

Power Networks

Anupam Thatte, Marija Prica, Marija Ilic

Carnegie Mellon University

Summer Engineering Experience
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<http://www.geocities.com/cmusee2007/start.html>

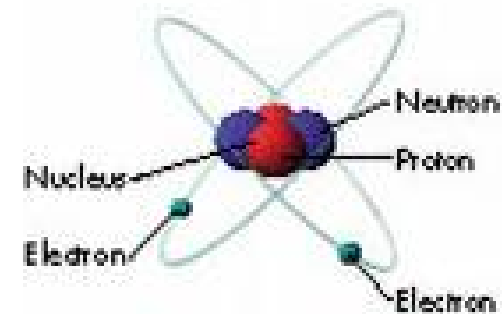
Electricity

- What is electricity? Where does it come from?
How does it work?



Before we understand all that, we need to know a little bit about atoms and their structure.

The Atom



- All matter is made up of atoms, and atoms are made up of smaller particles. The three main particles making up an atom are the proton, the neutron and the electron.
- Electrons spin around the center, or nucleus, of atoms. The nucleus is made up of neutrons and protons.
- Electrons contain a negative charge, protons a positive charge.
- Neutrons are neutral -- they have neither a positive nor a negative charge.

Where Does the Word 'Electricity' Come From?

- Electrons, electricity, electronic and other words that begin with "electr..." all originate from the Greek word "elektor," meaning "beaming sun." In Greek, "elektron" is the word for **amber**.

- Amber is a very pretty goldish brown "stone" that sparkles orange and yellow in sunlight.

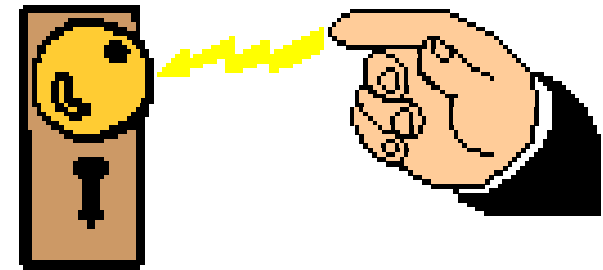


Ooh, its shiny!

Ancient Greeks discovered that amber behaved oddly – like attracting feathers - when rubbed by fur or other objects. They didn't know what it was that caused this phenomenon. But the Greeks had discovered one of the first examples of **static electricity**.

Example of Static electricity

- You walk across the rug, reach for the doorknob and.....ZAP!!!
- You get a static shock.



Can you think of another example?

<http://micro.magnet.fsu.edu/electromag/java/lightning/index.html>

Electrical Basics

Electricity: is a general term for the variety of phenomena resulting from the presence and flow of electric charge. The term **electricity** is applied to several related concepts that are better identified by more precise terms:

Charge:

Charge is measured in coulombs and is the “**amount** of electricity” present (or flowing).

Charge can be positive or negative. Like charges repel each other. Unlike charges attract each other. Charge moves about and may be stored (e.g. in a capacitor or battery).

Understanding Electrical Basics - an analogy with water

- Electrical current seems very difficult for most people to understand. *You can't taste it or smell it so what is it?*
- We can understand it by comparing it to the flow of water.
- Water flowing through a system of pipes can behave in many respects like electricity flowing in a circuit.
- The analogy is not perfect, but it is helpful and understanding will come not only from the similarities but also from the differences.

Current:

Current is a *flow of charge*; the rate of movement of charge through a system. It is analogous to the **flow** of water in a hydraulic system (in liters/s). It is measured in amps; an amp is quite big. **Body parts feel a shock with a current as low as 0.5 mA.**

Voltage:

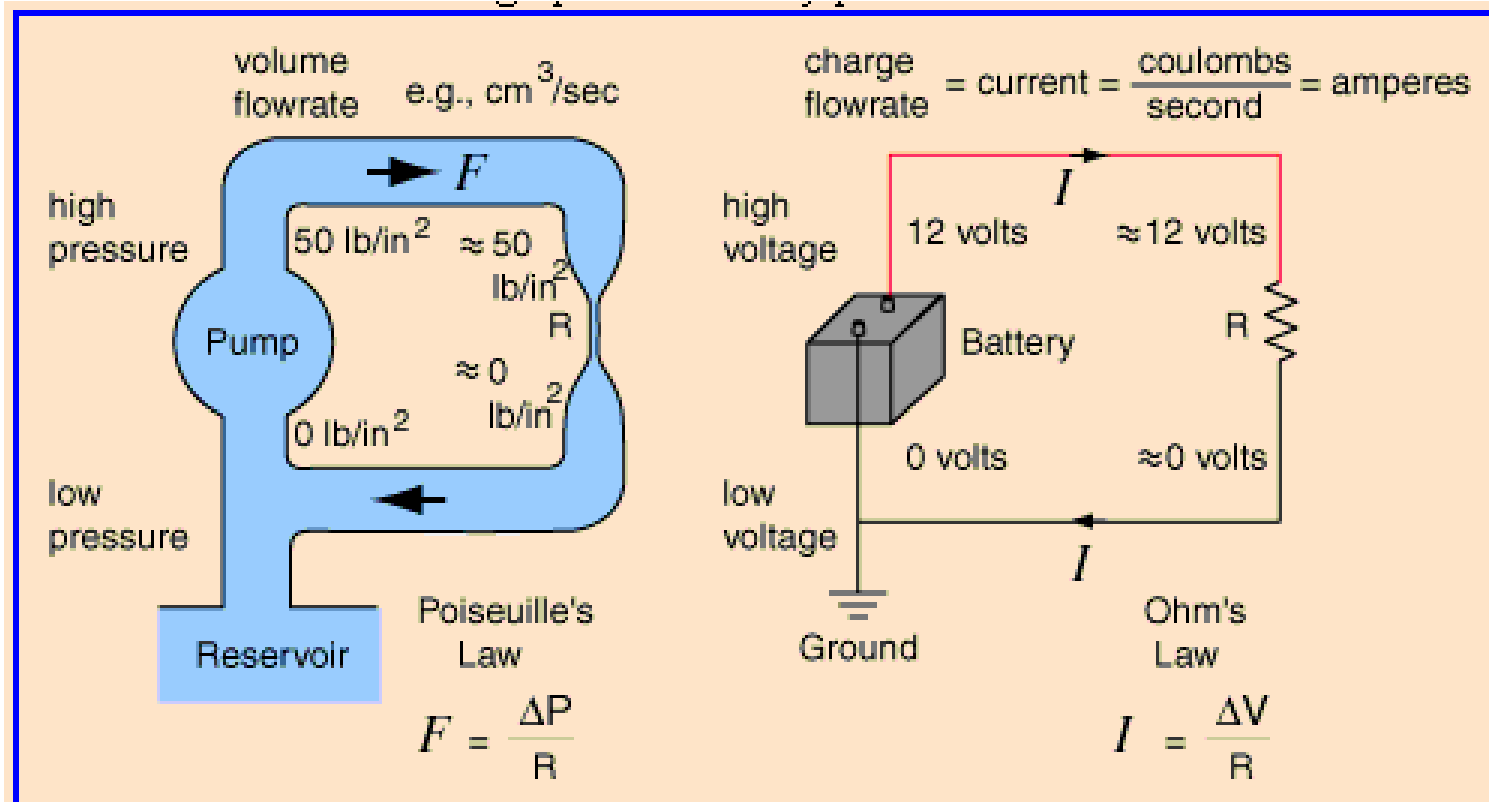
Voltage is electrical “**pressure**”. It is analogous to the pressure of a hydraulic system (say like the height of a reservoir). Voltage is measured in volts; contrary to media opinion, volts do not flow.

- Electrical current is conducted through some things better than others do. Its **resistance** measures how well something conducts electricity.
- Some things hold their electrons very tightly. Electrons do not move through them very well. These things are called **insulators**. Rubber, plastic, cloth, glass and dry air are good insulators and have very high resistance.
- Other materials have some loosely held electrons, which move through them very easily. These are called **conductors**. Most metals -- like copper, aluminum or steel -- are good conductors.

Ohm's Law

- **Ohm's law** states that, in an electrical circuit, the current passing through a conductor from one terminal point on the conductor to another terminal point on the conductor is directly proportional to the potential difference (i.e. voltage drop or voltage) across the two terminal points, and inversely proportional to the resistance of the conductor between the two terminal points.
- In mathematical terms, this is written as:
$$I = V/R$$
- where I is the current, V is the potential difference, and R is a constant called the resistance. The potential difference is also known as the voltage drop.
- The SI unit of resistance is the ohm, equal to one volt per ampere.

DC Circuit Water Analogy



Each quantity and each operational relationship in a battery-operated DC circuit has a direct analog in the water circuit. In the water circuit, the pressure P drives the water around the closed loop of pipe at a certain volume flow-rate F . If the resistance to flow R is increased, then the volume flow-rate decreases proportionately.

Problem 3

You have three different devices. First device has resistance 5 ohm, second device has resistance of 10 ohm, and the third device has resistance 15 ohm.

If you plug-in all three devices into 120 V outlet, what will be the current through each of device?

What you can say about relationship between current and resistance when the voltage is constant?

Problem 3 - Solution

Resistance [Ω]	5 ohm	10 ohm	20 ohm
Voltage [V]	120 V	120 V	120 V
Current [A]	24 A	12 A	6 A

If the voltage is constant, and resistance increases, current will decrease.

Energy

- What is it? Where does it come from? What is it used for?
- In simple terms, energy is the ability to do work. There are many forms of energy: radiant (which includes light), thermal, chemical, mechanical, electrical, nuclear, and gravitational.
- Energy itself is never created or destroyed (that's the First Law of Thermodynamics); it's only changed from one of these forms to another.
- **Power** is energy used per unit time.

Quiz

Give examples of all the changes energy undergoes in your home/daily life.

Our lives are surrounded by energy conversion technologies:

- Chemical to thermal
 - Home furnace using fuel oil, natural gas or wood
- Chemical to thermal to mechanical
 - Automobile engine
- Chemical to electrical
 - Fuel cell
- Electrical to mechanical
 - Electric motor
- Electrical to radiant
 - Toaster, light bulb

Power plants are simply energy conversion facilities converting fuel and energy sources into electricity.

Units of Measurement

- Watt (W) — The basic unit of measure of electric power. The power dissipated by a current of 1 ampere flowing across a resistance of 1 ohm.
- Kilowatt (kW) — A unit of power equal to 1,000 watts.
- Kilowatt Hour (kWh) — A unit (of energy) by which residential and most business customers are billed for monthly electric use. It represents the use of one kilowatt of electricity for one hour.
 - > A 100 watt light bulb burning for 10 hours would use 1 kilowatt-hour of electricity.
- Megawatt (MW) — A unit of power equal to one million watts
- Megawatt Hour (MWh) — The use of 1 million watts (or 1,000 kilowatts) of electricity for one hour.

- The average U.S. household uses 11.3 MWh(11,327 kWh) of electricity every year.
- In DC circuits and purely resistive AC circuits (i.e. no inductance or capacitance):
Power (measured in Watts) equals current (measured in Amps) times voltage (measured in Volts)
- i.e., $P = V \times I$

Problem 1:



1000 W

120 V **Current ?**



6-outlet strip



1600 W



1000 W



10 W



360 W

Problem 1- Solution Q1:

Total current is:
$$I = \frac{P_{total}}{V} = \frac{3970}{120} = 33\frac{1}{12} \approx 33.08 \text{ A}$$



1000 W

$$I = \frac{P}{V} = \frac{1000\text{W}}{120\text{V}} = \frac{25}{3} \text{ A} = 8\frac{1}{3} \text{ A} \approx 8.33 \text{ A}$$

120 V



6-outlet strip



1600 W

$$I = \frac{P}{V} = \frac{1600\text{W}}{120\text{V}} = \frac{40}{3} \text{ A} = 13\frac{1}{3} \text{ A} \approx 13.33 \text{ A}$$



1000 W

$$I = \frac{P}{V} = \frac{1000\text{W}}{120\text{V}} = \frac{25}{3} \text{ A} = 8\frac{1}{3} \text{ A} \approx 8.33 \text{ A}$$

10 W



$$I = \frac{P}{V} = \frac{10\text{W}}{120\text{V}} = \frac{1}{12} \text{ A} \approx 0.08 \text{ A}$$



360 W

$$I = \frac{P}{V} = \frac{360\text{W}}{120\text{V}} = 3 \text{ A}$$

Problem 1- Solution Q2:

If maximal current is 30 A, maximal power is: $P_{\max} = I_{\max} \cdot V = 30\text{A} \cdot 120\text{V} = 3600\text{W}$
Any combination of devices which total consumption in W is less then 3600 W is acceptable.



1000 W

120 V



6-outlet strip



1600 W



1000 W

10 W



360 W

Comparison of AC and DC

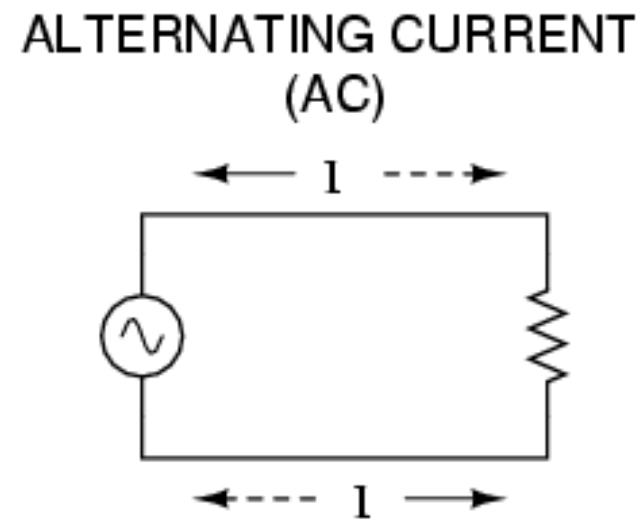
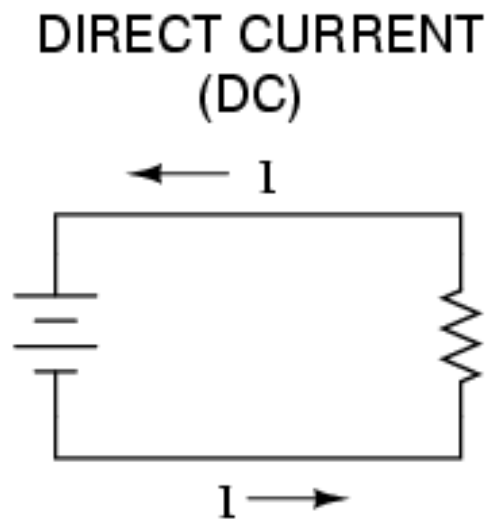


AC/DC: What's the difference?

- <http://www.pbs.org/wgbh/amex/edison/sfeature/acdc.html>

- ***Direct current*** (DC): which is electricity flowing in a constant direction, and/or possessing a voltage with constant polarity.
- DC is the kind of electricity made by a battery (with definite positive and negative terminals), or the kind of charge generated by rubbing certain types of materials against each other.
- As useful and as easy to understand as DC is, it is not the only “kind” of electricity in use. Certain sources of electricity (most notably, rotary electro-mechanical generators) naturally produce voltages alternating in polarity, reversing positive and negative over time.
- Either as a voltage switching polarity or as a current switching direction back and forth, this “kind” of electricity is known as ***Alternating Current*** (AC).

Direct vs alternating current



- But the question arises.
- **How is electricity produced?**

Electromagnetic Induction

- **Electromagnetic induction** is the production of voltage across a conductor situated in a changing magnetic field or a conductor moving through a stationary magnetic field.
- Michael Faraday made this discovery in 1831.
- He hypothesized that a changing magnetic field is necessary to induce a current in a nearby circuit.
- <http://micro.magnet.fsu.edu/electromag/java/faraday2/>
- <http://micro.magnet.fsu.edu/electromag/java/faraday/index.html>

AC machine

- If a machine is constructed to rotate a magnetic field around a set of stationary wire coils with the turning of a shaft, AC voltage will be produced across the wire coils as that shaft is rotated, in accordance with Faraday's Law of electromagnetic induction. This is the basic operating principle of an AC generator, also known as an *alternator*.
- <http://micro.magnet.fsu.edu/electromag/java/generator/ac.html>

DC generators

- While DC generators work on the same general principle of electromagnetic induction, their construction is not as simple as their AC counterparts.
- With a DC generator, the coil of wire is mounted in the shaft where the magnet is on the AC alternator, and electrical connections are made to this spinning coil via stationary carbon “brushes” contacting copper strips on the rotating shaft.
- All this is necessary to switch the coil's changing output polarity to the external circuit so the external circuit sees a constant polarity.

DC generator action

- <http://micro.magnet.fsu.edu/electromag/java/generator/dc.html>

Motors Everywhere!

Look around your house and you will find that it is filled with electric motors. Here's an interesting experiment for you to try. Walk through your house and count all the motors you find.

Starting in the kitchen, there are motors in:

- The fan over the stove and in the microwave oven
- The dispose-all under the sink
- The blender
- The can opener
- The refrigerator - Two or three in fact: one for the compressor, one for the fan inside the refrigerator, as well as one in the icemaker
- The mixer

In the utility room, there is an electric motor in:

- The washer
- The dryer
- The electric screwdriver
- The vacuum cleaner and the Dustbuster mini-vac
- The electric saw
- The electric drill
- The furnace blower

Even in the bathroom, there's a motor in:

- The fan
- The electric toothbrush
- The hair dryer
- The electric razor

Your car is loaded with electric motors:

- Power windows (a motor in each window)
- Power seats (up to seven motors per seat)
- Fans for the heater and the radiator
- Windshield wipers
- The starter motor
- Electric radio antennas

Plus, there are motors in all sorts of other places:

- The tape player in the answering machine
- Several in the VCR
- Several in a CD player or tape deck
- Many in a computer (each disk drive has two or three, plus there's a fan or two)
- Most toys that move have at least one motor (including Tickle-me-Elmo for its vibrations)
- Electric clocks
- The garage door opener
- Aquarium pumps
- Almost everything that moves uses an electric motor to accomplish its movement.

- So we know that AC generators and AC motors tend to be simpler than DC generators and DC motors. This relative simplicity translates into greater reliability and lower cost of manufacture.
- But what else is AC good for? Surely there must be more to it than design details of generators and motors!
- Indeed there is. There is an effect of electromagnetism known as ***mutual induction***, whereby two or more coils of wire placed so that the changing magnetic field created by one induces a voltage in the other.
- If we have two mutually inductive coils and we energize one coil with AC, we will create an AC voltage in the other coil. When used as such, this device is known as a ***transformer***.

Transformers



- No, I don't mean Optimus Prime !

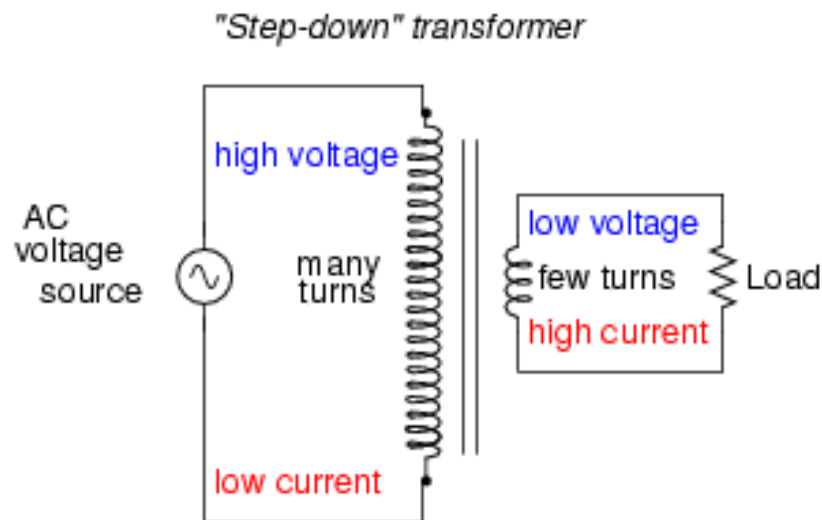
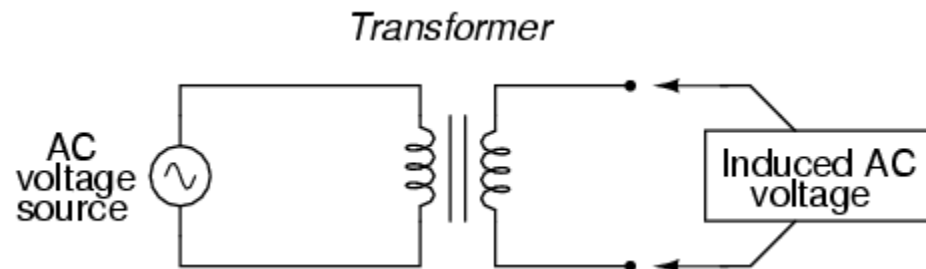
Transformers



Power Transformer



Distribution Transformer



- The fundamental significance of a transformer is its ability to step voltage up or down from the powered coil to the unpowered coil.
- The AC voltage induced in the unpowered ("secondary") coil is equal to the AC voltage across the powered ("primary") coil multiplied by the ratio of secondary coil turns to primary coil turns.
- If the secondary coil is powering a load, the current through the secondary coil is just the opposite: primary coil current multiplied by the ratio of primary to secondary turns.

Advantage of Transformer

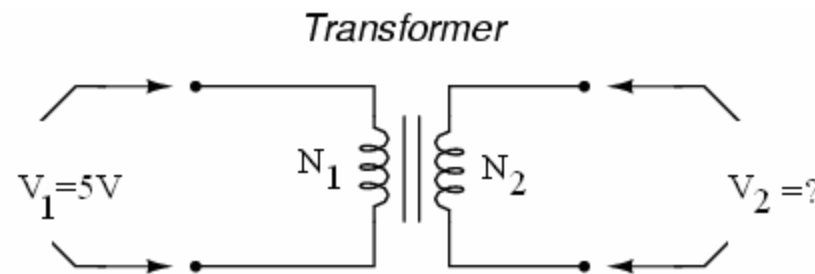
- The transformer's ability to step AC voltage up or down with ease gives AC an advantage unmatched by DC in the realm of power distribution.
- When transmitting electrical power over long distances, it is far more efficient to do so with stepped-up voltages and stepped-down currents (smaller-diameter wire with less resistive power losses), then step the voltage back down and the current back up for industry, business, or consumer use.

- As useful as transformers are, they only work with AC, not DC. Because the phenomenon of mutual inductance relies on *changing* magnetic fields, and direct current (DC) can only produce steady magnetic fields, transformers simply will not work with direct current.

Problem 2:

The voltage induced in the secondary of transformer is determined by the turns ratio:

$$\frac{\text{primary voltage}}{\text{secondary voltage}} = \frac{V_1}{V_2} = \frac{\text{Number of primary turns}}{\text{Number of secondary turns}} = \frac{N_1}{N_2}$$



If the primary has $N_1=5000$ turns and the secondary has $N_2=500$ turns, what is the turns ratio?

If the primary voltage is $V_1=5$ volts what is the secondary voltage $V_2=?$

Problem 2 - solution:

If the primary has $N_1=5000$ turns and the secondary has $N_2=500$ turns, what is the turns ratio?

$$\text{Turns ratio} = \frac{N_1}{N_2} = \frac{5000}{500} = 10:1 = 10$$

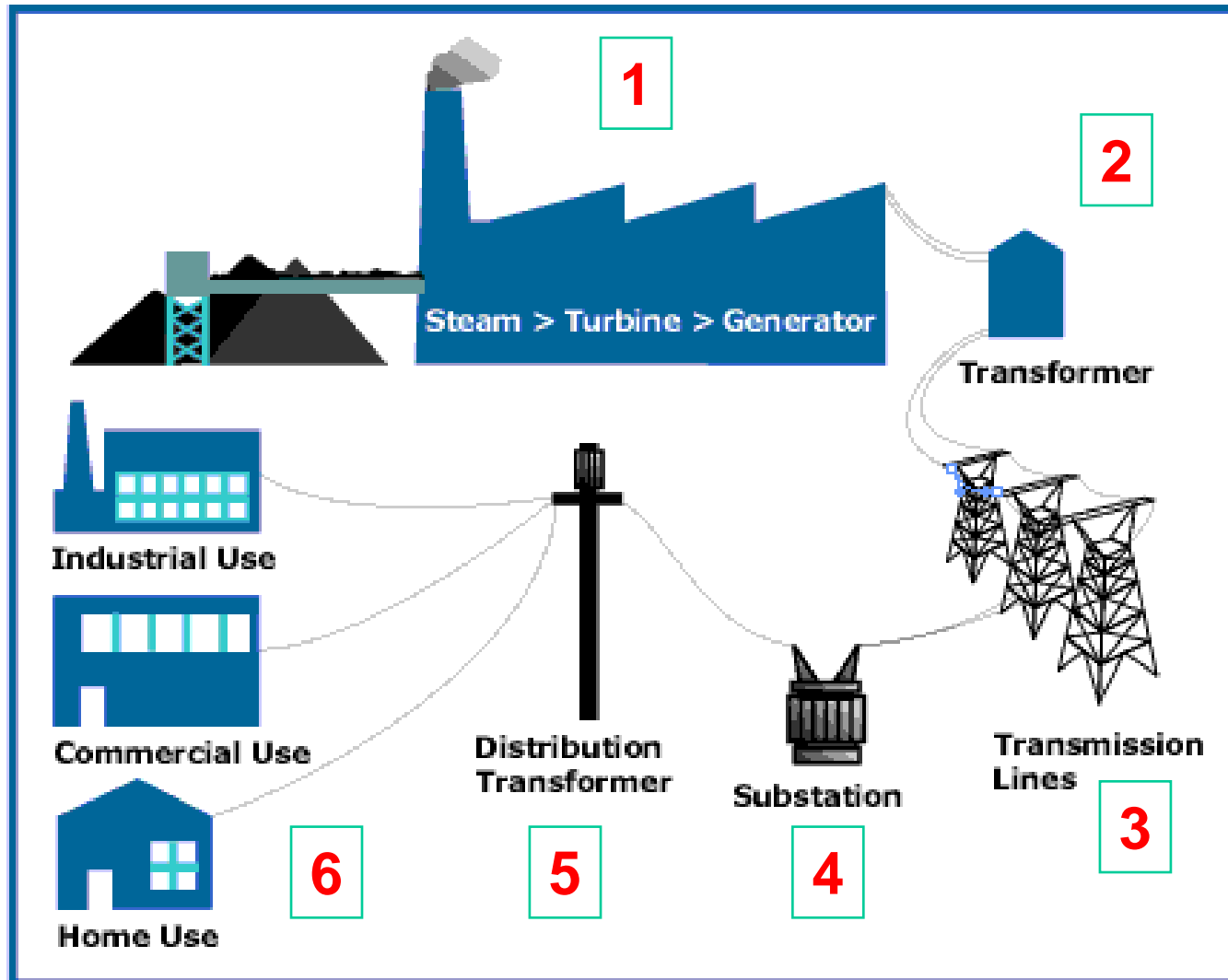
If the primary voltage is $V_1=5$ volts what is the secondary voltage $V_2=?$

$$\frac{V_1}{V_2} = \frac{N_1}{N_2} = 10 \Rightarrow V_1 = 10 \cdot V_2 \Rightarrow V_2 = \frac{V_1}{10} = \frac{5\text{V}}{10} = 0.5\text{V}$$

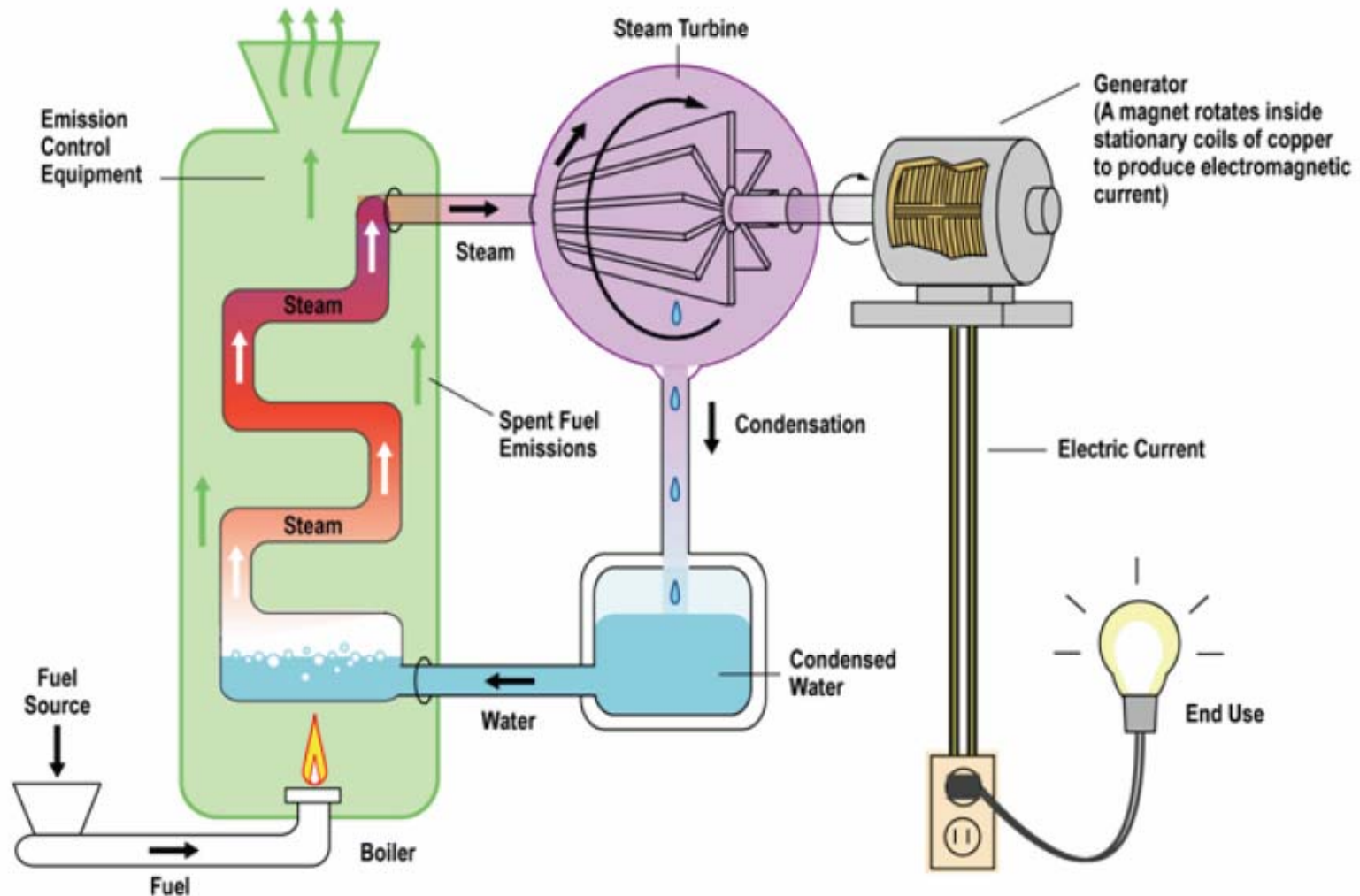
How electricity is brought into your home?

1. Electricity is generated and leaves the power plant
2. Its voltage is increased at a “step-up” substation by transformers.
3. The energy travels along a transmission line to the area where the power is needed.
4. Once there, the voltage is decreased or “stepped-down,” at another substation by transformers.
5. A distribution power line carries the electricity
6. Electricity reaches your home or business

Power network

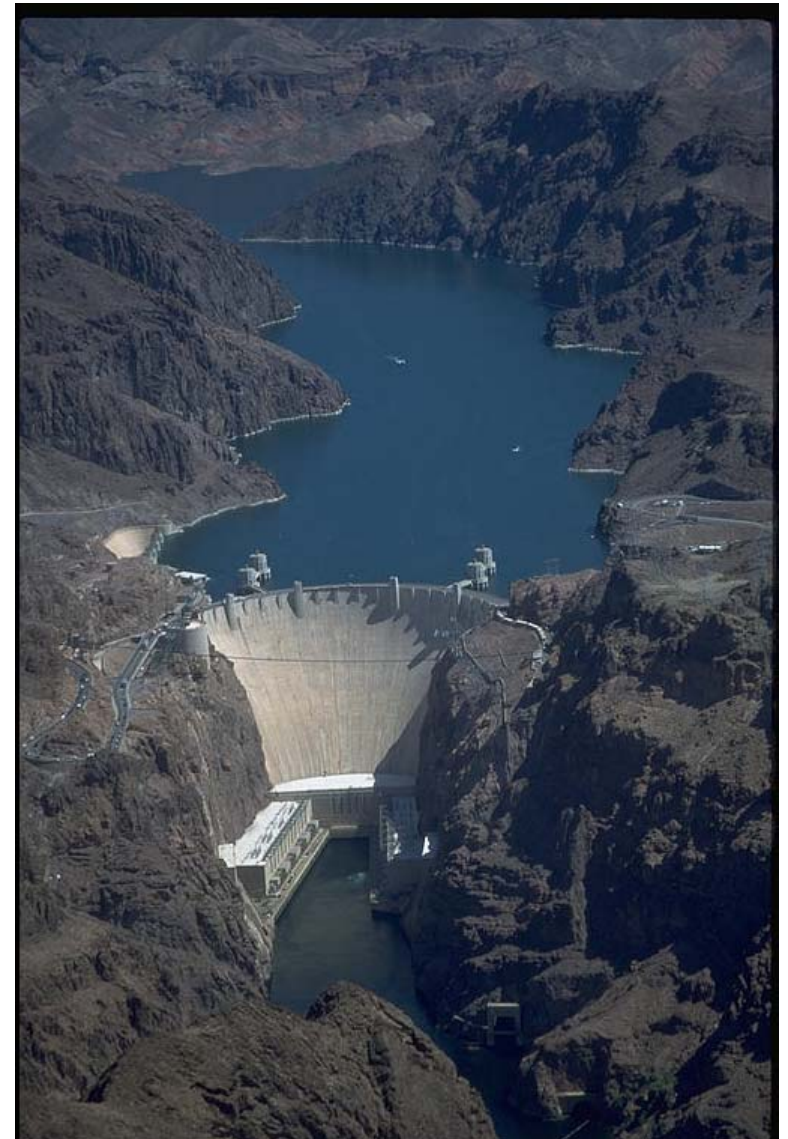
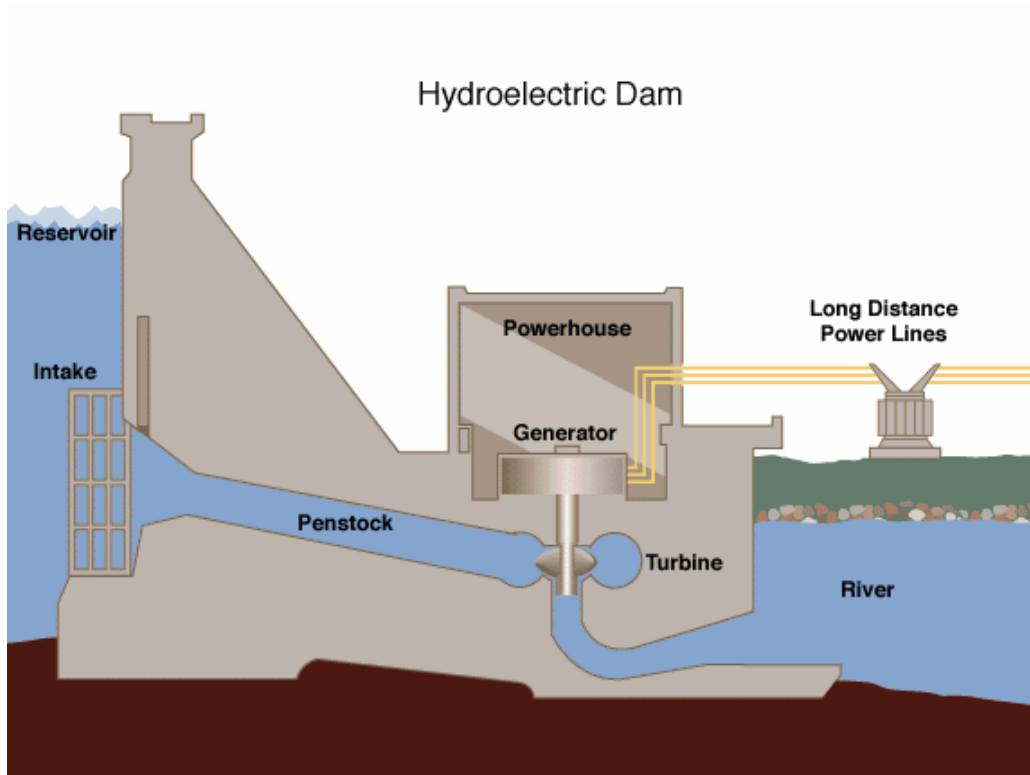


Generation (Thermal)



http://electricuniverse.com/acomon/content_games/buildturbine.html

Hydroelectric power



Generation (Hydro)

- The water behind the dam flows through the intake and into a pipe called a penstock. The water pushes against blades in a turbine, causing them to turn.
- Instead of using steam to turn the turbine, water is used. The turbine spins a generator to produce electricity.
- *Quiz: What are the energy conversions involved in generating hydro-electric power?*

Energy conversions in hydropower

- Water stored in dam at height flows down pipe → P.E. to K.E.
- Flowing water causes turbine blades to spin → K.E. to mechanical
- Turbine is attached to generator → mechanical to electrical

Transmission

- **Transmission tower** is a tall steel lattice structure used to support overhead electricity wires for electric power transmission from power plants to areas where the electricity is used.

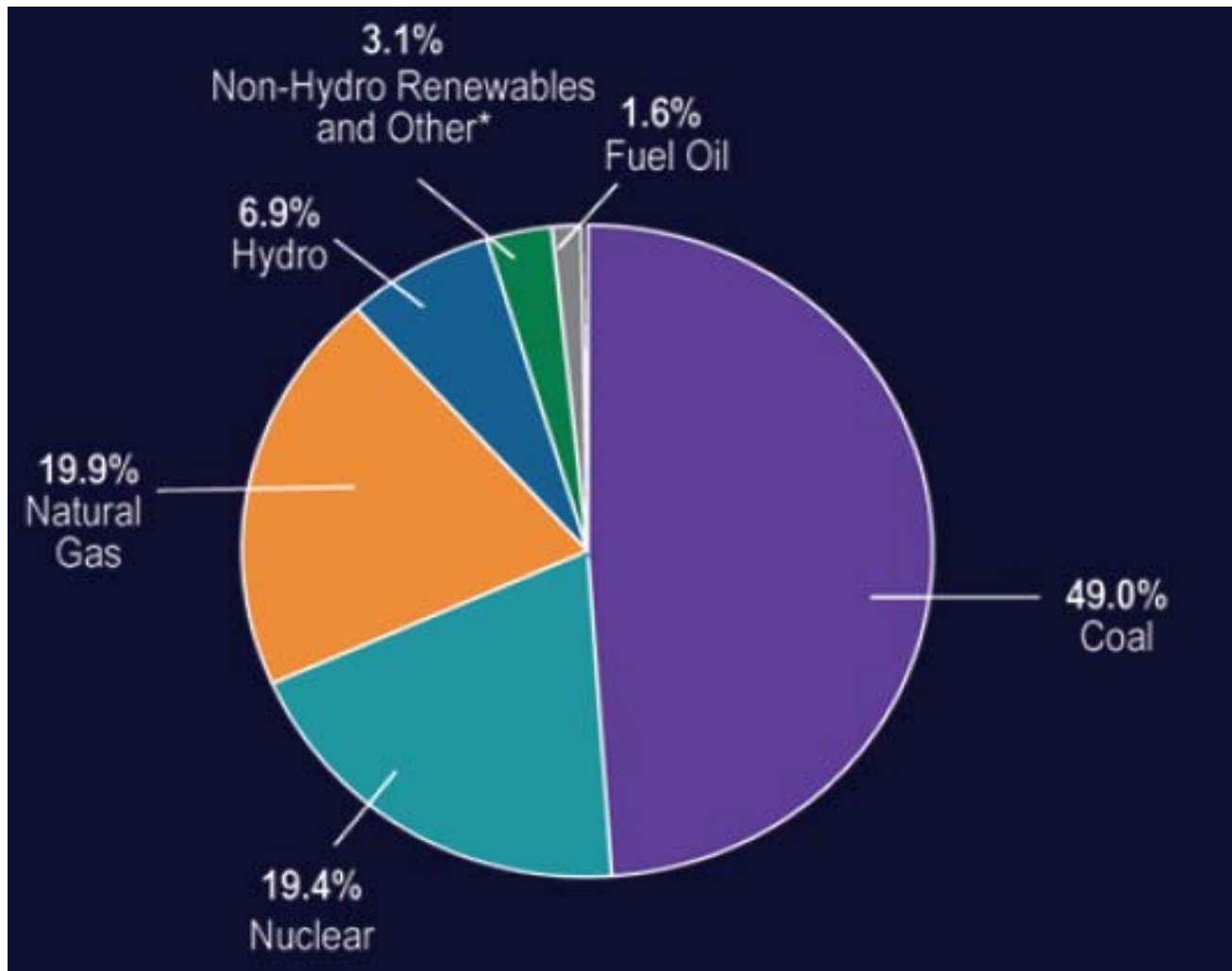


Distribution

- Thinner wires on small poles (or underground cables) carry electricity at a lower voltage to homes and businesses.



National Fuel Mix



Note: Sum of components do not add to 100.0% due to independent rounding.

**"Non-Hydro Renewables and Other" includes generation from solar, wind, geothermal, biomass (agricultural waste, municipal solid waste, landfill gas recovery, wood, pitch), hydrogen, batteries, chemicals, non-wood waste, purchased steam, sulfur and miscellaneous technologies.

Source: U.S. Department of Energy, Energy Information Administration, Power Plant Report (EIA-920), Combined Heat and Power Plant Report (EIA-920), and Electric Power Monthly (2006 Preliminary).

Fuel Diversity: Key to Affordable and Reliable Electricity

- No individual fuel is capable of meeting all of our nation's electricity demands
- Maintaining the diversity of available fuel resources helps to ensure that we do not become too dependent on one fuel source
- Fuel diversity protects consumers from contingencies such as fuel unavailability, price fluctuations, and changes in regulatory practices
- Fuel prices greatly affect the price of electricity—today, fuel costs are on the rise.

Looking Forward

- By 2030, average household consumption is expected to increase by more than 11 percent
- This increase will be entirely driven by appliance-related consumption, reflecting the use of computers and other digital technologies

References

- Electricity_101 – Edison Electric Institute (EEI)
www.eei.org
- Molecular Expressions
<http://micro.magnet.fsu.edu/index.html>
<http://micro.magnet.fsu.edu/electromag/java/index.html>
- PBS: Edison's Miracle of Light
<http://www.pbs.org/wgbh/amex/edison/filmmore/index.html>
- How Stuff Works
<http://electronics.howstuffworks.com/motor7.htm>

The Power Grid Simulation

- The applet <http://www.mste.uiuc.edu/projects/tcip/lesson2.html> provides a simulation of a large-scale power system network. Students are encouraged to explore the applet.

Power and energy in home

- <http://www.mste.uiuc.edu/projects/tcip/lesson1.html>
- Power comes from a power plant to your home through a system of power lines, power substations, and transformers that make up the power grid. This applet shows power flowing through the transformer drum, the meter and into the circuit breaker panel.

Some extra fun stuff

- <http://www.eldian.com/chaoslab/ChaoslabFunAppElectricityFullColor.html>