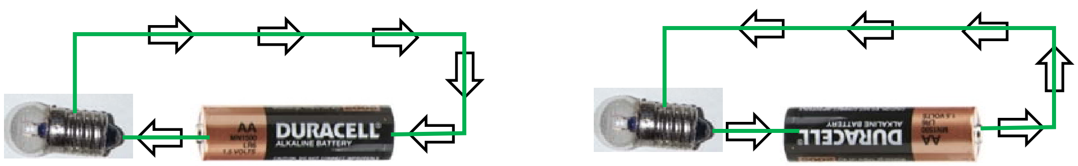
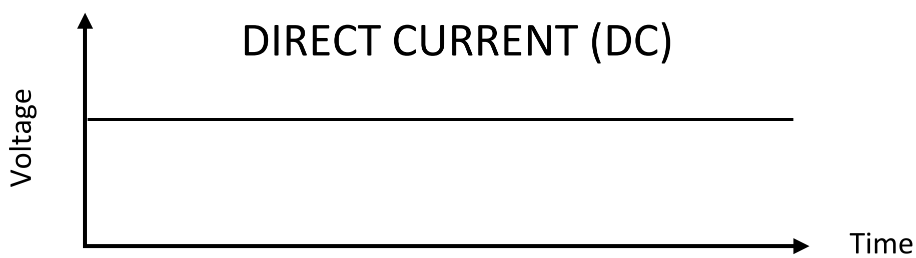
**PHYS:1200 LECTURE 26 — ELECTRICITY AND MAGNETISM (4)**

In this lecture we will discuss the difference between **direct current** (DC) and **alternating current** (AC), the methods that are used to generate AC, the transmission of electric power from the power plant to your home, the wiring in your home, and finally how the cost of electricity is calculated.

**26-1. Direct Current (DC).—**The circuits that we have been discussing so far in this course are powered by DC **sources – batteries**. In DC circuits t**he currents always flow in the same direction and remain nearly at a constant value.** Solar cells also generate DC power. The direction of current flow depends on how the battery is connected to the load; two possibilities are shown:

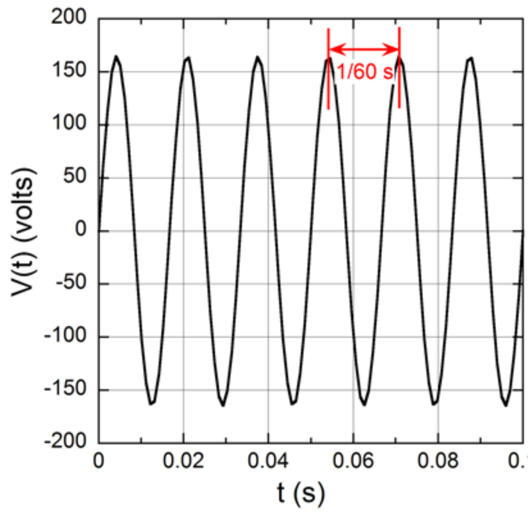


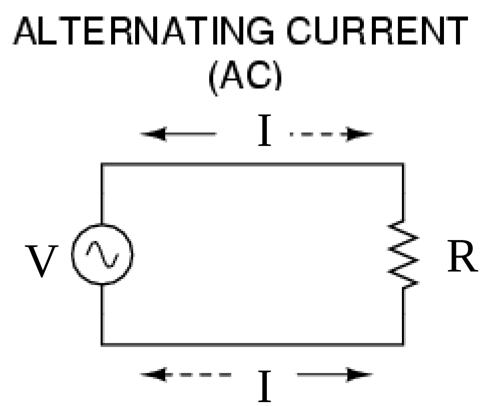

As long as the batteries are fully charged, the current through the light bulb will be constant. A plot of the DC voltage in a circuit with time would simply be a straight line:




Direct currents are used in all battery chargers. Your cell phone charger converts the alternating power from the wall socket into direct current. Rechargeable batteries, like the ones in cell phones and tablets can only be charged with DC.

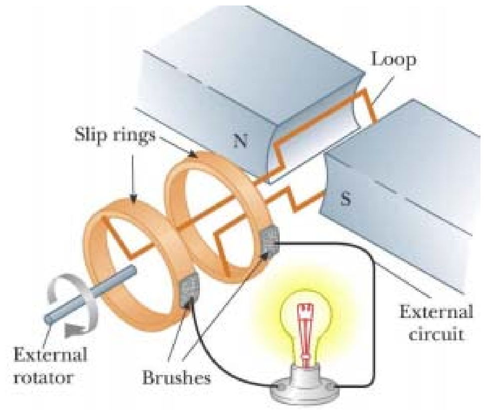
**26-2. Alternating Current (AC).—**AC is the power provided by the power companies, and is available in the wall sockets. **In AC circuits the current reverses direction periodically, in the US 60 times a second.** The "line" voltage has a peak value of approximately 165 V. A plot of the line voltage is shown below. Since the power is provided at a frequency of 60 Hz, the time between successive voltage peaks is 1/60 s. Since the voltage oscillates with time, **an effective voltage value is typically used which is approximately 110 V—120 V**. Many electrical devices including light bulbs, heaters, toasters, motors, etc., can operate with currents that reverse direction. Other devices like battery chargers require units which convert the AC to DC. A simple AC circuit containing a resistor and an AC voltage source is shown below. The circle with the wiggly line on the left side is the symbol used to represent an AC voltage source. The solid and dashed lines indicate that the current reverses periodically. The current in the circuit at time $t, I(t)$ is given by **Ohm's Law** $I(t)=V(t)/R$, in terms of the value of the voltage at time $t, V(t)$.



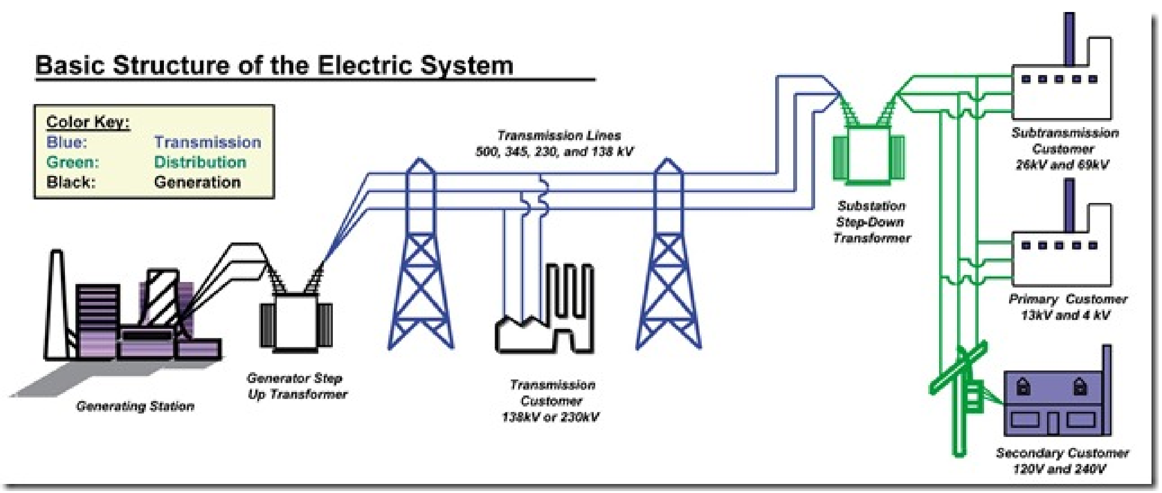




AC is the preferred method of electrical power distribution because **AC is easier to generate and transmit than DC**. There is only one main source of DC – the battery. Batteries produce power at a specific voltage depending on the materials used, and can only be changed by adding more batteries in series. **DC power is expensive to transmit over large distances**, so DC power plants would have to be located in close proximity to population centers. AC can be generated in plants far from cities and transmitted over long distances. **Finally, and this is a major advantage of AC, the voltage at which AC is transmitted can be easily changed (increased or decreased) by devices called transformers.** Thomas Edison and Nikola Tesla in the late 1800's fought a number of protracted battles in courts to determine whether New Your City would be powered by AC (Tesla) or DC (Edison). Tesla, who worked for the Westinghouse Company, won.

**26-3. The Electric Generator**.—The generation of electricity is an application of the principle of **electromagnetic induction** discovered independently by Michael Faraday in 1831 in England, and Joseph Henry in 1832 in the US. We will describe this important discovery later in connection with magnetic fields. The basic principle is illustrated in the diagram on the right. A coil of wire (Loop) is located between the poles (North, N and South, S) of a permanent magnet. The loop is attached to an axle which is rotated by some external agent that is not shown. When a loop is rotated in a magnetic field, Faraday and Henry showed that a current is produced (induced) in the loop. To extract this current from the rotating coil, slip rings with brushes are used to allow sliding electrical connections to be made. This device generates alternating currents. **Obviously, a mechanical energy source is required to rotate the loop.** In a coal or gas-fired power plant, fuel is burned to produce steam and the steam is used to drive a turbine which turns the loop inside the magnet (slide 10). In a hydroelectric plant (slides 11, 12), flowing water is used to rotate the turbines. In a wind turbine, the wind turns the blades which turn the turbine. In a nuclear power plant, the process is the same as in a coal or gas-fired power plant, except that the heat used to make the steam comes from nuclear energy.




**26-4. Electric Power Distribution**.— How does the electric power get from the power plant to your home? The power is transmitted over a network of lines that make up the **power grid**. A diagram of a typical power grid is shown below. Electric power is very difficult to store once



produced. Therefore, it must be continuously generated to meet peak power demands. The important parameter is the amount of energy used per unit time -- or the power measured in Watts. Recall that electric power is the product of voltage and current, $P = IV$. In terms of efficiency (reducing losses), **it is better to transmit power at high voltage and low current**. Transmitting high currents requires that large diameter wires be used to keep their resistance low. This is not cost effective. Thus the voltages produced in the generators are “stepped up” before the power is transmitted on the grid along the tansmission lines. This exploits the advantage of AC power, in that transformers which can be extremely efficient, can be used to increase the voltage. Typically the generator voltages are stepped up at the power plant to 150,000 - 500,000 V and then transmitted along the lines connected to the very high towers. This high voltage power enters a locale through a substation. At the substation, the high voltage is stepped-down (reduced) to a voltage to a more manageable value for distribution within the city. Various voltages can be supplied depending on the needs of the customers. Higher voltages are provided to high capacity customers. When the power eventually reaches the neighborhoods where residents live, it is stepped down to 120 V and 240 V by transformers that are located on utility poles or on boxes located just above the ground for burried cables. In homes, the higher voltage lines (240 V) are used to power the devices like electric ranges and clothes dryers that require high currents. The 120 V lines are used to power other appliances and lighting.

The distribution of power inside a home is shown on slide 20. Typically several power outlets are connected in parallel to a single line that contains either a **fuse or circuit breaker**. The fuses or circuit breakers are safety devices that automatically interrupt the circuit if the current exceeds a specified value. Some details of the electric outlets are given on slide 18.

**26-5. Paying for Electricity, the Kilowatt Hour (KWH)**.—Each month the utility company sends you a bill for the **total amount of electrical energy** used in the last month**. We pay for the total energy used** in a particular period. Remember that power measures the ***rate*** of energy usage. We pay for the total amount of water (in gallons, for example) used in a specified period, not the amount of water used per second. Since power is energy per time, the amount of energy used is power multiplied by the total time that the power was used; energy in J = power in W (J/s) x time in s.

**Example 26-1:** How much electrical energy is used to power a 100 W light bulb for 1 hour?

Solution- total energy = 100 W x (60 min x 60 s) = 100 W x 3600 s = 360,000 J.

Because of the large amounts of power involved, it is more convenient to express power in **kilowatts (kW),** where **1 kW = 1000 W**. Also it is more convenient to express the time in hours. This leads to the use of the energy unit called the kilowatt-hour (kW x hr). This is an energy unit because it is the product of a power and a time unit. The amount of electrical energy used in a household in one month is expressed in **kilowatt-hours (KWH).** We pay for the total number of KWH used each month. The unit cost of electricity is expressed as $/KWH or cents/KWH. The cost of electricity varies by location and other factors, but is generally in the range of about 10 cents/KWH. When calculating your electricity bill, the energy used must be expressed in KWH, and the time in hours.

**Example 26-2:** What is the cost of operating a 200 W appliance continuously for one week, if the cost of electricity is 10 cents/KWH?

Solution- The power must be expressed in kW → 200 W = 0.2 kW.

Total energy used = 0.2 kW x (7 days x 24 hours/day) = 33.6 KWH

Cost = 33.6 KWH x 10 cents/KWH = 336 cents or $3.36.

**26-6. Incandescent, Compact Fluorescent, and LED Lights**.—Twenty years ago, the main light sources were either incandescent lights or fluorescent lights in long tubes. We now have more options: compact fluorescents lights (CFLs) which are replacing the incandescent lights and LED

INCANDESCENT

COMPACT FLUORESCENT

LED

(light emitting diodes) which are replacing both. **Incandescent light bulbs**, which were invented by Thomas Edison, use a tungsten filament which emits light when heated to a high temperature by passing a large current through it. (Tungsten has a very high melting point, 3410 C, so that it can be heated to high temperatures and not melt.) Incandescent lights are very inefficient because most of the electrical energy is used to produce heat rather than light. The **compact fluorescent light** uses the fact that light is produced in electrical discharges. The fluorescent tube contains gas at a pressure of roughly 1/1000 of an atmosphere and a small amount (few milligrams) of mercury. This gas is ionized by passing a current through it and some of the atoms excited in the discharge emit radiation. The mercury significantly increases the amount of light produced in the discharge. Most of the light however is in the ultraviolet (UV) part of the spectrum. The inside of the glass tube is coated with a white powder that fluoresces (glows) in the visible when excited by UV radiation. Compact fluorescent lights pose an environmental concern because of the mercury which is highly toxic. To avoid mercury getting into landfills, the compact fluorescent bulbs must be disposed of carefully. **LED lights** operated on the principle that certain semiconducting materials give off light when a voltage is applied to it. There are no direct environmental concerns with LEDs.

The important figure of merit for a light bulb is how much electrical energy is needed to produce a certain amount of light energy. Comparing an incandescent bulb, compact fluorescent, and LED light all of which produce roughly the same amount of light, the incandescent uses 60 W, the compact fluorescent 15 W, and the LED 7 W. The compact fluorescent and LED lights are more expensive, but they have a longer lifetime than the incandescent bulbs. Thus, it costs roughly 9 times less to operate an LED light compared to an incandescent light. So, in addition to being more environmentally friendly because they require less power to operate, CFLs and LEDs are more economical to operate.