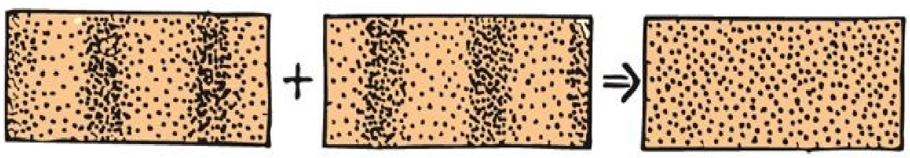
The superposition of two identical transverse waves in phase produces a wave of increased amplitude.

(b) 

The superposition of two identical longitudinal waves in phase produces a wave of increased intensity.

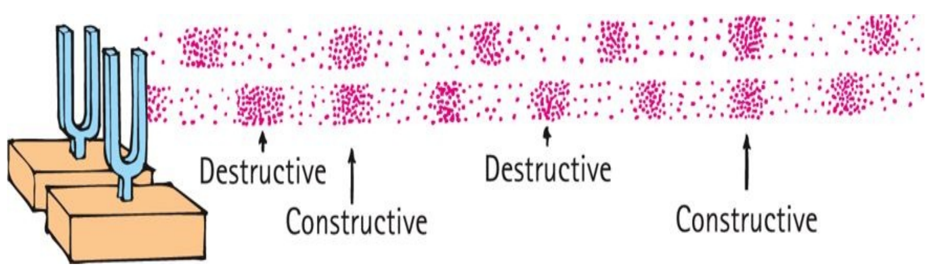
(c) 

Two identical transverse waves that are out of phase destroy each other when they are superimposed.

(d) 

Two identical longitudina waves that are out of phase destroy each other when they are superimposed.

Constructive (a, b) and destructive (c, d) wave interference in transverse and longitudinal waves.



The interference of two sound sources of slightly different frequencies produces beats.

Speed of Sound:

- through a Solid = fastest
- through a Liquid = moderate
- through a Gas = slowest

Chapter 26: Properties of Light

Electromagnetic wave An energy-carrying wave emitted by a vibrating charge (often electrons) that is composed of oscillating electric and magnetic fields that regenerate one another.

Electromagnetic spectrum The range of electromagnetic waves extending in frequency from radio waves to gamma rays.

Transparent The term applied to materials through which light can pass in straight lines.

Opaque The term applied to materials that absorb light without reemission and thus through which light cannot pass.

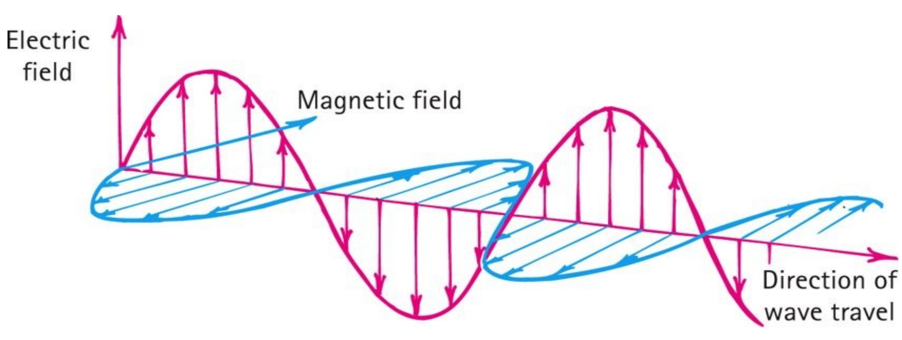
Shadow A shaded region that appears where light rays are blocked by an object.

Umbra The darker part of a shadow where all the light is blocked.

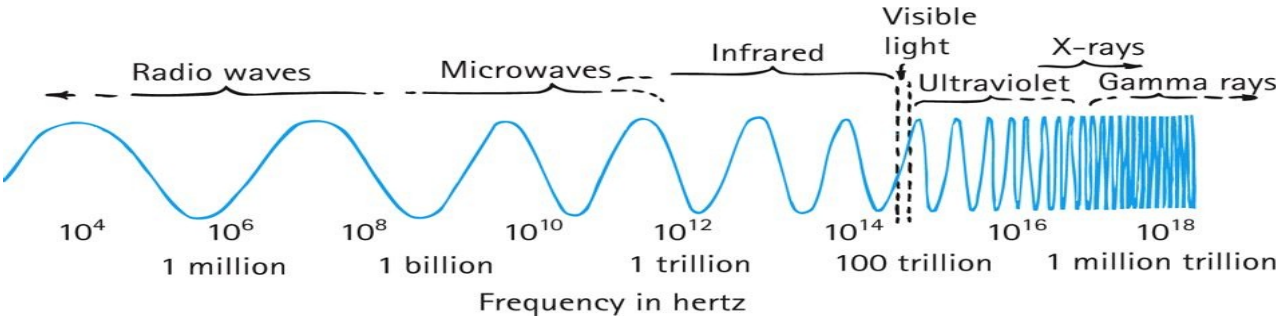
Penumbra A partial shadow that appears where some but not all of the light is blocked.

Solar eclipse An event wherein the Moon blocks light from the Sun and the Moon's shadow falls on part of Earth.

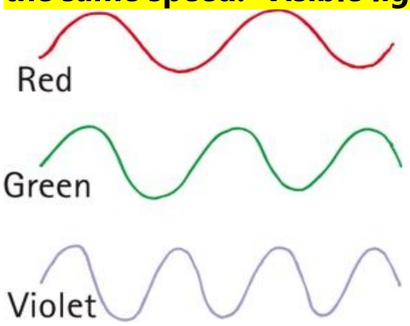
Lunar eclipse An event wherein the Moon passes into the shadow of Earth.



The electric and magnetic fields of an electromagnetic wave are perpendicular to each other and to the direction of motion of the wave.

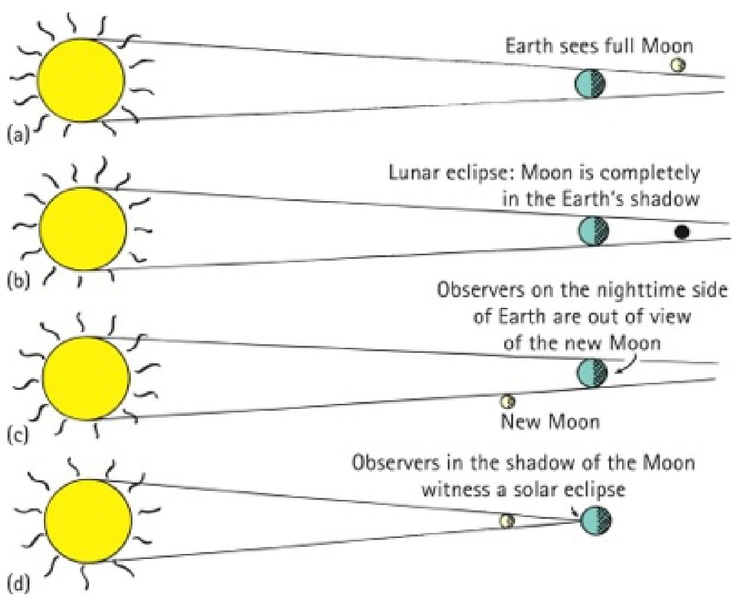


The electromagnetic spectrum is a continuous range of waves extending from radio waves to gamma rays. The descriptive names of the sections are merely a historical classification, for all waves are the same in nature, differing principally in frequency and wavelength; **all travel at the same speed. Visible light comprises the smallest portion of the spectrum.**



ROY-G-BIV (longest wavelength to shortest wavelength)

Relative wavelengths of red, green, and violet light. Violet light has nearly twice the frequency of red light and half the wavelength.



- (a) A full Moon is seen when Earth is between the Sun and the Moon.
- (b) When this alignment is perfect, the Moon is in Earth's shadow, and a lunar eclipse is produced.
- (c) A new Moon occurs when the Moon is between the Sun and Earth.
- (d) When this alignment is perfect, the Moon's shadow falls on part of Earth to produce a solar eclipse.

Chapter 28: Reflection and Refraction

Reflection The return of light rays from a surface.

Fermat's principle of least time Light takes the path that requires the **least time** when it goes from one place to another.

Law of reflection The angle of reflection equals the angle of incidence.

Refraction The bending of an oblique ray of light when it passes from one transparent medium to another.

Critical angle The minimum angle of incidence inside a medium at which a light ray is totally reflected.

Total internal reflection The total reflection of light traveling within a denser medium when it strikes the boundary with a less dense medium at an angle greater than the critical angle.

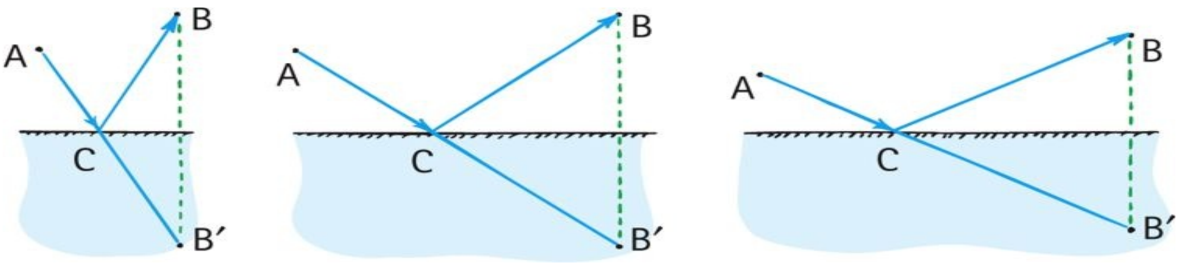
Converging lens A lens that is thicker in the middle than at the edges and that refracts parallel rays to a focus.

Diverging lens A lens that is thinner in the middle than at the edges, causing parallel rays to diverge as if from a point.

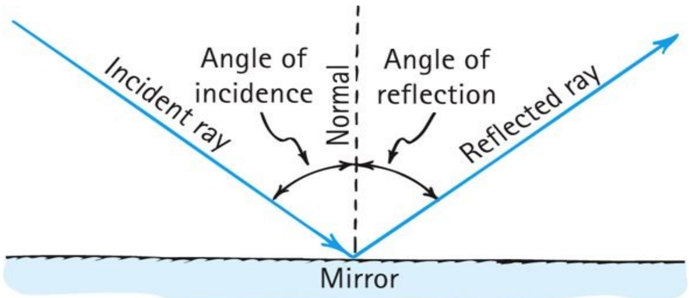
Virtual image An image formed by light rays that do not converge at the location of the image.

Real image An image formed by light rays that converge at the location of the image. A real image, unlike a virtual image, can be displayed on a screen.

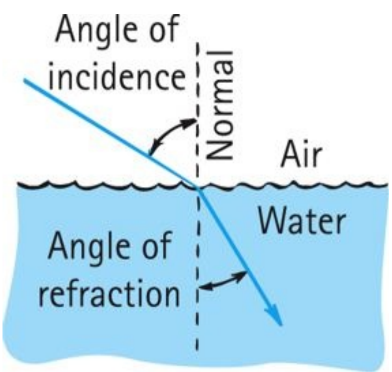
Aberration Distortion in an image produced by a lens, which to some degree is present in all optical systems.



Reflection.



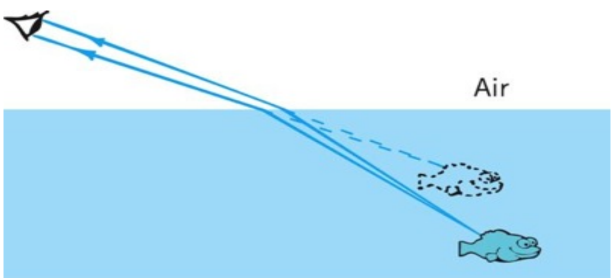
The law of reflection. **The angle of incidence equals the angle of reflection.**



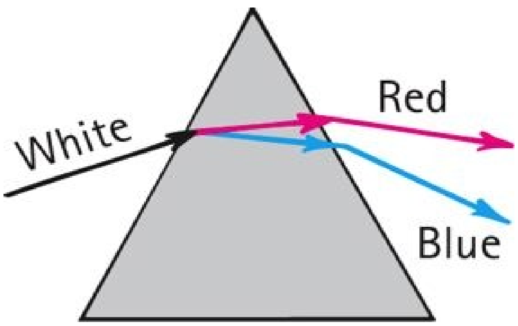
Refraction.

$$n = \frac{\text{speed of light in vacuum}}{\text{speed of light in material}}$$

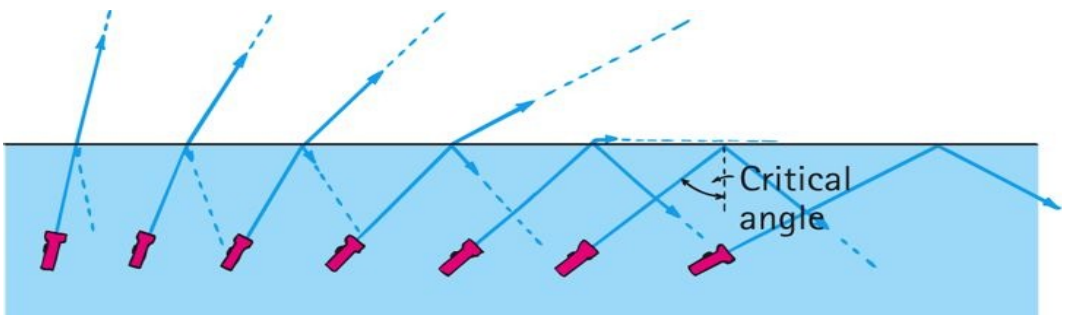
- speed of light in a vacuum = 300,000 km/s



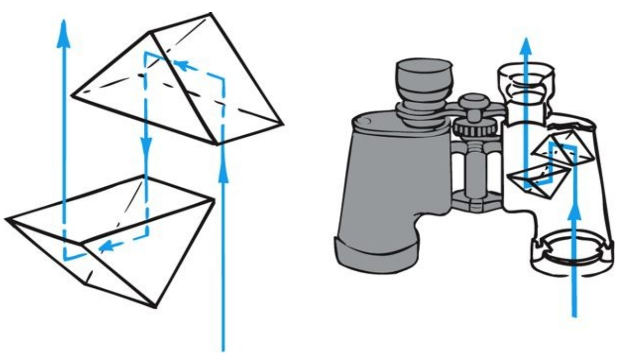
Refraction occurs when the average speed of light *changes* in going from one transparent medium to another. Because of refraction, a submerged object seems to be nearer to the surface than it actually is.



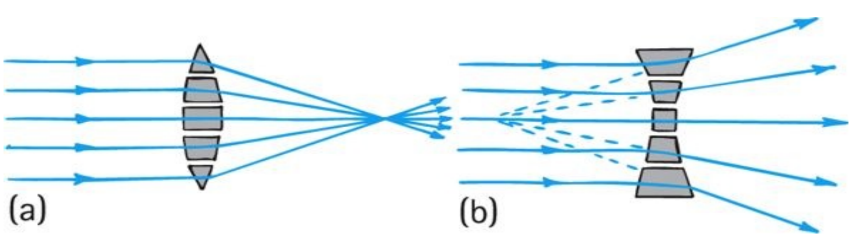
Dispersion by a prism makes the components of white light visible.



Light emitted in the water is partly refracted and partly reflected at the surface. The blue dashes show the direction of light and the length of the arrows indicates the proportions refracted and reflected. Beyond the critical angle, the beam is totally internally reflected.



Total internal reflection in a pair of prisms, common in binoculars.



A lens may be thought of as a set of blocks and prisms. (a) A converging lens. (b) A diverging lens.

<u>Chapter 29: Light Waves</u>

Huygens' principle Every point on a wavefront can be regarded as a new source of wavelets, which combine to produce the next wavefront, whose points are sources of further wavelets, and so on.

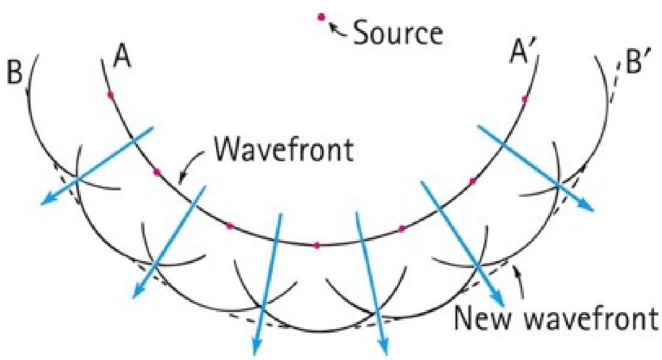
Diffraction The bending of light that passes near the edge of an object or through a narrow slit, causing the light to spread.

Superposition The overlapping and combining of waves.

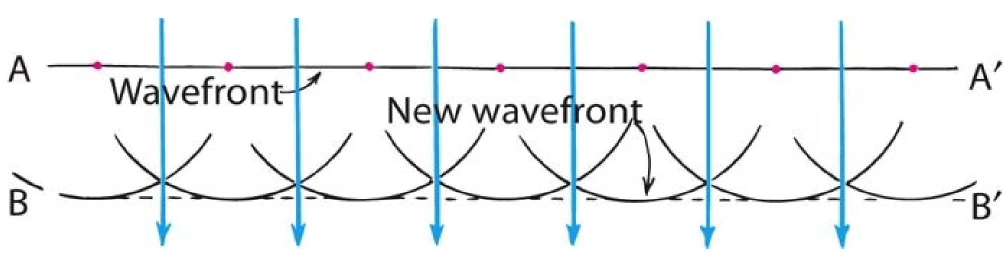
Interference The result of superposing different waves, usually of the same wavelength. Constructive interference results from crest-to-crest reinforcement; destructive interference results from crest-to-trough cancellation. The interference of selected wavelengths of light produces colors known as *interference colors.*

Polarization The alignment of the transverse electric vibrations of electromagnetic radiation. Such waves of aligned vibrations are said to be *polarized.*

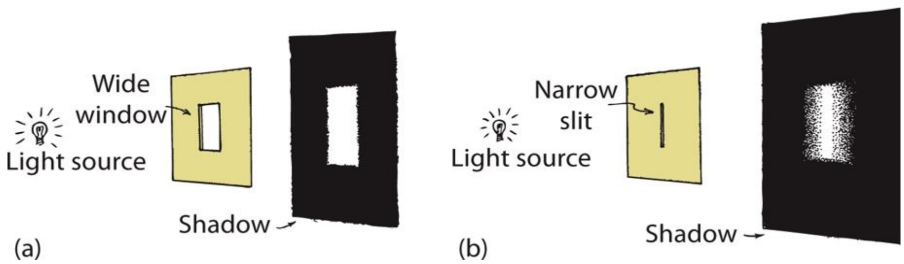
Hologram A two-dimensional microscopic interference pattern that shows three-dimensional optical images.



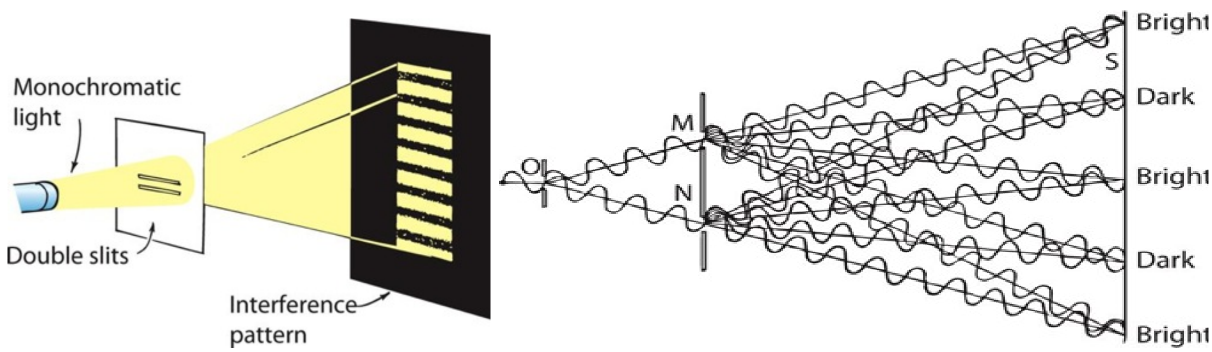
Huygens' principle applied to a spherical wavefront.



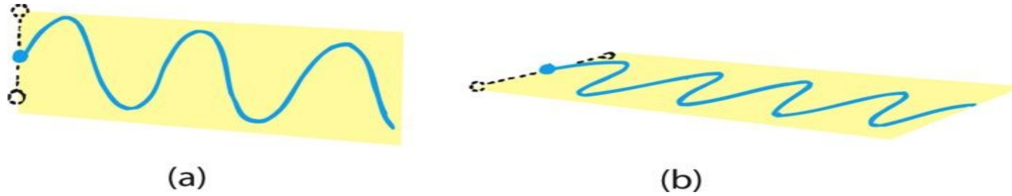
Huygens' principle applied to a plane wavefront.



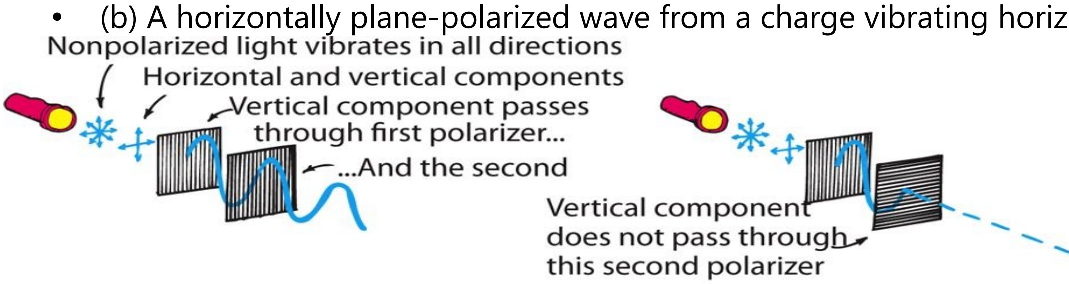
- (a) Light casts a sharp shadow with some fuzziness at its edges when the opening is large compared with the wavelength of the light.
- (b) When the opening is very narrow, diffraction is more apparent and the shadow is fuzzier.

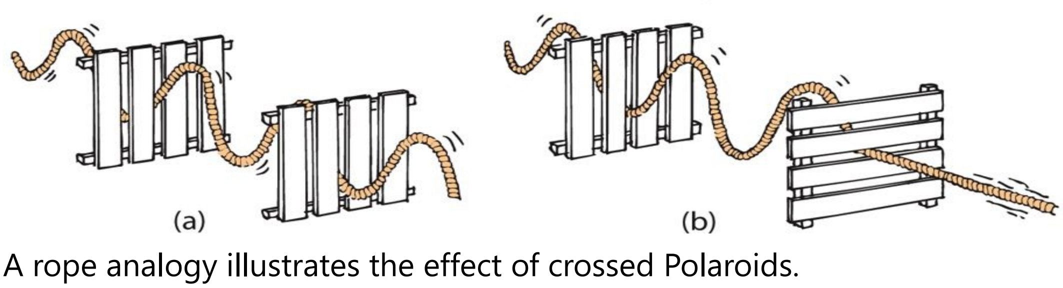


- When monochromatic light passes through two closely spaced slits, a striped interference pattern is produced.
- Light from O passes through slits M and N and produces an interference pattern on the screen S.



- (a) A vertically plane-polarized wave from a charge vibrating vertically.
- (b) A horizontally plane-polarized wave from a charge vibrating horizontally.





A rope analogy illustrates the effect of crossed Polaroids.

Unit 5: Thermodynamics

Chapter 15: Temperature, Heat, and Expansion

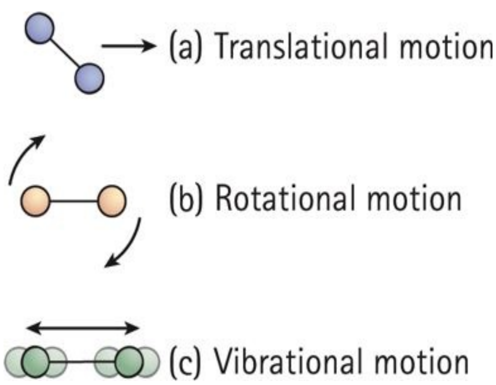
Temperature A measure of the average translational kinetic energy per molecule in a substance, measured in degrees Celsius or Fahrenheit or in kelvins (K).

Absolute zero The lowest possible temperature that a substance may have—the temperature at which molecules of the substance have their minimum kinetic energy.

Heat The energy that flows from a substance of higher temperature to a substance of lower temperature, commonly measured in calories or joules.

Internal energy The total of all molecular energies, kinetic plus potential, that are internal to a substance.

Specific heat capacity The quantity of heat per unit mass required to raise the temperature of a substance by 1 Celsius degree.



Particles in matter move in different ways. They move from one place to another, they rotate, and they vibrate to and fro. All these modes of motion, plus potential energy, contribute to the overall energy of a substance. Temperature, however, is defined by translational motion.

Just as dark is the absence of light, cold is the absence of internal energy.

For two things in thermal contact, heat flow is always from the higher-temperature substance to the lower-temperature substance.

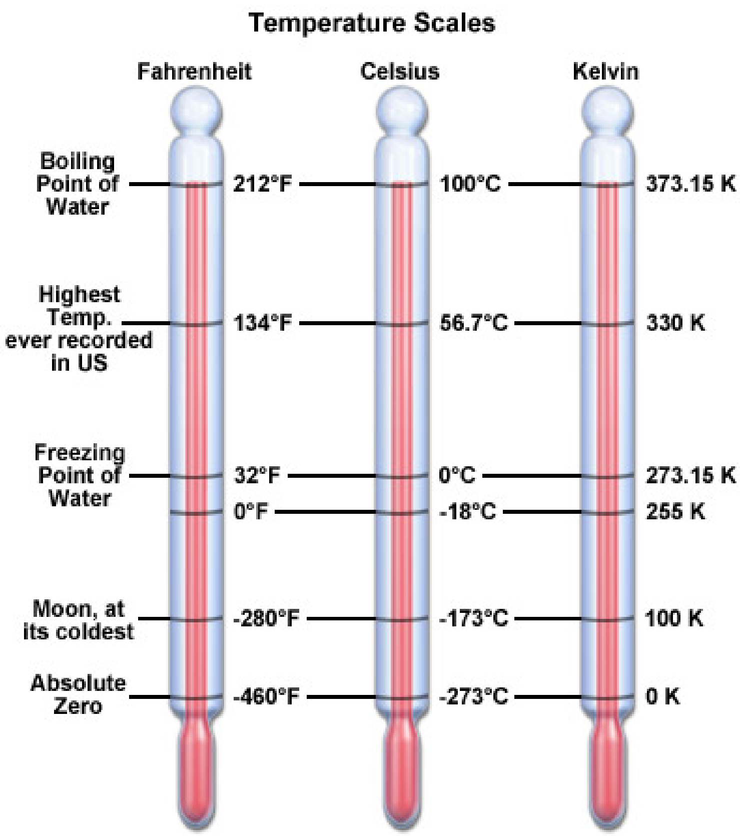
Temperature is measured in degrees; heat is measured in joules.

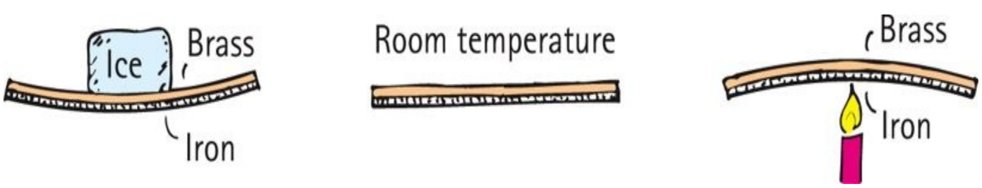
Both heat and work are ways in which energy can be transferred from one substance to another. Although they are measured in joules, they shouldn't be confused with energy itself.

The specific heat capacity of any substance is defined as the quantity of heat required to change the temperature of a unit mass of the substance by 1 degree.

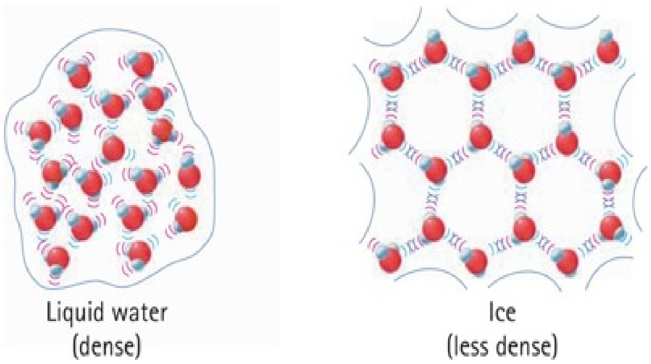
- calorie = the amount of energy required to raise the temperature of 1 gram of water by 1°C.
- **C**alorie (capital letter) = 1000 calories i.e. a kilocalorie.

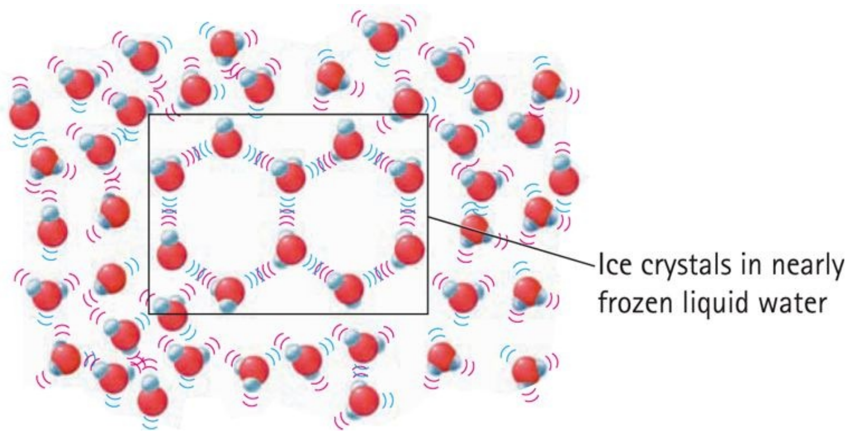
A substance that heats up quickly has a low specific heat capacity. Likewise, a substance that heats up slowly has a high specific heat capacity.



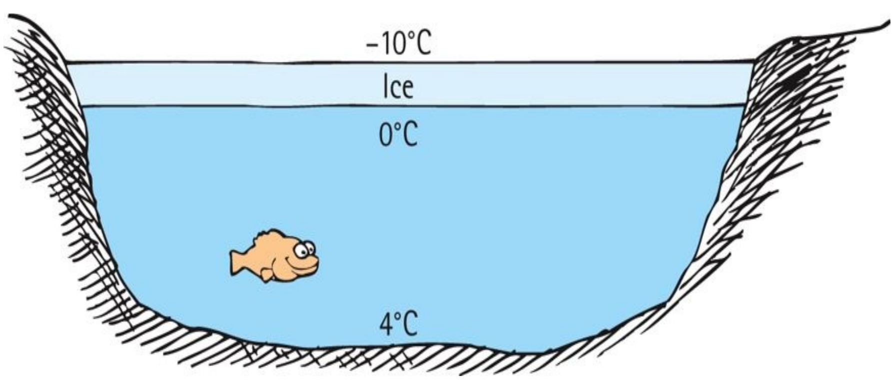


A bimetallic strip. Brass expands more when heated than iron does and contracts more when cooled. Because of this behavior, the strip bends as shown.





Liquid water is more dense than ice because water molecules in a liquid are closer together than water molecules frozen in ice, where they have an open crystalline structure. Close to 0°C, liquid water contains crystals of ice. The open structure of these 3-D cagelike crystals increases the volume of the water slightly.



As water is cooled at the surface, it sinks until the temperature of the entire lake is 4°C. Only then can the surface water cool to 0°C without sinking. Once ice has formed, temperatures lower than 4°C can extend down into the lake.

Chapter 16: Heat Transfer

Conduction The transfer of heat energy by molecular and electron collisions within a substance (especially a solid).

Convection The transfer of heat energy in a gas or liquid by means of currents in the heated fluid. The fluid moves, carrying energy with it.

Radiation The transfer of energy by means of electromagnetic waves.

Terrestrial radiation The radiation emitted by Earth to outer space.

Newton's law of cooling The rate of loss of heat from a warm object is proportional to the temperature difference between the object and its surroundings. (Similarly for the gain of heat by a cool object.)

Greenhouse effect Warming of the lower atmosphere by short-wavelength radiation from the Sun that penetrates the atmosphere is absorbed by Earth and is reradiated at longer wavelengths that cannot easily escape Earth's atmosphere.

Solar constant 1400 J/m^2 received from the Sun each second at the top of Earth's atmosphere on an area perpendicular to the Sun's rays; expressed in terms of power, 1.4 kW/m^2.

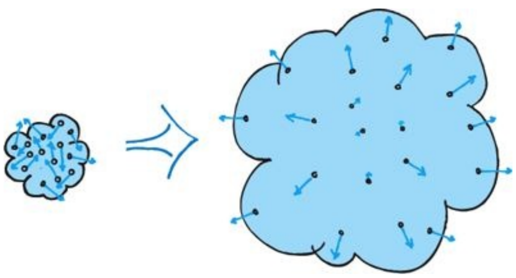
Solar power Energy per unit time derived from the Sun.

The spontaneous transfer of heat is always from warmer objects to cooler objects and is brought about in three ways: by *conduction,* by *convection,* and by *radiation.* **Heat is transmitted from a higher to a lower temperature.**

The feeling of warmth or cold for different materials involves rates of heat transfer, not necessarily temperatures.

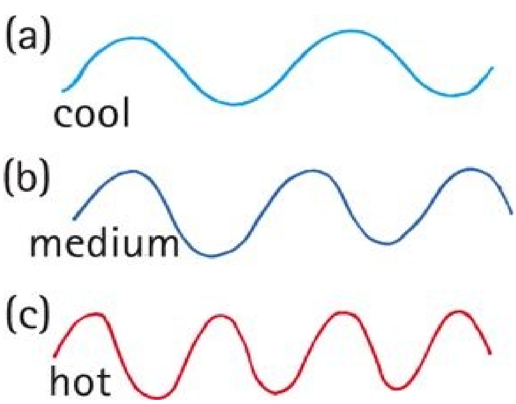
A hot pizza placed outside on a winter day is a net emitter. The same pizza placed in a hotter oven is a net absorber.

The tile floor feels colder than the wooden floor, even though both floor materials are at the same temperature. This is because tile is a better conductor of heat than wood, and so heat is more readily conducted out of the foot touching the tile.

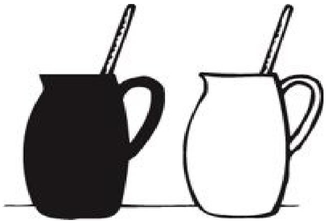


Molecules in a region of expanding air collide more often with receding molecules than with approaching ones. Their rebound speeds therefore tend to decrease and, as a result, the expanding air cools.

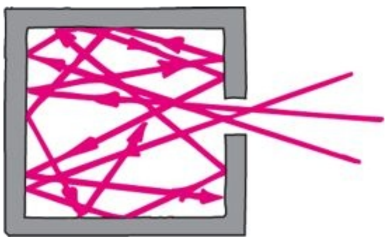
Radiation by Earth is *terrestrial radiation.* Radiation by the Sun is *solar radiation.* Both are regions in the electromagnetic spectrum.



- (a) A low-temperature (cool) source emits primarily low-frequency, long-wavelength waves.
- (b) A medium-temperature source emits primarily medium-frequency, medium-wavelength waves.
- (c) A high-temperature (hot) source emits primarily high-frequency, short-wavelength waves.

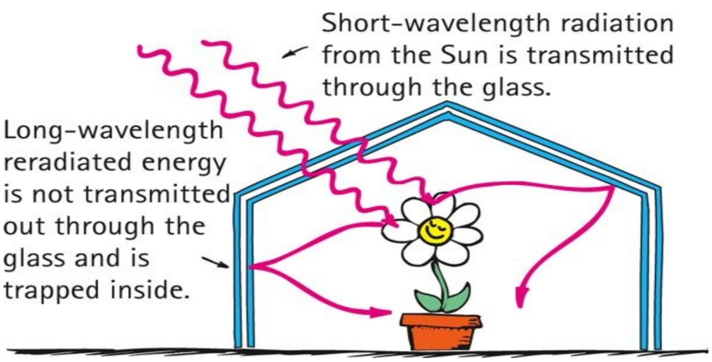


When the containers are filled with hot (or cold) water, the blackened one cools (or warms) faster.

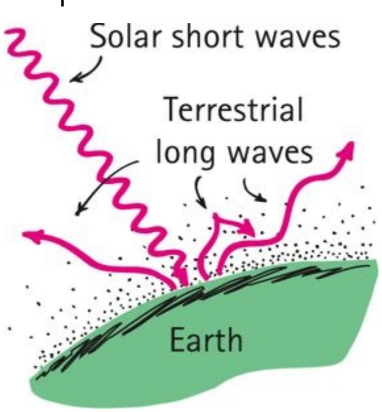


Radiation that enters the cavity has little chance of exiting because most of it is absorbed. For this reason, the opening to any cavity looks black to us.

The Greenhouse Effect



Glass is transparent to short-wavelength radiation but opaque to long-wavelength radiation. Reradiated energy from the plant is of long wavelength because the plant has a relatively low temperature.



The hot Sun emits short waves, and the cool Earth emits long waves. Water vapor, carbon dioxide, and other "greenhouse gases" in the atmosphere retain heat that would otherwise be radiated from Earth to space.

Chapter 18: Thermodynamics

Thermodynamics The study of heat and its transformation to different forms of energy.

Absolute zero The lowest possible temperature that a substance may have; the temperature at which particles of a substance have their minimum kinetic energy.

Internal energy The total energy (kinetic plus potential) of the submicroscopic particles that make up a substance. *Changes* in internal energy are of principal concern in thermodynamics.

First law of thermodynamics A restatement of the law of energy conservation, applied to systems in which energy is transferred by heat and/or work. The heat added to a system equals its increase in internal energy plus the external work it does on its environment.

Adiabatic process A process, often of fast expansion or compression, wherein no heat enters or leaves a system.

Temperature inversion A condition in which upward convection of air ceases, often because an upper region of the atmosphere is warmer than the region below it.

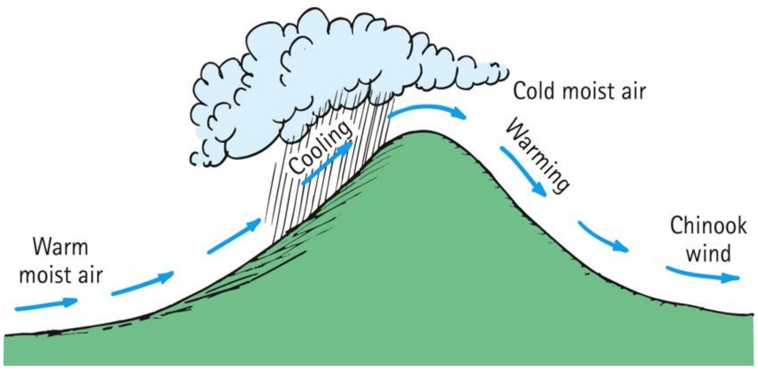
Second law of thermodynamics Thermal energy never spontaneously flows from a cold object to a hot object. Also, no machine can be completely efficient in converting heat to work; some of the heat supplied to the machine at high temperature is dissipated as waste heat at lower temperature. And finally, all systems tend to become more and more disordered as time goes by.

Heat engine A device that uses heat as input and supplies mechanical work as output, or that uses work as input and moves heat "uphill" from a cooler to a warmer place.

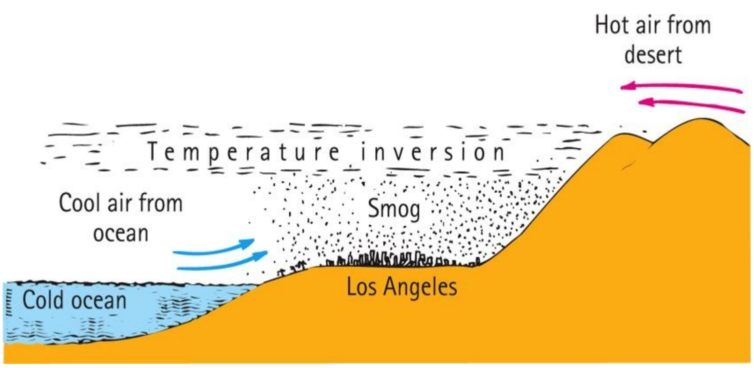
Entropy A measure of the disorder of a system. Whenever energy freely transforms from one form to another, the direction of transformation is toward a state of greater disorder and therefore toward one of greater entropy.

First Law of Thermodynamics:

- **When heat flows to or from a system, the system gains or loses an amount of energy equal to the amount of heat transferred.**
- **Heat added to a system = increase in internal energy + external work done by the system.**
- **Air temperature rises as heat is added or as pressure is increased.**
- **Air temperature rises (or falls) as pressure increases (or decreases).**



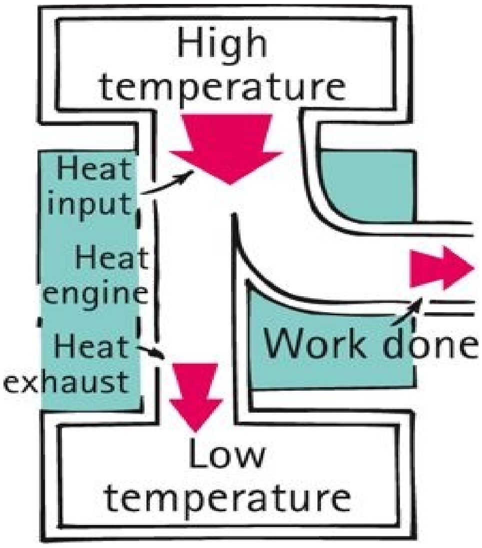
Chinooks, which are warm, dry winds, occur when high-altitude air descends and is adiabatically warmed.



Smog in Los Angeles is trapped by the mountains and a temperature inversion caused by warm air from the Mojave Desert overlying cool air from the Pacific Ocean.

Second Law of Thermodynamics:

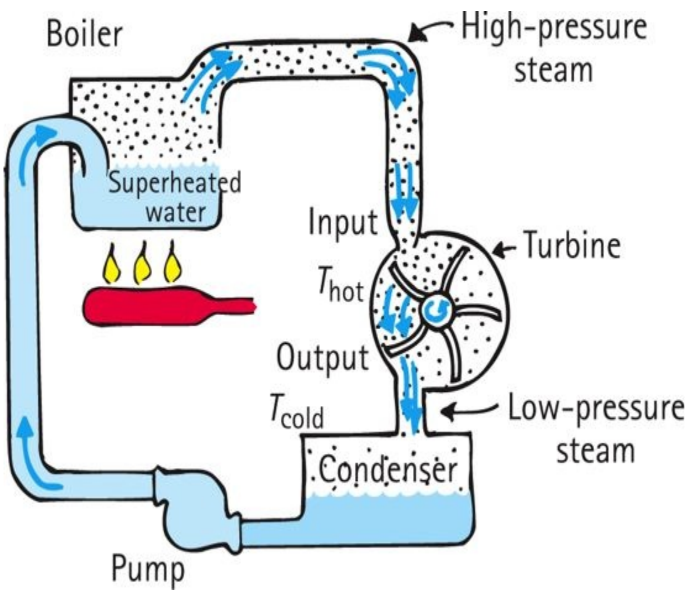
- **Heat of itself never flows from a cold object to a hot object.**
- **When work is done by a heat engine operating between two temperatures, T_{hot} and T_{cold}, only some of the input heat at T_{hot} can be converted to work, and the rest is expelled at T_{cold}.**
- **In natural processes, high-quality energy tends to transform into lower-quality energy—order tends toward disorder.**



When heat in a heat engine flows from the high-temperature reservoir to the low-temperature sink, part of the heat can be turned into work.

$$\text{Ideal efficiency} = \frac{T_{\text{hot}} - T_{\text{cold}}}{T_{\text{hot}}}$$

Where T_{hot} is the temperature of the hot reservoir and T_{cold} is the temperature of the cold sink.



The steam cycle. The turbine turns because pressure exerted by high-temperature steam on the front side of the turbine blades is greater than that exerted by low-temperature steam on the back side of the blades. Without a pressure difference, the turbine would not rotate and deliver energy to an external load (such as an electric generator). The presence of steam pressure on the back side of the blades, even without friction, prevents the turbine from being a perfectly efficient engine.

Unit 6: Modern Physics
Chapter 11: The Atomic Nature of Matter

Atom The smallest particle of an element that has all of the element's chemical properties.

Brownian motion The haphazard movement of tiny particles suspended in a gas or liquid resulting from their bombardment by the fast-moving atoms or molecules of the gas or liquid.

Electron Negatively charged particle that whizzes about within an atom.

Atomic nucleus The core of an atom, consisting of two basic subatomic particles—protons and neutrons.

Proton Positively charged particle in the nucleus of an atom.

Element A pure substance consisting of only one kind of atom.

Atomic number The number that designates the identity of an element, which is the number of protons in the nucleus of an atom; in a neutral atom, the atomic number is also the number of electrons in the atom.

Periodic table of the elements A chart that lists the elements in horizontal rows by their atomic number and in vertical columns by their similar electron arrangements and chemical properties.

Ion An electrically charged atom; an atom with an excess or deficiency of electrons.

Isotope An atom of the same element that contains a different number of neutrons.

Atomic mass unit (amu) The standard unit of atomic mass, which is equal to 1/12 the mass of the most common atom of carbon. One amu has a mass of 1.661×10^{-27} kg.

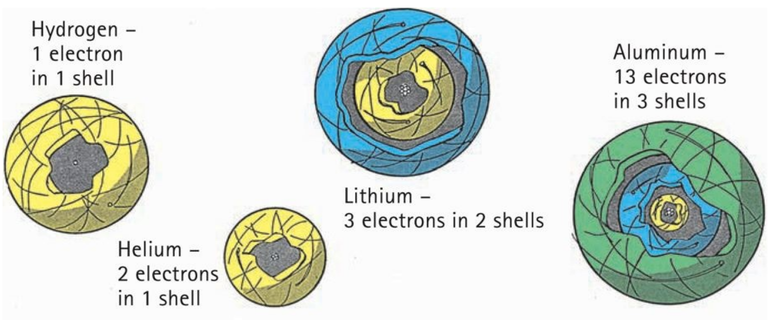
Compound A material in which atoms of different elements are chemically bonded to one another.

Mixture A substance whose components are mixed together without combining chemically.

Molecule Two or more atoms that bond together by a sharing of electrons. Atoms combine to become molecules.

Antimatter A "complementary" form of matter composed of atoms with negative nuclei and positive electrons.

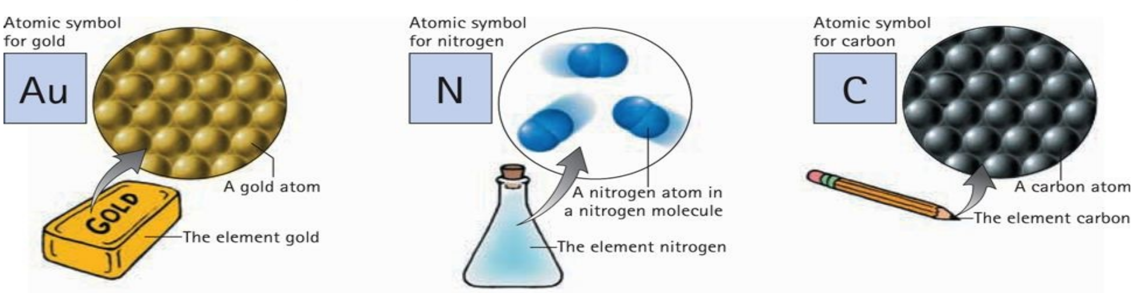
Dark matter Unseen and unidentified matter that is evident by its gravitational pull on stars in the galaxies. Dark matter, along with dark energy, constitutes perhaps 90% of the stuff of the universe.



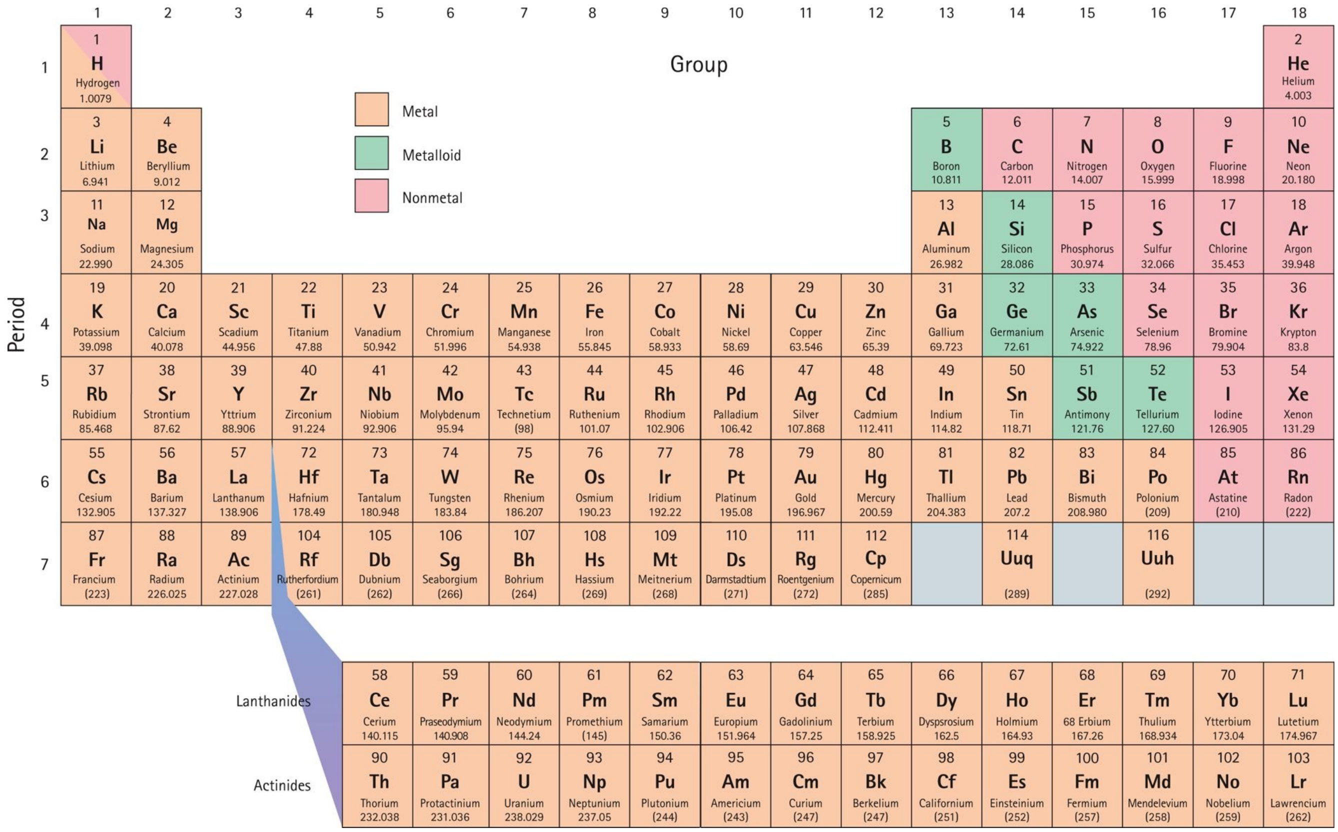
A simplified model of the atom consists of a tiny nucleus surrounded by electrons that orbit in shells. As the charges of nuclei increase, electrons are pulled closer, and the shells become smaller.

Characteristics of Atoms:

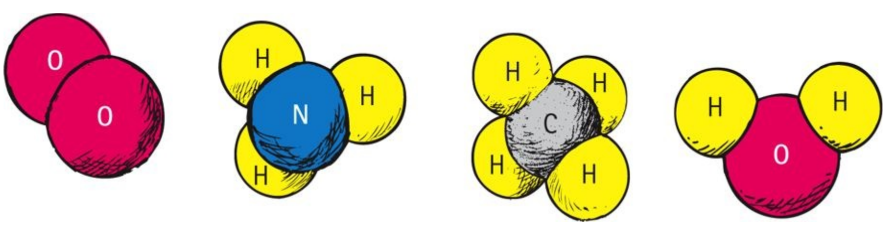
- **Atoms Are Incredibly Tiny**
- **Atoms Are Numerous**
- **Atoms Are Perpetually Moving**
- **Atoms Are Ageless**



Any element consists only of one kind of atom. Gold consists only of gold atoms, a flask of gaseous nitrogen consists only of nitrogen atoms, and the carbon of a graphite pencil is composed only of carbon atoms.



The periodic table of the elements. The number above the chemical symbol is the *atomic number,* and the number below is the *atomic mass* averaged by isotopic abundance in Earth's surface and expressed in atomic mass units (amu). Atomic masses for radioactive elements shown in parentheses are the whole number nearest the most stable isotope of that element. Most of the elements of the periodic table are found in interstellar gases.



Models of simple molecules: O_2, NH_3, CH_4, and H_2O. The atoms in a molecule are not just mixed together, but are joined in a well-defined way.

Chapter 31: Light Quanta

Quantum (*pl.* quanta) From the Latin word *quantus,* meaning "how much." A quantum is an elemental unit of a quantity, a discrete amount of something. One quantum of electromagnetic energy is called a photon.

Quantum physics The physics that describes the microworld, where many quantities are granular (in units called *quanta*), not continuous, and where particles of light *(photons)* and particles of matter (such as electrons) exhibit wave as well as particle properties.

Planck's constant A fundamental constant, *h*, that relates the energy of light quanta to their frequency:

- $h = 6.6 \times 10^{-34}$ J·s

Photoelectric effect The emission of electrons from a metal surface when light shines upon it.

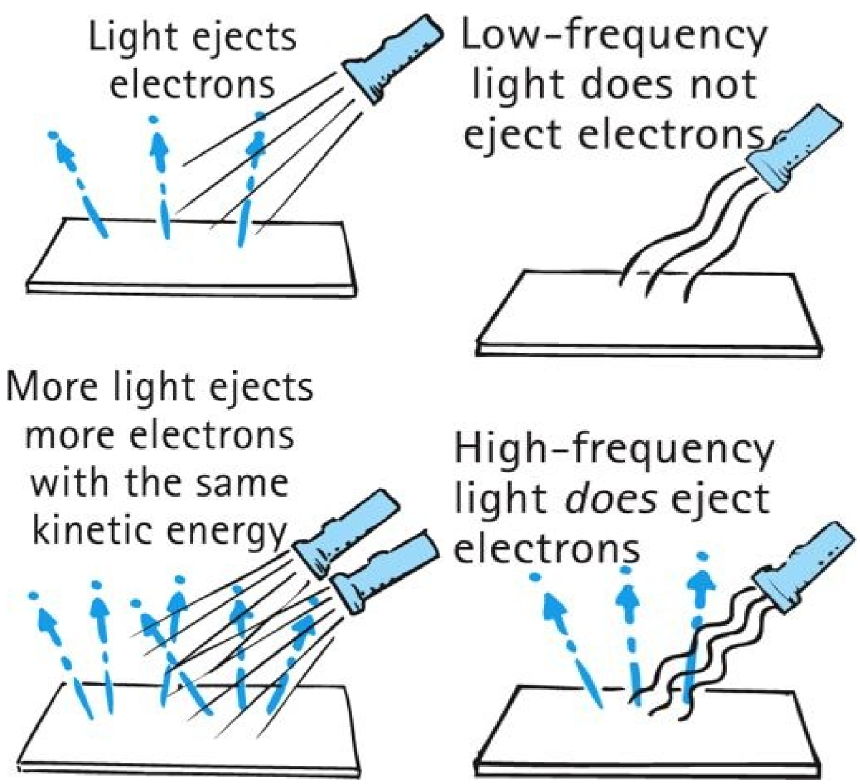
Uncertainty principle The principle, formulated by Werner Heisenberg, stating that Planck's constant, *h*, sets a limit on the accuracy of measurement. According to the uncertainty principle, it is not possible to measure exactly both the position and the momentum of a particle at the same time, nor the energy and the time during which the particle has that energy.

Complementarity The principle, enunciated by Niels Bohr, stating that the wave and particle aspects of both matter and radiation are necessary, complementary parts of the whole. Which part is emphasized depends on what experiment is conducted (i.e., on what question one puts to nature).

Light quanta, electrons, and other particles all behave as if they were lumps in some respects and waves in others.

Light travels as a wave and hits like a particle.

The number of photons in a light beam affects the brightness of the *whole beam,* whereas the frequency of the light controls the energy of each *individual photon.*



- a) The photoelectric effect depends on intensity.
- b) The photoelectric effect depends on frequency.

$$\text{Wavelength} = \frac{h}{\text{momentum}}$$

- where *h* is Planck's constant
  - $h = 6.6 \times 10^{-34}$ J·s

<u>Chapter 35: Special Theory of Relativity</u>

Frame of reference A vantage point (usually a set of coordinate axes) with respect to which position and motion may be described.

Postulates of the special theory of relativity

- (1) All laws of nature are the same in all uniformly moving frames of reference.
- (2) The speed of light in free space has the same measured value regardless of the motion of the source or the motion of the observer; that is, the speed of light is a constant.

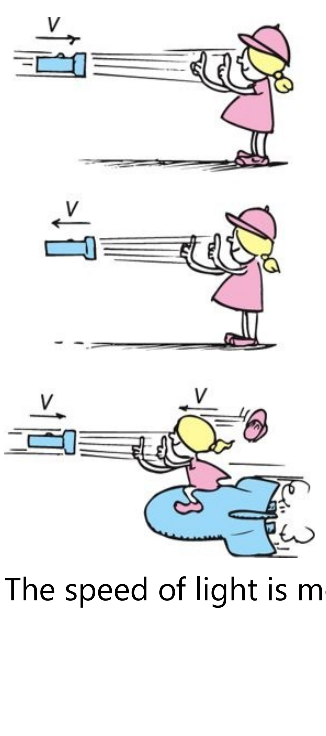
Simultaneity Occurring at the same time. Two events that are simultaneous in one frame of reference need not be simultaneous in a frame moving relative to the first frame.

Spacetime The four-dimensional continuum in which all events take place and all things exist: Three dimensions are the coordinates of space, and the fourth is time.

Time dilation The slowing of time as a result of speed.

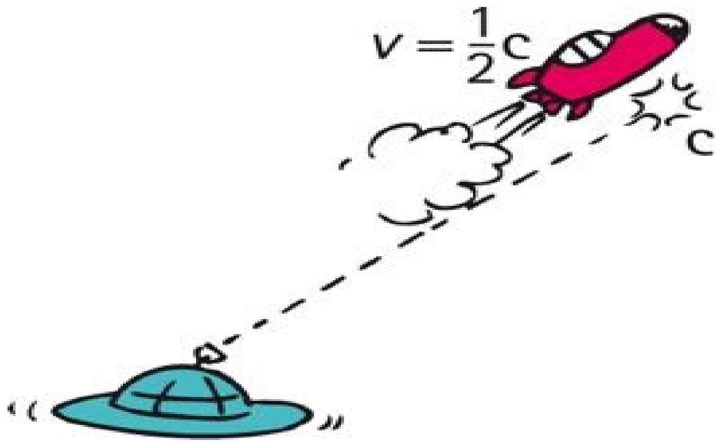
Length contraction The contraction of space in an observer's direction of motion as a result of speed.

All laws of nature are the same in all uniformly moving frames of reference.



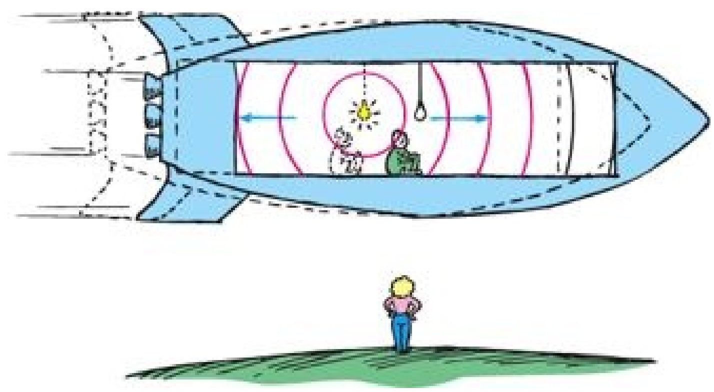
The speed of light is measured to be the same in all frames of reference.

The speed of light in free space has the same measured value for all observers, regardless of the motion of the source or the motion of the observer; that is, the speed of light is a constant.



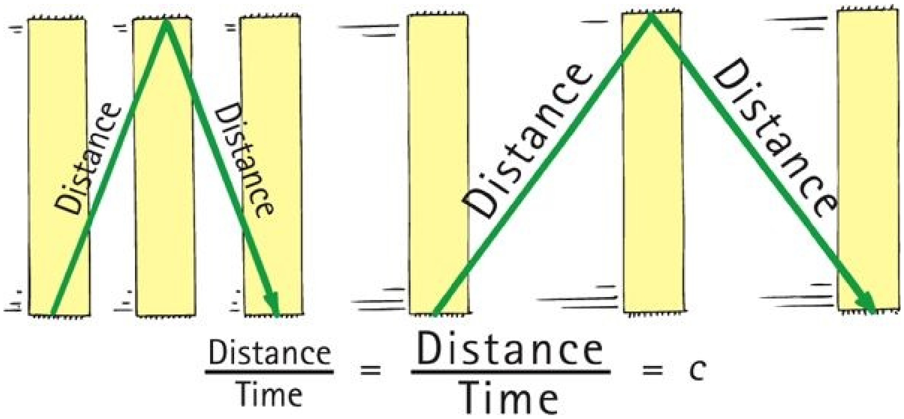
The speed of a light flash emitted by the space station is measured to be *c* by observers on both the space station and the rocket ship.

Two events that are simultaneous in one frame of reference need not be simultaneous in a frame moving relative to the first frame.



The events of light striking the front and back of the compartment are not simultaneous from the point of view of an observer in a different frame of reference. Because of the ship's motion, light that strikes the back of the compartment doesn't have as far to go and strikes sooner than light that strikes the front of the compartment.

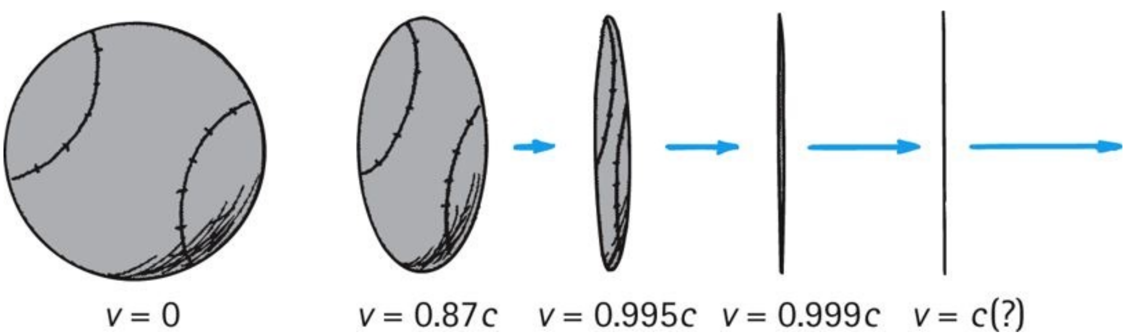
Time Dialation



The longer distance covered by the light flash in following the longer diagonal path on the right must be divided by a correspondingly longer time interval to yield an unvarying value for the speed of light.

Time dilation: Moving clocks run slowly.

Length contraction: Moving objects are shorter (in the direction of motion).



As speed increases, length in the direction of motion decreases. Lengths in the perpendicular direction do not change.

***E = mc*^2 says that energy and mass are related. Mass is congealed energy.**

Supplementary Material 1: Magnetoresistance

Magnetoresistance (MR)

- There is a relationship between magentism and electrical resistance.
- If the magnetic field points the same direction as an electric current in a magnetic material, resistance decreases.
- This effect is due to **electron scattering**.

Electron spin

- Electrons can have "up" spin or "down" spin.
- This results in tiny magnetic fields for each electron.

Giant Magnetoresistance (GMR)

- The effect of electron spin on electrical resistance at the interface between magnetic materials and nonmagnetic materials.
- Electrons with spins in different directions from those in magnetic materials get scattered more.

Comparison between MR and GMR

- MR and GMR causes change in current with changing external magnetic field.
- Both depend on electron scattering to make them work.
- GMR effect causes larger change in electrical resistance, but requires "sandwich" of magnetic and nonmagnetic materials.
- Both effects especially useful if external magnetic fields are very small.

Application: Hard disk drives

- Hard disk drives work by writing tiny magnetic "bits" to a rotating platter and reading them back.
- Original read heads used magnetic induction.
- As bits grew smaller, read heads began to use MR.
- Most recently, bits too small to detect using MR.
- GMR was the solution to read tiny bits of information.

Supplementary Material 2: Semiconductors

What is a Semiconductor?

- Behave sometimes as insulators and sometimes as conductors.
- Adding impurities can drastically alter the way these materials behave.
- Used to make transistors, which are widely used in modern electronics.
- Consist of a narrow band of chemical elements that appear on the right side of the Periodic Table, clustered together.

Silicon

- 14 protons and 14 neutrons in the nucleus.
- 14 electrons orbit outside the nucleus.
- Forming a crystal lattice:
    - Silicon atoms have four electronics in their outer-most shell.
    - They want to have eight.
    - Silicon atoms come together in a crystal to share their outermost electrons.
- The trouble with pure silicon:
    - Pure silicon (or any semiconductor) will not conduct electricity.
    - The electrons are all in their most comfortable positions.
    - The remedy: add impurities in small amounts.

Semiconductor Doping

- Adding impurities is called doping.
- Extra electrons are pushed into higher energy levels.
- This allows them to move.
- Moving electrons is electrical conduction.
- Doped material is therefore conducting.

MOSFET

- MOSFET = Metal-Oxide-Semiconductor Field Effect Transistor
- Positive voltage applied to gate and drain.
- Electrons attracted to gate more strongly than their own nuclei.
- Conduction channel created between source and drain.
- Any device that uses transistors likely use MOSFETS:
    - Computer memory and processors
    - Consumer electronics (radios, MP3 players, clocks, TVs)
    - Control systems for industrial processes