CHAPTER 5 - BASIC CLASSICAL (NEWTONIAN) PHYSICS.

Visual #5-1

Classical physics is distinguished from modern physics, which includes relativity and quantum mechanics. Relativity has to do with motion at velocities that are a significant fraction of the speed of light, and with the effects of strong gravity on time and perhaps space. Quantum mechanics has to do with events on the scale of atoms and smaller. These will be touched on briefly in later chapters.

Classical physics is concerned with the study of forces, motion, energy, waves, optics, acoustics, and similar topics that are capable of investigation without high-powered instruments such as particle accelerators and scanning tunneling electron microscopes. It is often called Newtonian physics, after Isaac Newton (1642-1727).

Visual #5-2

Though Newton was a devout Christian and wrote more on the subject of religion than on science, he is best known for his work in the development of classical physics. He was interested in gravity, motion, mathematics, optics, astronomy, and many other topics. Though he is considered perhaps the greatest scientist of all time, he did not believe in taking all the credit for his discoveries. He recognized that he owed much of his success to the groundwork that others such as Copernicus, Galileo, and Kepler had laid previously. He wrote in a 1675 letter to Robert Hooke that "if I have seen further [than others], it is by standing on the shoulders of giants."

Newton began his college training in 1661 at Trinity College, Cambridge, near London. When the bubonic plague spread outward from London in 1665, he moved to his family's property about sixty miles away. While there, he further developed his ideas. These included the discovery of the Law of Gravity and his three Laws of Motion. He is credited with inventing differential calculus. He also studied light, colors, vision, and many other topics.

> An apple did not fall on Newton's head, but in front of him. He wrote that he wondered what the force could be that attracted both the apple and the moon toward the center of the earth.

I. ENERGY.

Visual #5-3

The technical definition of energy is "the ability to do work," but the definition if work is the energy put into or taken out of an object by the application of a force through a distance. In practical terms, energy could be described as the ability to produce change. If something changes there had to be a transfer of energy; if nothing changes then no energy was used.

There are two major types of energy.

A. KINETIC ENERGY

Kinetic energy is energy due to motion. The motion may be at a visible scale such as the motion of a baseball or a planet, or it may be on a small scale such as the flow of electricity, the motion of molecules, or the motion of light.

B. POTENTIAL ENERGY.

Potential energy is energy of position. For instance, if an object is some distance above the earth's surface it has gravitational potential energy. If two magnets are held a certain distance apart they try to attract or repel each other. They have magnetic potential energy. If a spring is stretched, it has elastic potential energy, and so on

II. THERMODYNAMICS.

As the "thermo" part of the word implies, thermodynamics is the study of heat energy. However, since energy can be transformed from one form to another, thermodynamics is not limited to the study of heat.

Though nothing in science can be said to be absolutely proven, the two best-demonstrated laws in all of science have to do with thermodynamics. No exception has ever been observed in centuries of observation.

A. FIRST LAW OF THERMODYNAMICS (conservation of matter and energy).

Visual #5-4

The First Law has to do with the *quantity* of energy.

Energy can neither be created or destroyed. To put it another way, the total amount of energy in an isolated system (one not subject to outside influence), is constant. Energy can be converted from one form to another, e.g. heat to light, light to electricity, and even back and forth between matter and energy as described by the equation $e = m c^2$, but the total remains constant.

Closely related to this is the Law of Charge Conservation, which says that if we add up all the positive and negative charges in an isolated system, the total is constant.

B. SECOND LAW OF THERMODYNAMICS (the law of entropy).

The Second Law has to do with the *quality* of energy.

The Second Law is often expressed in terms of the *entropy* or randomness of a system. Unless forced to do otherwise, energy tends to flow from greater to lesser concentration. For example, unless some external influence makes them do otherwise, heat tends to flow from hot objects to cold ones, electric charges tend to spread out from a battery rather than assembling themselves in it, and the energy in a bomb tends to explode outward rather than coming together.

This does not mean that there never could be an instance where energy spontaneously became more concentrated in a local area for a very short time. (The next chapter will deal with conditions necessary for such an event to occur.) Though there would be a local decrease of entropy that area, the overall entropy of the universe would still increase.

The study of thermodynamics is particularly important in many areas relating to the origin of the universe, earth, and life.

Visual #5-5

- In cosmology: If there was a big bang, what could force the expanding cloud of gas and dust to reverse direction trillions of trillions of times to form stars?
- In chemistry: what would force energy to reverse its outward expansion to concentrate itself to form the nuclei of atoms an estimated 10^{80} or more times?
- In biology: what would force energy to concentrate itself to form the amino acids of the first living cell, then form progressively more organized RNA and DNA over millions of years?

III. HOW OBJECTS MOVE: KINEMATICS

The study of *how* objects move is called kinematics. The study of why they *change* their motion is called dynamics.

A. MOTION AND FRAME OF REFERENCE.

Visual #5-6

In classical physics, certain properties are intrinsic to matter. Mass is the quantity of matter in an object. Inertia is resistance to change in motion. It depends on the amount of mass.

Many other quantities are not innate characteristics. Think about this question: are you moving? Compared to your chair, probably not. But compared to an observer looking at you from a spacecraft orbiting the earth, definitely so.

Motion is a change of position. In order for us to describe position and therefore motion, we need to have a *frame of reference*. There are often many valid frames of reference for analyzing any particular motion. For instance, it would be equally valid to observe the runners in a race from the starting line, the finish line, halfway down the track, or just about anywhere you wanted.

Many measurements involve not just a magnitude but also a direction, also as compared to a frame of reference. These are called *vector* quantities. Some of them that are important at this point are velocity, acceleration, momentum, and angular momentum.

Visual #5-7

1. **Inertial reference frame.** Newton's Laws apply in an *inertial* reference frame, one that is not accelerating. For example, a ball sitting on a table would appear to stand still.
2. **Non-inertial reference frame.** Newton's First Law would not seem to apply in a *non-inertial* frame of reference, one that is accelerating. A ball left sitting on a table in a train accelerating toward the east would seem to accelerate toward the west of its own accord, when actually it was the frame of reference that was accelerating.

Acceleration is a change of either speed or direction or both. In most cases we consider our position on earth an inertial frame of reference, but it is actually accelerating a tiny amount. Since the earth has a circumference of about 25,000 miles, a person sitting in a beach chair on the equator moves that distance during each rotation of the earth, an average *speed* of over 1,000 miles per hour. Since the speed is constant, the person does not notice any change.

Meanwhile, the person's *direction* changes by 360 degrees over 24 hours. However, the acceleration is so tiny – 360 degrees in 24 hours, or about 4/1000 of a degree per second – that the person never notices it. Because the change of direction is so gradual, in most cases the surface of the earth can be used as a close approximation of an inertial frame of reference. On a merry-go-round, though, we would have to take the change into account.

Position is one of many quantities in physics that requires a frame of reference.

Visual #5-8

- What is your position? *Compared to what?*
- Velocity is a change of position over time. What is your velocity? *Compared to what?*
- Momentum is the product of mass times velocity. What is your momentum? *Compared to what?*
- Potential energy is energy of position. What is your potential energy? *Compared to what?* The formula for gravitational potential is $GPE = m\,g\,h$. If you are standing on a cliff you have zero GPE compared to it, but a great deal compared to the ground below.
- Kinetic energy is energy due to motion. What is your kinetic energy? *Compared to what?* The formula for kinetic energy is $KE = \frac{1}{2} m v^2$. If you are in a spaceship traveling 64,000 km/hr, you have zero kinetic energy compared to the ship but a great deal compared to the planet you are about to smash into.

Do you have mass/inertia? Yes. These do not require a frame of reference.

There are also other important conservation laws related to the conservation of energy that require a frame of reference. These will be dealt with after Newton's Third Law.

B. KINEMATIC EQUATIONS OF MOTION

Visual #5-9

One of the ways physics attempts to make sense of the world is by describing it in an orderly fashion. Each time we perform experiments on how objects move, we obtain data. After enough data is accumulated, we analyze it either with statistical analysis of perhaps graphing. Many times the data form shapes such as straight lines, curves, ellipses, or other sort of curve. In almost every case, we can find an equation that fits that shape.

The following experimentally determined equations describe one-dimensional (straight line) motion. They can easily be combined to describe two dimensional or three dimensional motion. *Note that sometimes x or s are used as variables instead of d.*

Visual #5-10

1. **First equation of motion.** Involves velocity, acceleration, and time. Given an initial velocity of v_0 , an acceleration a and a time t, an object's final velocity is given by $$\boldsymbol{v_f = v_0 + a\,t}$$
2. **Second equation of motion.** There are several variations, involving position, velocity, time, and possibly acceleration.
    - **a.** *(First variation.)* If there is *no acceleration*, given an initial position d_0, an initial velocity v_0, and a time t, the simplest way to find the object's final position d_f is $$\boldsymbol{d_f = d_0 + v_0\,t}.$$

b. *(Second variation.)* If there is *unknown acceleration* and the initial position d_0, initial velocity v_0, final velocity v_f and time t are known, the simplest way to find the object's final position is to find the average velocity and multiply it by the time. Since average velocity is $\left(\frac{v_0 + v_f}{2}\right)$, we can substitute this expression for v_0 in the previous equation. We obtain $\boldsymbol{d_f = d_0 + \frac{v_0 + v_f}{2}\, t}$.

c. *(Third variation.)* Suppose that there is a *known* acceleration or that we are trying to find the acceleration. If we start v_0 at zero in the first equation we obtain $v_f = a\, t$. The average velocity is therefore $\frac{v_f}{2}$. Since v_0 is zero and $v_f = a\, t$, we can substitute and obtain an average velocity of $\frac{a\, t}{2}$. Substituting this for in the equation above, we obtain $d = d_0 + \left(\frac{a\, t}{2}\right) t$. This is usually written

$$\boldsymbol{d_f = d_0 + \tfrac{1}{2} a\, t^2}\ .$$

d. *(Fourth variation.)* There is still one more variation on the second equation: if both the *initial velocity* and *acceleration* are known, it works out to

$$\boldsymbol{d_f = d_0 + v_0\, t + \tfrac{1}{2}\, a\, t^2}$$

3 **Third equation of motion.** The third equation of motion is the only one that does not mention time. It requires a few more steps to derive than the equations above.

To eliminate time as a variable, start with the first equation $v_f = v_0 + a\, t$. Rearrange to isolate t.

$$t = \frac{v_f - v_0}{a}$$

Substitute this for t in the fourth variation of the third equation above,

$$d_f = d_0 + v_0\, t + \tfrac{1}{2}\, a\, t^2$$

to get

$$d_f = d_0 + v_0 \frac{v_f - v_0}{a} + \tfrac{1}{2}\, a \left(\frac{v_f - v_0}{a}\right)^2$$

Rearranging, we get

$$d_f - d_0 = \frac{v_0(v_f - v_0)}{a} + \tfrac{1}{2}\, a \left(\frac{v_f - v_0}{a}\right)^2$$

Working out all the algebra, we get

$$d_f - d_0 = \frac{v_0(v_f) - v_0^2)}{a} + \tfrac{1}{2}\, a\, \frac{v_f^2 - 2 v_f v_0 + v_0^2}{a^2}$$

We can cancel out a/a^2 in the last term to get $1/a$.

Then, multiplying both sides by $2a$ to cancel out the $1/a$ and the 1/2, we get

$$2a\,(d_f - d_0) = 2v_0v_f - 2v_0^2 + v_f^2 - v_0v_f + v_0^2$$

Canceling out positive and negative terms, we get

$$2a\,(d_f - d_0) = v_f^2 - v_0^2$$

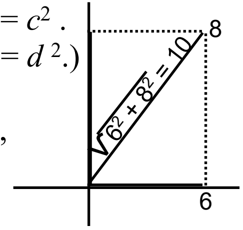
In the last step we rearrange to get v_f^2 by itself.

This gives the third equation of motion, $\boldsymbol{v_f^2 = v_0^2 + 2a\,(d_f - d_0)}$.

C. TWO DIMENSIONAL MOTION.

Visual
#5-11

Any problem involving two dimensional motion (along both the *x* and *y* axes) can be solved by separating the *x* dimension from the *y*, solving for each separately, then combining them by using the well-known Pythagorean Theorem, often written as $a^2 + b^2 = c^2$. (The Pythagorean Theorem also applies in three dimensions, $a^2 + b^2 + c^2 = d^2$.)



For example, suppose you find that the distance along the *x* axis is 6 units, and the distance along the *y* axis is 8 units. To get the total distance, use the Pythagorean Theorem. $c^2 = 6^2 + 8^2$. Thus, $c^2 = 36 + 64 = 100$. Taking the square root of 100, $c = 10$.

To find the direction, you would use a trigonometric function such as arctangent to obtain the angle formed by the values of 6 on the *x* axis and and 8 on the *y* axis.

IV. WHY OBJECTS CHANGE MOTION: DYNAMICS (FORCES AND MOTION).

The study of why motion *changes* is called **dynamics**. It has a great deal to do with forces.

Visual #5-12 A force is a push or pull. An *unbalanced* or *net* force is one that is not canceled out by an opposing force. A *balanced* force is one that is canceled out by a force equal in magnitude but opposite in direction. The balancing force may be either a push or a pull. For instance, if you hold an apple in your hand it experiences the force of gravity trying to pull it downward but it does not move because your hand pushes it up. While it was hanging from the tree, the balancing force was the upward pull from the stem.

Visual #5-13 Scientists presently believe there are four *fundamental forces*: gravity (always a pull), electromagnetism (may be either a pull or push), strong nuclear (always a pull) and weak nuclear (unclear, probably a push). The latter two will be dealt with in the chapter on chemistry.

The forces we deal with every day (except for gravity) are manifestations of the electromagnetic force. A *contact* force (friction in all its forms, buoyancy, the pull of a rope, your hand pushing an object, the impact of a collision, etc.) is transmitted through what seems to be direct contact. At the subatomic level, though, the atoms do not actually touch each other, though it feels like it to us.

A *field* force such as gravity or magnetism may go through seemingly empty space.

A. THE LAW OF GRAVITY.

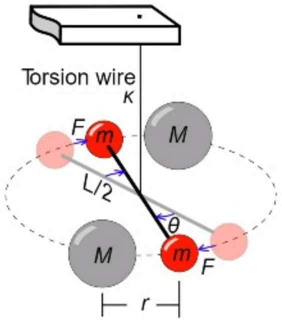
Though Kepler was able to derive the laws of planetary motion from his data, he did not know why the planets followed those laws. It was Newton who realized that there must be a force attracting any two objects to each other without there being any contact between them. He called the force gravity. The Law of Gravity is expressed in the equation

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

Visual #5-14 where F_g is the force of attraction between two objects, G is a gravitational constant that depends on the measuring system, m_1 and m_2 are the masses of the two objects, and d is the distance between their centers. The equation applies not just to large objects such as planets but to any two objects, even atoms.

As to why the force of gravity exists, we still do not know for sure, though there are several theories.

It is relatively easy to determine the value of G by using a device called a Cavendish Torsion Balance as shown at right. The device is placed inside a draft-free box. Two nonmagnetic balls (e.g., lead) of known mass are hung by a wire of known resistance to twisting (torsion). Two other larger balls fastened to the frame are brought closer until the two hanging balls begin to move. The balls need not be of very much mass to attract each other enough to cause a twisting force that makes them rotate around the torsion wire in the center. The amount of movement allows us to calculate G.



https://commons.wikimedia.org/wiki/File:Cavendish_Torsion_Balance_Diagram.svg. Released into public domain by Chris Burks (Chetvorno), via Wikimedia Commons

B. NEWTON'S LAWS OF MOTION

1. **Newton's First Law** is called the Law of Inertia. It says that objects resist changes in motion. That is, unless acted upon by an unbalanced force, an object in motion maintains its motion and an object at rest maintains its condition of rest. To put it another way,

   if there is **no** force   there is **no** change.

   Visual #5-15

2. **Newton's Second Law.** Acceleration is a change in an objects speed, direction, or both. Newton's Second Law says that objects experiencing an **unbalanced** force will accelerate in a manner directly proportional to the magnitude (size) of the force and inversely proportional to the mass. To put it another way,

   if there **is** a force   there **is** a change according to $f = m a$ where f is force, m is mass, and a is acceleration.

3. **Newton's Third Law** says that for every action (i.e., force) there is an equal and opposite reaction. The reaction to a push is a push, and the reaction to a pull is a pull. (This is not the same as a *balancing* force, which may be either a push or pull.)

For instance, if you are sitting in a chair you do not go floating away because the earth is pulling you down by gravity. The reaction is NOT your weight against the chair; instead, it is your pull right back on the earth. You are pulling the earth as hard as it is pulling you.

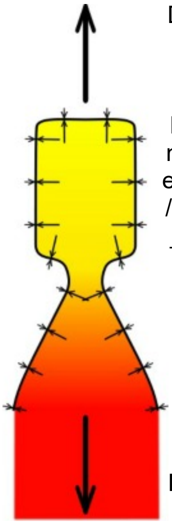
Why don't you fall? Any time there is no acceleration, it is because there is no net force. There has to be a second set of forces involved. You are being pulled down by the earth but you are pulling up an equal amount on the earth. Meanwhile, the chair is pushing up to prevent you from falling while you are pushing it down.

a. **How rockets fly.**

Visual #5-16

Some have the mistaken impression that rockets move because the burning fuel pushes on the atmosphere as it leaves the rocket engine. This is incorrect. As the fuel burns inside the engine, it tries to expand in all directions. However, it is surrounded by solid walls on all sides except at the exhaust nozzle. Everywhere else, the outward force is balanced by the inward force of the walls. The fuel escapes because the combustion inside the engine pushes it out of the nozzle. The escaping fuel exerts an opposing force inside the engine, not outside.

Because there is no air resistance in space, rockets actually fly better in a vacuum.



https://commons.wikimedia.org/wiki/File:Rocket_thrust.svg Placed in public domain by Wikimedia Commons user Hohum.

b. **How airplanes fly.**

Visual #5-17

The flight of an airplane is an example of three dimensional motion, but if we ignore its sideways motion we can consider just the forces in two dimensions.

i. *Horizontal motion.*

The burning fuel in the engines causes them to spin either a propeller or a turbine whose blades force air through at high speed. Either way, the air is pushed backward. The Third Law response is to push forward on the engine, causing it and the aircraft to accelerate forward. As long as there is a net force forward, there will be acceleration.

Air resistance depends largely on velocity. The faster the aircraft goes, the more air resistance it encounters. After a while, the forward thrust will be balanced by the drag due to air resistance. Since there is now a zero net force, there is zero acceleration (First Law). The plane does not stop; it merely stops accelerating and moves at constant velocity. This is similar to the way a skydiver reaches terminal velocity when the force of gravity is exactly balanced by the force of air resistance.

ii. *Vertical motion.*

Gravity constantly tries to pull the aircraft downward. However, the wings are designed with a curved upper edge that forces the air going over the top to flow much faster than the air underneath.

Since air molecules are in constant motion, they normally exert pressure in all directions. However, because the plane is rapidly moving in the horizontal direction, the molecules going over the top of the wing have to move so fast upward and horizontally to get over the curve that they do not have enough time to push downward as the wing goes past them. Meanwhile, the air under the wings is not moving as fast and exerts its normal pressure in all directions. This results in a net upward force from the air called the Magnus Force. (The process is also described as Bernoulli's Principle.) The lift force depends on velocity. When the aircraft is going fast enough, the lift force balances the force of gravity and the plane stays in the air.

The same principle allows you to throw a fastball in baseball or "bend it" in soccer. As the ball spins, the seams drag on the air to create high and low pressure regions.

c. Conservation of momentum.

Visual #5-18

Momentum is the product of mass times velocity ($p = m\ v$), so it has a specific direction. The Law of Conservation of Momentum says that the total amount of momentum within an isolated system (nothing enters or escapes) is constant. Momentum may be transferred between the parts of the system, for example, in collisions, but the total momentum remains constant. Put another way, momentum is neither created nor destroyed in an isolated system.

This principle has to do with Newton's second and third laws. An unbalanced force produces an acceleration, which is a change in speed or direction or both. In a collision, at least two objects apply forces to each other. Each exerts a force on the others but also experiences an equal and opposite force from the others.

How is momentum conserved when there is air resistance? Remember, this law has to do with a system from which nothing, not even energy, is allowed to escape. In reality, there is no such thing. Some kinetic energy always radiates into space in the form of heat (2nd Law of Thermodynamics). Except for the escaping heat energy, though. momentum is almost entirely conserved.

Before we even see anything happen, some of the air molecules have momentum in one direction, others in another. Momenta of some of the parts are already canceling out even before they collide with each other. Then, as the air molecules collide with the larger objects, they do not stop but still have momentum in various directions. When we add up the momenta of all the parts including the larger objects and the air molecules, it is still the same after the collisions as it was before.

d. Conservation of angular momentum.

Closely related to linear momentum is the phenomenon of angular momentum.

Visual #5-19

Just as a moving object has a certain amount of momentum in a particular frame of reference, a rotating object has a quantity called *angular* momentum. The simplest example would be a rigid body. Though there are several different formulas to calculate angular momentum, the easiest is probably $L = r\ m\ v$ where L is the angular momentum, m is the mass, and v is the velocity in the direction of motion.

Though it may not be as intuitively obvious as in linear motion, the equal and opposite aspect has to do with the size and rate of rotation. As the object increases in size, it decreases in its rate of rotation so as to keep the angular momentum constant. As it decreases in size, it rotates faster. (This is why a spinning figure skater rotates faster as she pulls her arms in.)

- *Earth-moon system.*

  The earth-moon system is not a rigid object. The mass of the moon is a significant percentage of the mass of the earth. As the moon orbits us, the earth-moon system wobbles around its center of mass. The moon exerts a gravitational pull on the oceans, causing tides. The tides exert a pull on the moon. As a result, the moon is slowing down a tiny bit each year. Meanwhile, the earth also slows down a tiny bit. To conserve angular momentum, the moon is gradually spiraling away. There is no need to worry, because the rate is only about 4 centimeters a year. We know this because, despite the claims of those who say we never landed on the moon, astronauts left shiny objects that lasers reflect back from. This allows us to measure the distance.

In keeping with the conservation of angular momentum, the change of distance is inversely proportional to the change of velocity. The total energy of the system remains constant. As the earth and moon slow down, their reduced kinetic energy is converted to increased gravitational potential energy as the distance increases.

The conservation of angular momentum has important implications for the age of the earth-moon system. Because the moon would have been closer in the past, it would have experienced an even greater retarding force from the oceans. Assuming that the rate of change was not less in the past than it is at present, the moon would have been scraping the earth's surface less than 1.5 billion years ago. This is billions of years less than the supposed age of the earth.

- *Gyroscopes.* Conservation of angular momentum also explains why a gyroscope does not fall over while it is spinning.

  Angular momentum has a direction, which can be found using the *right hand rule*. Imagine wrapping the fingers of your right hand around the object in its direction of rotation. The direcion your thumb points is the direction of the angular momentum. The fact that angular momentum is conserved implies that the direction of the axis of rotation will not change unless acted upon by an outside force. Thus, the gyroscope stays upright until it slows down enough for gravity to force it to change direction.

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- *Bicycles.* Conservation of angular momentum also explains why it is easier to maintain your balance on a fast-moving bicycle with rapidly spinning wheels than on a slow one. The faster they spin, the harder it is to change the direction of angular momentum.

Newton's Laws and the conservation laws work in conjunction with the equations of kinematics to allow us to predict the motion of any object under the conditions of classical physics.

WHY ARISTOTLE WAS WRONG ABOUT FALLING OBJECTS.

Visual #5-20 The Law of Gravity and Newton's Second Law show why Aristotle was wrong when he said that heavier objects always fall faster. It is true that there gravity tries to accelerate any object in accordance with $F_g = \frac{G\,m_1\,m_2}{d^2}$ where m_1 is the mass of the object in question. Working against this is the fact that an object with more mass has more inertia, making it harder to accelerate in accordance with $f = m\,a$. Whether heavy or light, the object's mass cancels out in the two equations. The acceleration due to gravity depends on the earth, not the object.

Aristotle drew a wrong conclusion because he did not take air resistance into account. In a famous experiment done during the Apollo 15 moon mission, a feather and a hammer were dropped at the same time on the moon. Since there was no air resistance, they both fell at the same rate. (See https://www.youtube.com/watch? v=Oo8TaPVsn9Y)

C. IF GRAVITY IS EVERYWHERE, WHY DO YOU FEEL WEIGHTLESS IN SPACE?

Despite what you see in movies, gravity does not end once you leave the earth. If it did, the earth would leave its orbit around the sun, and the moon would go flying off into space.

Visual #5-21

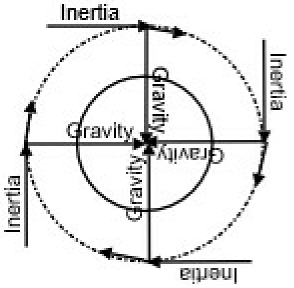
When you are on the surface of the earth, you are about 6400 km from its center. When astronauts are in orbit 300 km up, they are about 6700 km from the center. Since gravitational force depends on the square of the distance, the ratio of the gravitational pull in orbit compared to on the surface is about $6400^2 / 6700^2$, or 40,960,000 / 44,890,000, or 91.2 %. If you weighed 150 lbs on the surface, you would still weigh about 137 pounds in orbit.

Under normal circumstances, do you feel the earth pulling you down? No, most of what you feel is the push from whatever is holding you up. If the floor were suddenly removed you would start to fall. Many who have gone skydiving say there is no feeling of falling. Instead, they *feel* weightless, as you would if the floor disappeared.

The reason astronauts feel weightless is that they are continually falling toward the earth along with their spacecraft. There is a constant interaction between inertia (resistance to force) and the force of gravity. Inertia tries to keep them going in a straight line, but gravity tries to pull them down to the earth. As result, their direction constantly changes. They stay in orbit until some unbalanced force makes them speed up to go into space or slow down to come back to the earth.

D. FICTITIOUS FORCES.

1. "Centrifugal force."



Visual #5-22

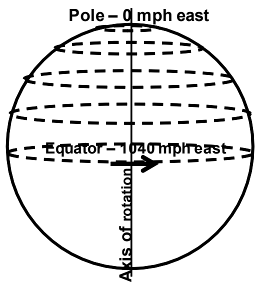
When you are spinning on a merry-go-round, it feels like a force is trying to throw you off. The apparent force, commonly called "centrifugal force," does not actually exist. Your inertia is trying to keep you moving in a straight line, but a *centripetal* (center-seeking) force such as the pull of a restraining bar or friction with your seat pulls you toward the center. What you are feeling is the centripetal force, not centrifugal force. If such a force really existed, it would try to push you straight out from the center rather than in a straight line forward.

David's stone killed Goliath (1 Sam. 17) by inertia, not centrifugal force. He placed it in a pouch attached to two strings, then swung the pouch in a circle. When he released one of the strings the stone went forward, not outward from the circle.

2. "Coriolis force."

Visual #5-23

Countless factors are involved in producing the weather. One of them that operates on a large scale is known as the Coriolis Effect, named for French scientist Gaspard-Gustave de Coriolis. It says that large weather systems such as hurricanes tend to rotate clockwise in the northern hemisphere, those in the southern hemisphere counterclockwise.



Because the circumference of the earth at the equator is about 25,000 miles and it rotates every 24 hours, objects at the equator are moving at about 1040 miles per hour toward the east. However, the circumference is less and less as we move away from the equator, so the speed of the surface becomes less and less as we move north or south. Since the circumference at the poles becomes zero, the speed of eastward motion is also zero.

On a calm day, air at the equator is moving *eastward* at about 1040 miles per hour. As it spreads out toward the *north* or *south*, the earth under it is not moving as fast. The air's inertia tries to make it keep moving east at that speed, but the ground is moving slower. From the frame of reference of observers on the ground, it looks like the air is curving toward the east as it moves north. If we were to look at the earth from the frame of reference of the air currents, though, it would look like the earth's surface at northern and southern latitudes was slowing down instead.

The Coriolis Effect is real, but there is no such thing as a coriolis force.

A common misconception related to the Coriolis Effect is that toilets and drains in the southern hemisphere swirl the opposite direction from those in the northern. This is not true. The Coriolis Effect operates on large masses of air and water as they move hundreds or thousands of miles away from the equator. The water in your toilet does not go away from the equator either north or south.

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V. WAVES.

Many physical objects such as water and air molecules move in waves. They transmit energy while the particles vary predictably in position and intensity of motion, but the particles almost never travel all the way from the source of the energy to the receiving end.

Scientists also use wave concepts to describe the behavior of subatomic particles too small to be seen and determine the distances of stars and the possible presence of planets outside the solar system. Since these last two items have to do with the age of the universe and the origin of life, it is useful for Christians to have some knowledge about whether current ideas about waves are reasonable or instead contradict God's Word.

There are two main types of waves, mechanical and electromagnetic. (A third concept, matter waves, is used to describe the dual wave/particle nature of matter and energy.)

Mechanical waves include sound, water waves, seismic waves, and the like. These all require some sort of medium to transmit energy. Sound, for instance, travels to you as a result of molecules bumping into one another from the source to your ear. The speed of the wave depends on the medium, which can be solid, liquid, or gaseous. Generally, the denser the medium, the faster the wave travels through it.

A. MECHANICAL WAVES.

Mechanical waves can be either longitudinal (compressional) or transverse.

1. Longitudinal waves.

Sound is an excellent example of a longitudinal wave.

Visual #5-24

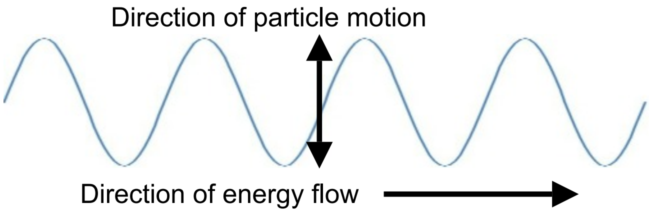
Though sound radiates out from a source in all directions, we usually deal with only one direction at a time. The particles of the medium move back and forth in straight lines while traveling from the source, somewhat like a child's spring toy. The places where the particles bunch up are called *compressions*, and the places where they spread out are called *rarefactions*. For convenience, the wave is usually represented on a line graph.

Dark areas represent compressions, light are rarefactions.

A sound wave would be represented on a graph like this.

Even if the source and the receiver are far apart, the particles do not need to go very far in order to transmit the sound energy. For instance, when a loudspeaker vibrates, the air molecules nearby only move a tiny bit before they hit other air molecules which in turn hit other air molecules, and so on until the sound energy reaches your ear. Unless they are moved by the wind, the molecules end up very close to the same place they started from.

2. **Transverse waves.**
   In transverse waves, the particles move perpendicular to the direction in which the energy propagates. If you hold the end of a rope while shaking it up and down, you form waves perpendicular to the rope. Even though the rope does not leave your hand, energy is transmitted down its length.



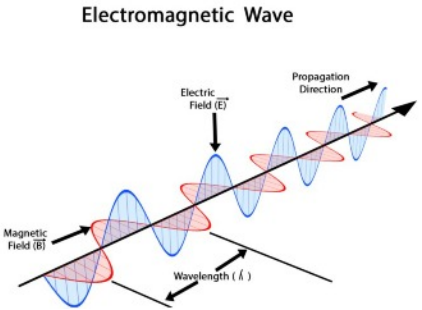
3. **Water waves.**
   Waves on the surface of a body of water are usually follow a combination of longitudinal and transverse motion. The water molecules go up and down and also left to right, following a circular or elliptical path. They only travel more than a short distance if a strong wind pushes them.

B. ELECTROMAGNETIC WAVES.

Electromagnetic waves include light, radio, X-rays, gamma rays, and so on. None of these are known to requires a medium in order to travel through seemingly empty space. Nevertheless, their speed is reduced when they go through a denser medium. The speed of light in a vacuum is about 3.00 x 10^8 m/s; in water it is about 2.25 x 10^8; in a diamond about 1.25 x 10^8.

An important difference between mechanical and electromagnetic waves is that in the former, we can physically observe the particles moving in specific directions. In the latter, there are no moving particles of matter.

Visual #5-25 Graphs make it easier to grasp difficult concepts. An electromagnetic wave as shown at right is not a physical object you can look at under even the most powerful microscope, but a representation of a wave equation. Electromagnetic waves are actually three dimensional waves in which the electric and magnetic fields are said to be perpendicular to each other, though we cannot physically identify the direction toward which each field points. We usually graph electromagnetic waves according to their maximum and minimum intensity. Since they are three dimensional, we really should use all three axes (*x*, *y*, and *z)* of the Cartesian system.



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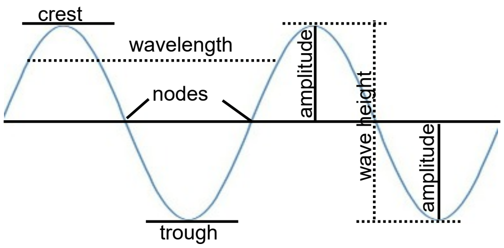
C. CHARACTERISTICS OF WAVES.

We usually use line graphs to represent both compressional and longitudinal waves. The graph has a wave repeatedly going above and below a center line.

1. Parts of a wave.

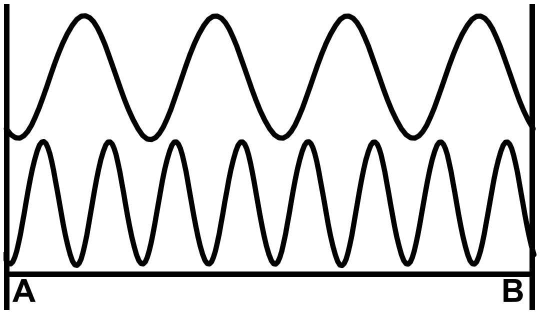
Visual #5-26
- The highest point on the wave is called the *crest*. The lowest is called the *trough*.
- The places where it crosses the center line are called *nodes*.
- The distance from the center line to either the crest or trough is called the *amplitude*.
- The distance from the crest to the trough



is called the *wave height*. This is twice the amplitude.

- The distance from any point on a wave to the corresponding point on the next wave is the *wavelength*.

Shown are graphs of two waves. Suppose points A and B represent a distance of 1 cm. Since the upper wave repeats 4 times in that distance, its *wavelength* is about ¼ cm. Since the lower one repeats 8 times, it has a wavelength of about 1/8 cm.



Suppose instead that the distance between points A and B represents a time of 1 second. The measure of how frequently a wave repeats is its *frequency*, usually given in a unit called the Hertz (Hz). Since the upper wave repeats four times per second, it has a frequency of 4 Hz. The frequency of the lower one is 8 Hz.

The frequency of a wave is often represented by the Greek letter ν (*nu*), which looks like the English letter v. Wavelength is usually represented by the Greek letter λ (*lambda*).

Wavelength and frequency are inversely proportional. When multiplied together, frequency times the wavelength equals the speed of the wave. ($\nu \lambda$ = speed)

2. **Speed of a wave.**

The speed of a wave depends on the medium. A mechanical wave travels faster in a denser medium. For instance, sound travels much faster in solids than in liquids or gases. However, the temperature of the medium has an opposite effect. Though the molecules are more spread out in warm air than in cold, sound travels much faster in warm air because the molecules are already vibrating much faster.

The speed of electromagnetic waves goes the opposite direction. As it moves from a less dense to a denser medium, e.g., from air to water, light slows down. Its speed in air is about 3.0×10^8 m/s, but in water about 2.25×10^8.

(Light travels over 900,000 times faster than sound.)

3. **Behavior when moving around or through a barrier or from one medium to another.**

When a wave goes through or around a barrier or crosses the boundary between one medium and another, its behavior changes.

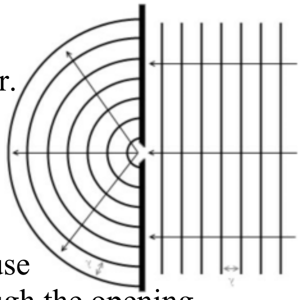
***a. Reflection*.**

Visual #5-27

- The wave hits the boundary at an angle of incidence and bounces off at an angle of reflection with the same angle measure. Reflection may be partial or complete.
- Everything we see is because of light waves reflecting off of objects and into our eyes.
- Telescope mirrors and satellite dishes rely on the fact that if waves reflect off a curved surface, they will focus on a single point (the focal point).

b. Diffraction.

Diffraction occurs when a wave goes through an opening or around a barrier. If mechanical waves were not diffracted, you would only be able to hear sound traveling in a straight line. You do not have to stand in a doorway to hear sounds from the next room because they are diffracted when they go through the opening.



Diffraction through a slit.
https://commons.wikimedia.org/wiki/File:Difraction.png
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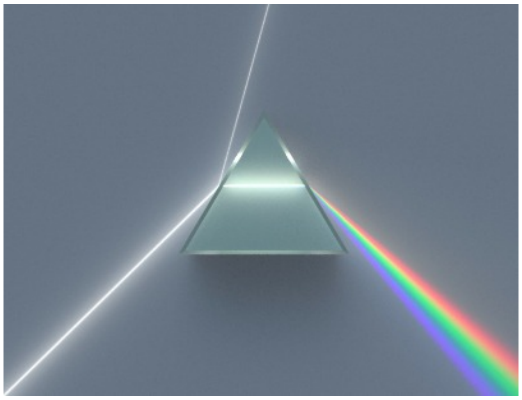
Longer waves are diffracted more than shorter ones. You can easily hear bass notes in the next room, but high pitched sounds do not reach you as easily.

c. Refraction.

Light bends when it goes from air into water, due to a process called *refraction*.

A wave has a certain amount of energy. It can be broken down into several waves which add up to the same total amount of energy as the original wave. For instance,



Refraction by a prism. https://commons.wikimedia.org/wiki/File:Dispersive_Prism_Illustration.jpg Attribution: Dispersive_Prism_Illustration_by_Spigget.jpg: Spiggetderivative work: Cepheiden, CC BY-SA 3.0 <https://creativecommons.org/licenses/by-sa/3.0>, via Wikimedia Commons

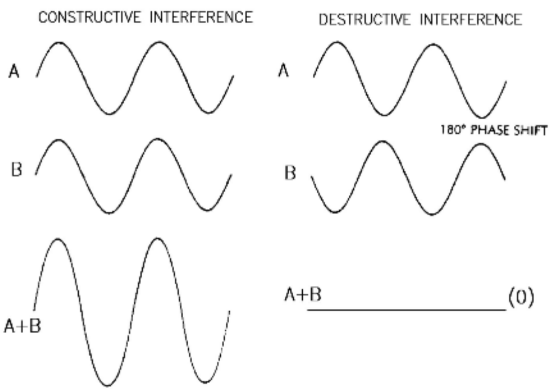
white light can be refracted into its component colors by using a prism. Each of the colors that make up white light (ROY G BIV) has a different frequency/ wavelength. The frequency of each color is determined by the source that emitted it, not the medium.

As noted above, frequency times wavelength = the speed of light. The speed of each component is reduced as it goes from the air into the glass, but the frequency is unchanged. This automatically makes the wavelength of each component decrease by a different amount, causing them to bend different amounts. Longer wavelengths (red) bend the least, violet the most. The result is a rainbow.

- *Why are there rainbows?* A rainbow in the sky results because countless water droplets each act as prisms and diffract the sunlight.
- *Why is the sky blue?* Our atmosphere is mainly made of nitrogen and oxygen. As the light from the sun goes through it, the colors with shorter wavelengths and higher energy (the blue end of the spectrum) make the air molecules vibrate faster and are thus scattered more. The sky looks blue to us even though there is more diffracted violet because our eyes are more sensitive to blue.

  The sky looks redder in the morning and evening because the blue and violet colors are bent the most, while the red can come to us in a more direct path. Much of the blue color is scattered below the horizon where we can’t see it. Later in the day, though, all the colors are able to come to us in a straight path.

4. Constructive and destructive interference.



a. Constructive.

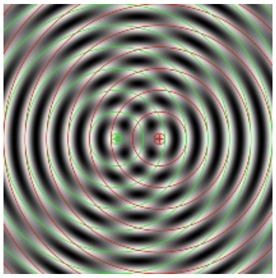
Visual #5-28 When two sound waves are *in phase* with each other, that is, the compressions of the two coincide, the two waves add together and produce a higher amplitude. This is called constructive interference.

b. Destructive.

When two sound waves are *out of phase* with each other, that is, the compression of one coincides with the rarefaction of another, they partially or completely cancel each other out. This is called *destructive interference*. It is most noticeable when two speakers producing the same sound, especially at low frequencies, are out of phase.

c. ***Interference patterns.***

The wavelength of electromagnetic radiation is so short that it is very unlikely for two waves to be exactly in or out of phase. They will probably not cancel each out completely but may produce an interference pattern of dark and light bands with varying intensity. This phenomenon is used to detect extremely small amounts of motion in astronomy and physics.



Interference pattern.
Image credit: Dr. Schorsch 12:32, 19 Apr 2005 (UTC) (Dr. Schorsch (talk)), CC BY-SA 3.0
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D. THE ELECTROMAGNETIC SPECTRUM.

Light, X-rays, gamma rays, infrared, ultraviolet and so on are all part of the *electromagnetic spectrum*. The spectrum is broken down according to wavelength/ frequency. Since for all waves, frequency x wavelength = speed of the wave, for all electromagnetic waves frequency x wavelength = *c*, the speed of light. This is usually represented by $\nu \lambda = \mathbf{c}$.

Frequency and wavelength are inversely proportional to each other and are related to energy level. Imagine what would happen if you fasten one end of a rope to a wall and shake the other end up and down. Shaking the rope slowly (low frequency) would not require much energy and would produce long waves. Shaking it rapidly (high frequency) would require more energy and would produce shorter waves. That is, low frequency = long wavelength = low energy, and high frequency = short wavelength = high energy.

Visual
#5-29

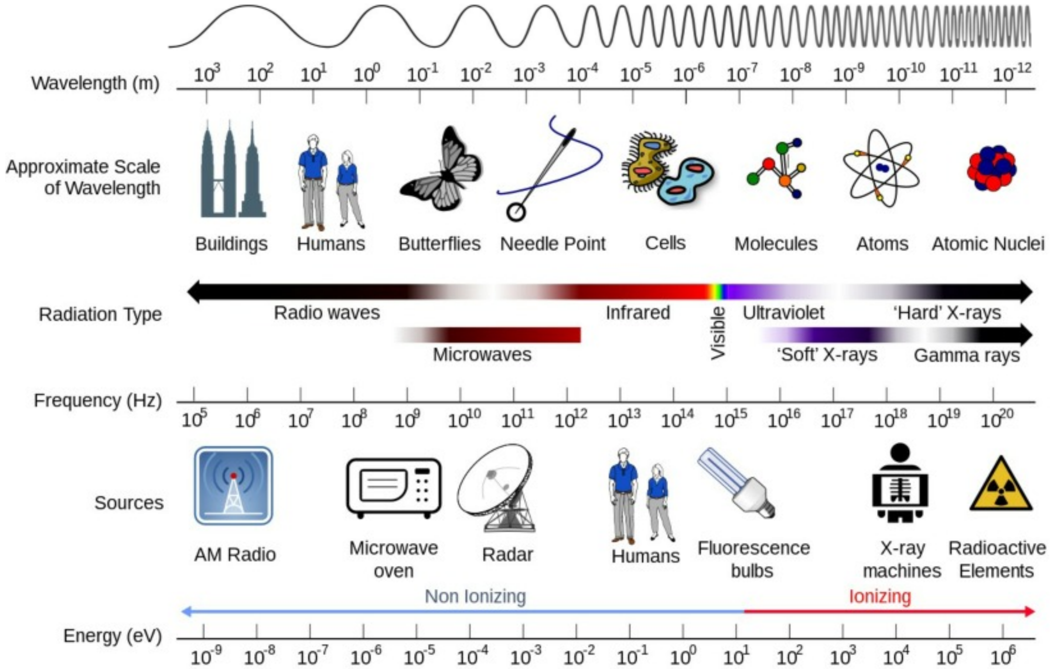

Image credit: WIKIMEdia User DrSciComm
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- ***Lowest energy.***

  As seen in the chart above, radio waves have the lowest frequency and longest wavelength, and thus lowest energy. The distance from one crest or trough to the next can be thousands of meters.

- ***Visible light.***
  Visible light makes up a tiny portion of the middle of the spectrum. Our eyes are only able to detect wavelengths from about 380 nanometers (extreme violet, almost ultraviolet) to 700 nm (extreme red, almost infrared), with frequencies close to 10^{15} Hz. Shorter or longer wavelengths go right through our retinas without registering signals to be sent to our brains.

  Science teachers often use the name of an imaginary friend ROY G. BIV to help students remember the seven main visible colors. From long to short wavelength (low to high energy) they are Red, Orange, Yellow, Green, Blue, Indigo, and Violet, the colors of the rainbow.

  > Some animals seem to be able to detect colors beyond those which humans can. Certain insects and birds seem to be able to see ultraviolet wavelengths. On the opposite end of the visible spectrum, some types of insects, reptiles, and bats seem to be able to see in the infrared range.

- ***Highest energy.***
  On the high end of the spectrum are gamma waves, with wavelengths of picometers (10^{-12} m) or shorter and frequencies of 10^{19} Hz or higher. Gamma rays are extremely dangerous because their high energy can rapidly damage living tissue. X-rays have slightly less energy, but are still dangerous.

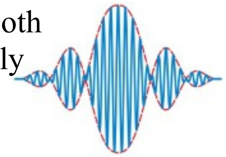
E. WAVE-PARTICLE DUALITY.

Visual #5-30

1. Electromagnetic radiation.

Electromagnetic radiation such as light does not require a physical medium to travel. Because it is able to move through seemingly empty space, it acts like a particle. However, it can also be refracted and diffracted, which are typically characteristics of waves. So, is light a particle, or is it a wave? The answer is YES. It is a particle or a wave. Depending on the type of experiments we do, light behaves as either. This is called the wave-particle duality.

Light is often treated as a particle called a *photon*. Since it has both wave and particle characteristics, though, it is sometimes humorously called a "wavicle," a packet of waves that travel as a unified group.



2. Subatomic particles.

Matter at the subatomic level can also act as either a particle or a wave depending on the type of experiment done. For instance, when an electron travels through a wire to light a flashlight bulb in a DC circuit, it acts like a particle. But when an electron is inside an atom or when a beam of electrons goes through a narrow slit, it acts like a wave.

3. Matter waves.

With the development of quantum mechanics from the early 1900s onward, scientists realized more and more that subatomic particles sometimes behave as much like waves as they do particles. In 1924 the French physicist Louis de Broglie realized that all material objects, no matter how large, have wave characteristics. Though the wavelengths become shorter as the objects get larger, all matter can be expressed in terms of waves.

Hebrews 11:3 hints at this conclusion when it says,

> "Through faith we understand that the worlds were framed by the word of God, so that things which are seen were not made of things which do appear."

Neils Bohr, one of the early developers of quantum theory is widely quoted as saying,

> “If quantum mechanics hasn’t profoundly shocked you, you haven’t understood it yet. Everything we call real is made of things that cannot be regarded as real.”

Material objects which can be seen are actually composed of waves, which cannot.

F. HUMAN PERCEPTION OF WAVES.

1. Sound.

Visual #5-31

A sound wave with a short wavelength (high frequency) seems high pitched to us and one with a longer wavelength (lower frequency) sounds lower. There is a difference between pitch and frequency, though. High or low *pitch* is a matter of opinion, whereas *frequency* or *wavelength* can be directly measured with the appropriate equipment.

Likewise, a sound with a high amplitude sounds louder to us, whereas one with a lower amplitude sounds softer. Loudness is a matter of opinion, but amplitude relates to a measurable quantity called sound pressure level.

2. Light.

The color of light depends on its wavelength, which is the same for all observers. However, favorite color is a matter of opinion.

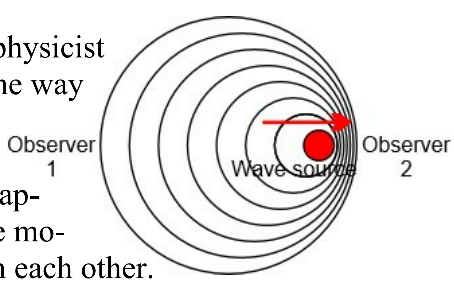
The brightness we perceive for a light is also a matter of opinion. Intensity is proportional to the square of the amplitude of the wave and can be directly measured by a light meter. Though brightness is related to intensity, brightness is not a measurable quantity. Whether a light is too bright or too dim is a matter of opinion.

If a tree falls in the forest the air molecules would still move. There would still be sound.

G. THE DOPPLER EFFECT.

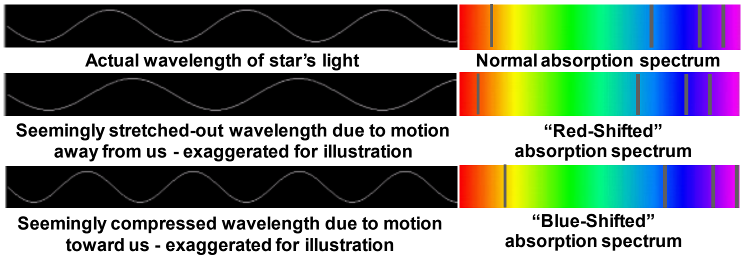
Visual #5-32

The Doppler effect was first described by the Austrian physicist Christian Doppler in 1842. A good example would be the way a passenger on a railroad train hears the bell at a crossing seem to make a higher-pitched sound as the train approaches and a lower-pitched sound as it leaves. The apparent shift in wavelength occurs because of the relative motion of the source and the observer toward or away from each other.



The phenomenon applies not only to sound but also to light and all other forms of electromagnetic radiation. Meteorologists use it in Doppler radar to to determine how the clouds are moving. Scientists interpret a shift of the light from a star toward the red (long wave) end of the spectrum to mean that it is moving away from us, and a blue shift to indicate that it is moving toward us.

The Doppler effect is widely used to calculate the distance and motion of heavenly bodies that are too far away to directly measure. Parallax only enables us to calculate stellar distances of less than about 100 light years away. For more distant objects, astronomers use a cosmic distance ladder that involves a number of assumptions. One of these is that the shifting toward the red end of the spectrum of the light from extremely distant galaxies and quasars is the result only of the Doppler effect. If any of the assumptions is wrong, the calculated distances may be unreliable.



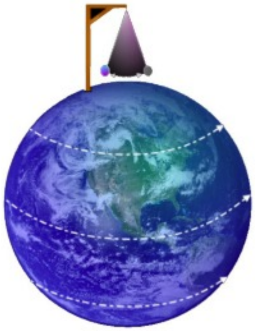
H. PENDULUMS (PENDULA)

Visual #5-33

A pendulum is a weight (a *bob*) suspended by a string or rod of low enough mass that it can be ignored in calculations. As the pendulum swings back and forth, its path follows an arc, which is part of a circle. That's why π (pi) is part of its equation.

On each swing, the pendulum starts with momentum in a particular direction. In accordance with Newton's first law, it tries to keep going. However, gravity pulls down on it. In accordance with Newton's second law, it slows down, stops, and reverses direction over and over. Its motion is described by the equation $t = 2\pi\sqrt{\frac{l}{g}}$ where t is the period, l is the length of the pendulum, and g is the acceleration of gravity. With careful enough measurements, a pendulum can easily be used to calculate the acceleration of gravity at any particular location, for instance, another planet.

A variation called a Foucault Pendulum enables us to actually observe the rotation of the earth. If we set up a very long wire or rope (20 meters or so) with a heavy bob (20 kg or more) and start it swinging, it will gradually change its direction. If it were at the north or south pole it would take 24 hours for the bob to swing all the way around a circle. However, the period is not 24 hours when we move away from the pole. The closer the device is to the equator, the longer it takes for the bob to go all the way around.


Foucault Pendulum at the North Pole. https://commons.wikimedia.org/wiki/File:Foucault_pendulum_at_north_pole_accurate.PNG Attribution: en:User:Krallja, CC BY-SA 3.0 <http://creativecommons.org/licenses/by-sa/3.0/>, via Wikimedia Commons

The mathematics of a Foucault Pendulum are complicated because they must take into account the fact that the earth is not a truly inertial frame of reference. While it usually escapes our notice, an object on the surface continually changes direction because of the earth's rotation and its orbit around the sun. A long, heavy Foucault Pendulum is sensitive enough to the acceleration in several directions to show a visible result.

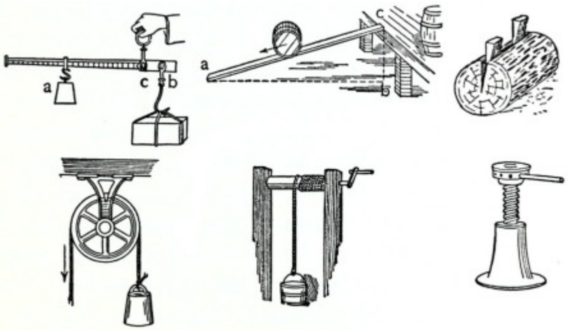
J. SIMPLE MACHINES.

Visual #5-34

When you move an object to a higher or lower elevation you put in or take out gravitational potential energy. Likewise, when you accelerate or decelerate the object you put in or take out kinetic energy. The energy added or removed is called work. Since work is just a change of energy, it is also measured in joules.

Since ancient times, humans have realized that they can do work more easily by using simple human-powered machines. The basic types of simple machines are:

1. A lever.
2. An inclined plane.
3. A wedge, which is an inclined plane with two sloping sides that come together to a narrow edge.
4. A pulley, which is a wheel and axle with a rope going around it.
5. A wheel and axle, which is a lever that can rotate all the way around a circle.
6. A screw, which is an inclined plane wrapped around a center post.



https://commons.wikimedia.org/wiki/File:Simple_Machines.png
1919 Public domain image by John Mills, via Wikimedia Commons.

Other devices such as gears are variations of these basic types.

In a simple machine, we put in an *effort* force that overcomes a *resistance* force. The machine (e.g., a lever) may put out more force than we put in, but it does NOT put out more energy than we put in. To compensate for the greater force output, we have to put in more distance. The end of a long lever has to move a greater distance to put out more force, The equation for work is $W = f\,d$, and the equation for power is $P = f\,d\,/\,t$. The reason a simple machine makes our work easier is that it allows us to spread our work over a longer distance and time. The total *energy* we have to put into the machine may even be greater than the work output because of friction, but the *power* we have to put in is less.

Simple machines can be combined into compound machines such as a block and tackle made of a rope going around multiple pulleys. The rope has to be pulled much farther, but the output force is much greater than the input force. No extra energy is created. We just spread the work out over a longer time and thereby reduce the power we have to put out..

VI. ELECTRICITY

Though electrons have a dual wave-particle nature, when it comes to electricity they act mainly like particles.

There are two main types of electricity.

A. STATIC ELECTRICITY.

Visual #5-35

Electrons flow easily through materials known as *conductors*, such as metals. Conductors have a low resistance to electric flow. *Insulators*, on the other hand, have a high resistance.

Static electricity occurs when a large number of electrons are trapped together on an insulating surface. This produces a negative charge on the surface. In response, electrons are pushed away from nearby objects, producing a positive charge on those objects in a process called *induction*.

You can observe this phenomenon if you rub a balloon against your hair on a dry day. If you then touch the balloon to a non-conductive wall, it will likely stick to it. (This does not work very well on a humid day because the moisture in the air allows the electrons to dissipate rapidly.)

> Ben Franklin was the first one to use the term “negative” regarding electricity, but no one knows why electrons and protons have opposite charges. They just do.

1. Lightning.

Electrons repel each other. If the negative charge is large enough, they can overcome the resistance of the insulator and produce a discharge, either through it or through the surrounding air. This is what happens in lightning.

- The most common type of lightning is cloud to cloud, in which the distribution of the electrons in the clouds evens out. This is sometimes referred to as “heat lightning.”
- The lightning we notice most often occurs when an extremely large number of electrons jump from a cloud to the ground. They take the path of least resistance, usually through the tallest object available. (This is why you shouldn’t stand under a tree in a lightning storm.) The flash of lightning is so fast that it may contain multiple discharges from the cloud to the ground and back in a tiny fraction of a second.
- It is possible for lightning to go from the ground to a cloud which has an extreme deficiency of electrons.

Despite the old saying, lightning often strikes twice in the same place. Lightning tries to find the easiest path to ground, usually a path it has followed before.

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https://commons.wikimedia.org/wiki/File:Lightning_striking_the_Eiffel_Tower_-_NOAA.jpg NOAA public domain image.

Tall buildings are equipped with lightning rods to give it a safe path.

- Down through the centuries there have been reports of "ball lightning" or "St. Elmo's fire" where a glowing ball of electric charge stayed together for several seconds before dissipating. However, these have not been replicated under laboratory conditions.

When lightning strikes, the surrounding air heats up very rapidly. It expands explosively and produces the sound we call thunder.

2. **Static discharge and static cling.**

When you walk across certain types of carpet with rubber shoes, the friction between your shoes and the floor results in a transfer of electrons. You build up a charge that discharges suddenly when you touch a doorknob. This is merely a small version of a lightning strike. Likewise, when certain types of fabrics tumble around in a clothes dryer they accumulate charges that produce a spark when you pull them apart. If you separate the fabric in a dark room you will see many small lightning strikes.

B. CURRENT ELECTRICITY.

Current electricity occurs when electric energy flows for longer than a sudden discharge.

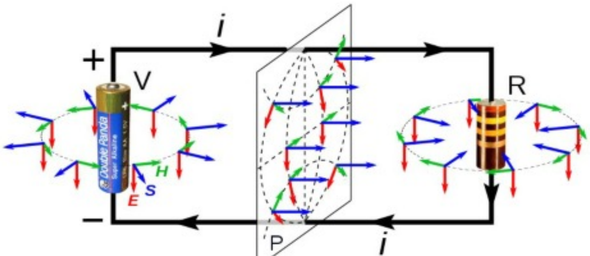
Visual
#5-36

An electric current propagates at close to the speed of light, but the electrons do not need to travel very rapidly at all. The electrons are not particles of energy; they simply produce the electric and magnetic fields that carry the energy through the circuit. As soon as the electrons begin to move, the wires containing them become surrounded by those fields, which spread out at nearly the speed of light. The fields exert a force on all the other electrons farther ahead in the wire, producing almost instantaneous results.

There are two main types of electric current.

1. **Direct current (DC).**

The electrons flow from the negative end of a source such as a battery to the positive end. Their speed depends on a number of factors such as the voltage and the conductivity of the wire. If the current keeps flowing for long enough, the individual electrons will eventually go all the way around.



https://commons.wikimedia.org/wiki/File:Poynting_vectors_of_DC_circuit.svg Attribution: Chetvorno, King of Hearts, CC0, via Wikimedia Commons

The advantage of DC is that all it requires is batteries. The disadvantage is that over long distances, a significant amount of the electrical energy is wasted as the wires heat up. In order for DC to be practical in a large area, there would have to be large battery stations set up every few blocks.

2. **Alternating current (AC).**

The electrons do not go all the way around an AC circuit, but simply oscillate back and forth a short distance. Their motion sets up electric and magnetic fields that reverse direction a certain number of times each second. The oscillating fields transfer energy to the load connected to the circuit.

Nikola Tesla, the inventor of alternating current, calculated that the optimum frequency was 60 Hz. On the other side of the Atlantic, European engineers decided to use 50 Hz because it was more compatible with the metric system. Tesla was right. There is a greater loss of energy in the form of heat in 50 Hz systems than in 60 Hz.

Though Tesla invented AC, Charles Steinmetz was the one who worked out the details of how to make it operate correctly.

The advantage of AC is that it can be stepped up to higher voltages (typically hundreds of thousands of volts) by means of a transformer, transmitted hundreds of miles, they stepped back down to give the proper voltage (typically about 120 volts) inside your house.

- The relationship between power, voltage, and current is given by the equation $P = V I$ where P is power, V is voltage, and I is current. (I is used for current because Georg Ohm, who laid much of the groundwork for studies in electricity, was German. The German word for current is *Intensität*.) The formula shows us that if we raise the voltage, we can reduce the current while transmitting the same amount of power.
- The equation for the power lost to resistance is given by the formula $P = I^2 R$ where P is power, I is current, and R is electrical resistance. Since I is lower at high voltage, the power lost in the form of heat is also much less.

The disadvantage of AC is that you need to have an outlet available to plug your appliance into.

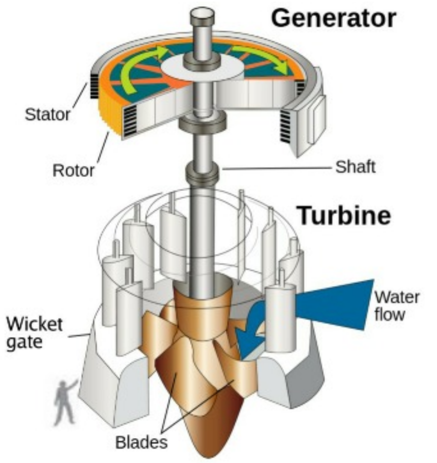
In the “war of the currents” of the late 1800s, Thomas Edison insisted that his DC system was better than AC. To show how dangerous AC was, he even filmed the electrocution of a number of animals, including an elephant. He neglected to mention that DC can be equally deadly.

C. ELECTRIC POWER GENERATION.

Solar panels use light from the sun to dislodge electrons from atoms and thereby produce electricity. Batteries use chemical reactions. These are both DC.

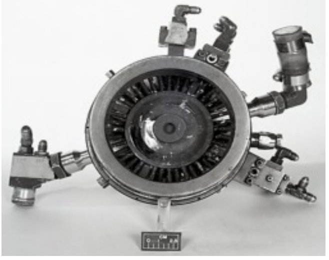
Except for these two, every other method of generating electricity relies on magnets moving past coils of wire. On a small scale, the alternator in your car produces electricity by spinning magnets past the coils. In large power plants, a massive turbine with magnets on it spins past coils of wire at a carefully controlled rate to produce AC at 60 Hz.

- The turbine may be turned by water running down a river or being released from behind a dam.
- It may be turned by wind.
- Most commonly, the force spinning the turbine comes from steam produced by burning coal, gas, or oil.
- The steam may be produced by nuclear fission in a reactor. That is, we use the most powerful source of energy known to mankind to boil water.



Water_turbine_(en).svg: *Water_turbine.svg: U.S. Army Corps of Engineers (Vector image: Gothika) This W3C-unspecified vector image was created with Adobe Illustrator.derivative work: Mikhail Ryazanov (talk)derivative work: Old Moonraker, Public domain, via Wikimedia Commons https://commons.wikimedia.org/wiki/File:Water_turbine_(en_2).svg

The magnets do not necessarily need to rotate, as long as them move back and forth past the coils. Spacecraft could be equipped with *Stirling* engines, which rely on heat to move part of the engine back and forth. If radioactive materials were used to furnish the heat, such a craft could operate for thousands of years.



Public domain image of Strirling engine heater head. National Archives and Records Admin., via Wikimedia Commons https://commons.wikimedia.org/wiki/File:HEATER_HEAD_FOR_STIRLING_ENGINE_-_NARA_-_17469796.jpg

The topics covered in this course are intended to give a very basic introduction to physics but are by no means exhaustive. The study of physics in college involves semester long courses in classical mechanics, quantum mechanics, waves and oscillations, electricity and magnetism, optics, acoustics, and so on. The topics in this course are intended to help the students gain an appreciation of the orderliness of the creation and the overwhelming wisdom of its Creator.

Visual #5-38 Einstein is widely quoted as saying, “The most incomprehensible thing about the universe is that it is comprehensible.” If the universe is merely the product of random processes, there is no reason we should be able to understand it.

CHAPTER 5 REVIEW QUESTIONS

1. Why is Newton often considered the greatest scientist of all time, even ahead of Einstein?

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2. What is the difference between kinetic and potential energy? ___

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3. What does the First Law of Thermodynamics say? ___

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4. What does the Second Law of Thermodynamics say? ___

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___

5. What does “frame of reference” mean? ___

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6. What does “two dimensional motion” mean? ___

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7. What is the difference between a balanced and unbalanced force? ___

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8. In space, what is a rocket engine pushing against? ___

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9. What does the conservation of angular momentum displayed by the earth-moon system show us about the ages of the two bodies? ______________________________

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10. Why do heavier objects often fall faster on the earth than lighter ones? ______________________________

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11. What would happen if you dropped a sack of concrete and a sheet of paper side by side on the moon? ______________________________

12. How does sound travel from a speaker to your ear? ______________________________

____

13. How do the molecules of water move in a wave on a lake? ______________________________

____

14. What is the relationship of speed, frequency, and wavelength? ______________________________

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15. What happens to the speed of light when it goes from a less dense to a denser medium, e.g., from air to water? ______________________________

16. What memory aid can you use to remember the order of colors in a rainbow? ______________________________

17. Why are gamma rays and x-rays so dangerous to living things? ______________________________

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18. How does the wave nature of matter fit with the Bible? ______________________________

____

19. What is the Doppler effect? ______________________________

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20. Since you cannot get more energy out of a simple machine (e.g., a lever) than you put in, what is the advantage of using one?? ______________________________

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21. Why is there lightning? ______________________________

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22. Why do we hear thunder when lightning strikes? ______________________________

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23. Why do electrons not have to go all the way around a circuit to carry electrical energy? _____

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24. Other than photoelectricity and batteries, how is most electrical power generated using various sources of energy? ____

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