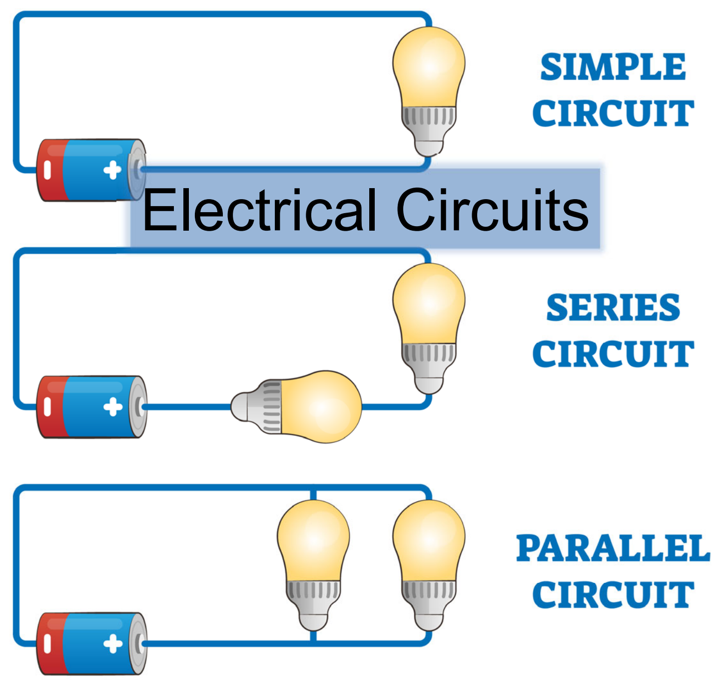
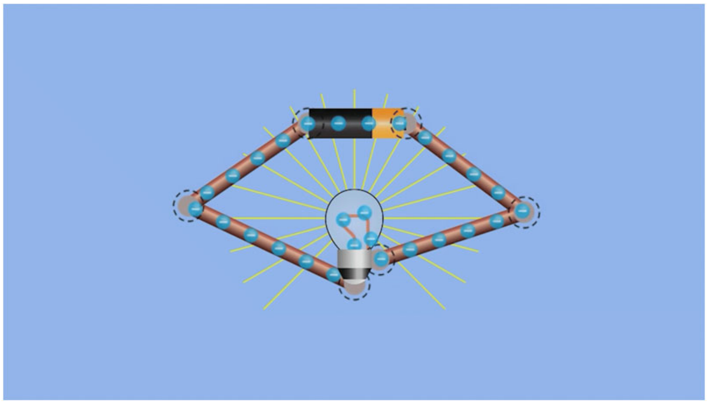
Electrical Circuits



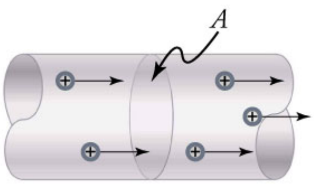
https://youtu.be/cY-kiddvAg0

Electric Current

- An electric current occurs when charges move through a wire.



- Current is defined as the rate at which charge flows through a circuit.



Physics. OpenStax. https://openstax.org/books/physics/pages/19-1-ohms-law (CC BY 4.0)

$$\boxed{I = \frac{Q}{t}}$$

Where:

Q – charge (coulomb, C)
t – time (seconds, s)
I – current (amperes, amps, A)

Example 1

- A total charge of 5 nC move past an area in a time 1 ns. Calculate the current in the wire.

$$I = \frac{Q}{t}$$
$$I = \frac{5 \times 10^{-9}\ \text{C}}{1 \times 10^{-9}\ \text{s}}$$
$$I = 5\ \text{A}$$

Example 2

- A lightning strike can transfer as many as 10^{20} electrons from the cloud to the ground. If the strike lasts 2 ms, what is the average electric current in the lightning?

$$I = \frac{Q}{t}$$
$$Q = (10^{20})(1.6 \times 10^{-19}) = 16\ \text{C}$$
$$I = \frac{16\ \text{C}}{2 \times 10^{-3}\ \text{s}}$$
$$I = 8000\ \text{A}$$

Electric Potential

- Electric potential is the electric potential energy per unit charge.

$$V = \frac{E}{Q}$$

Where:

E – electric potential energy (joules, J)
Q – charge (coulombs, C)
V – electric potential, voltage (volts, V)

Example

- An electron is exposed to an electric potential of 200 V. Calculate the potential energy.

$$V = \frac{E}{Q}$$

$$200 = \frac{E}{1.6 \times 10^{-19}}$$

$$E = 3.2 \times 10^{-17}\ \mathrm{J}$$

Current vs Voltage

- Current is related to the number of charges.
- Voltage (potential) is related to the energy of each charge.

Resistance

- The motion of charges in a wire can be affected by many factors, including impurities in the metal of the wire or collisions between other charges in the material.
- This is called **resistance**.
- Every time a collision occurs, some of the energy is transformed into heat.

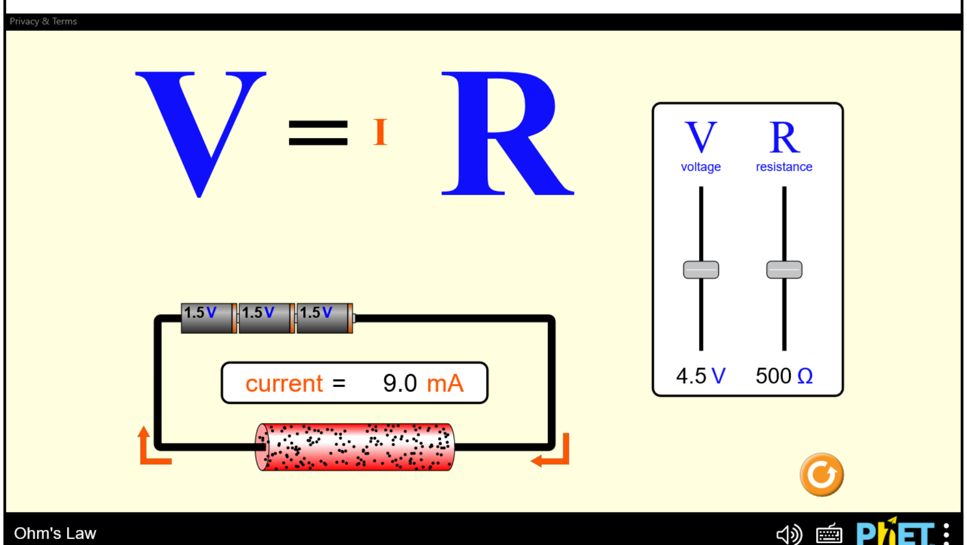
- Georg Ohm (German), 1827
  - current through a conductor is proportional to the voltage drop across a current-carrying conductor

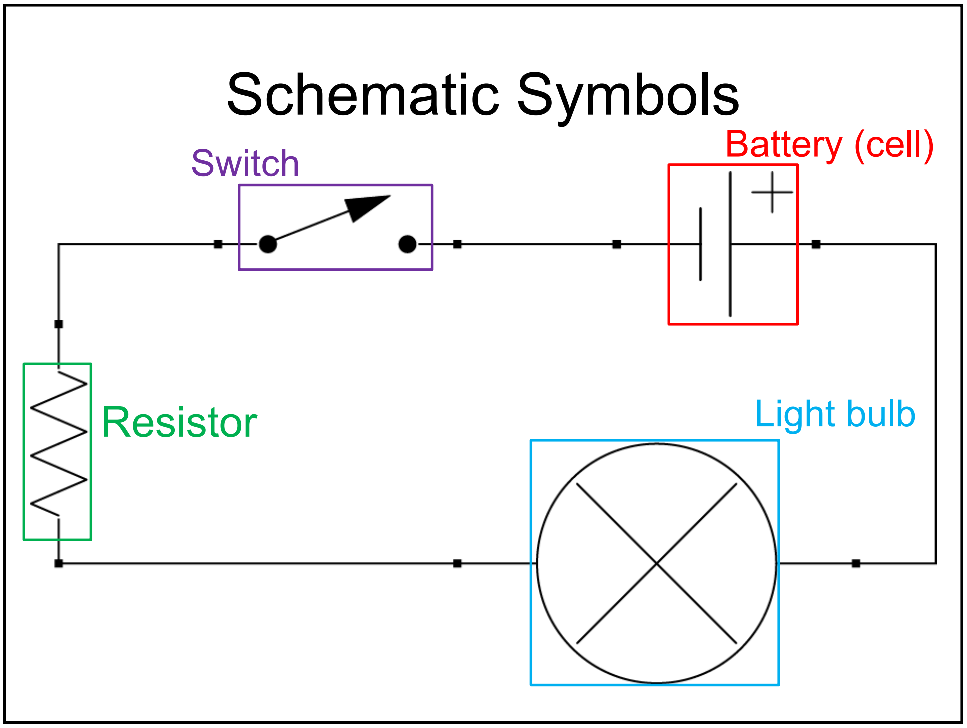
$$\boxed{V = IR}$$

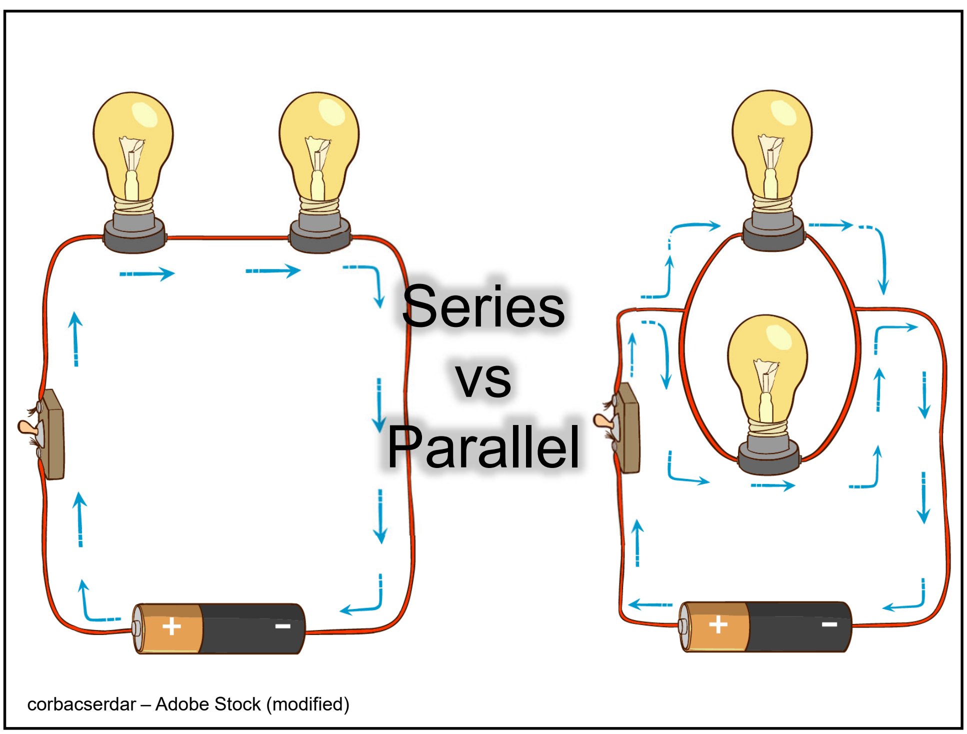
Georg Ohm – Unknown (public domain)

Where:

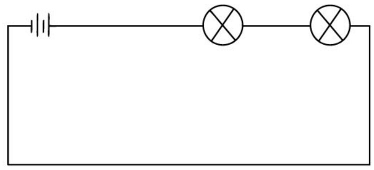
I – current (amperes, amps, A)
R – resistance (ohms, Ω)
V – voltage drop (volts, V)

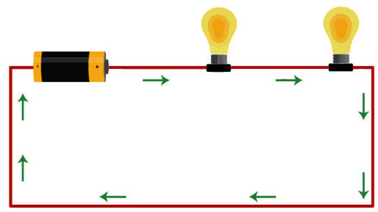


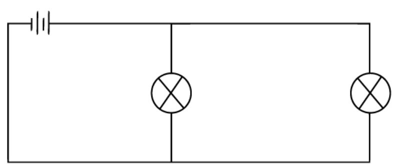

Schematic Symbols
Switch
Battery (cell)
Resistor
Light bulb

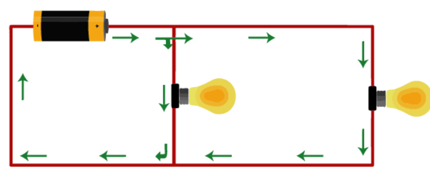

Series
vs
Parallel
+
-
+
-
corbacserdar – Adobe Stock (modified)

SERIES AND PARALLEL CIRCUITS


Series Circuit

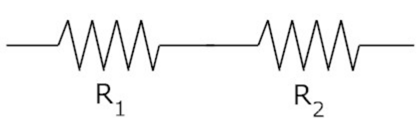

Series Circuit


Parallel Circuit


Parallel Circuit

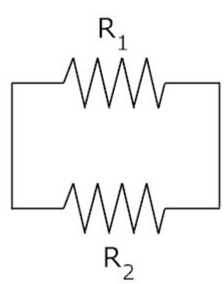
Series

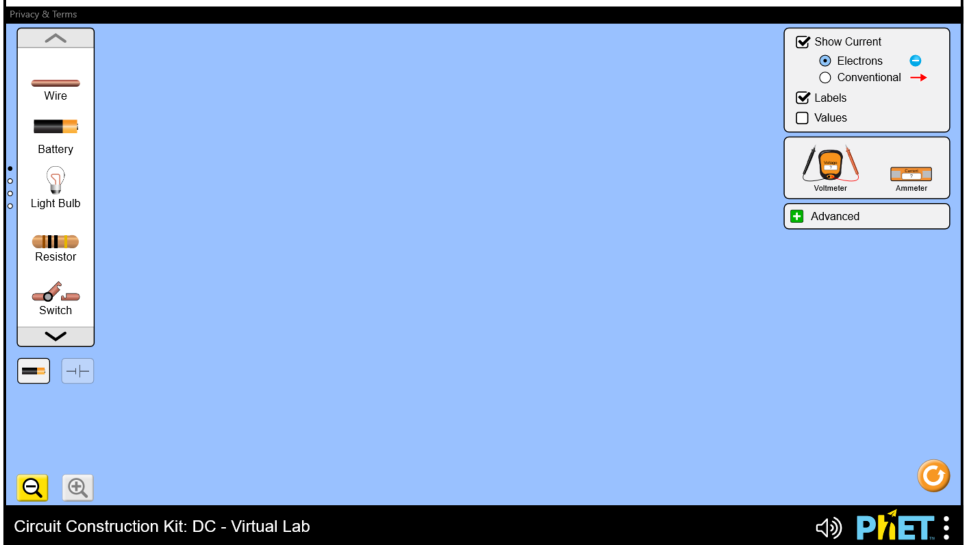
- Current flows directly from one component to the next



Parallel

- Current splits and part of it passes through each component





Series	Parallel
• **Current** is the **same** through all the components	• **Voltage** drop is the **same** across all components
• **Adding resistors** (components) without changing voltage **decreases total current** in the circuit	• **Adding resistors** (components) without changing voltage **increases total current** in the circuit

Series

- **Adding** resistors (components) **increases** total resistance

Parallel

- **Adding** resistors (components) **decreases** total resistance

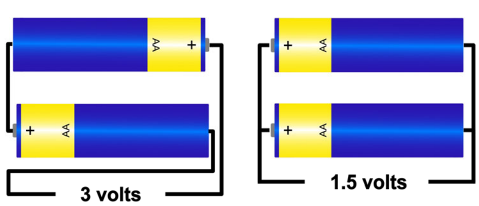
Batteries (Cells)

Series

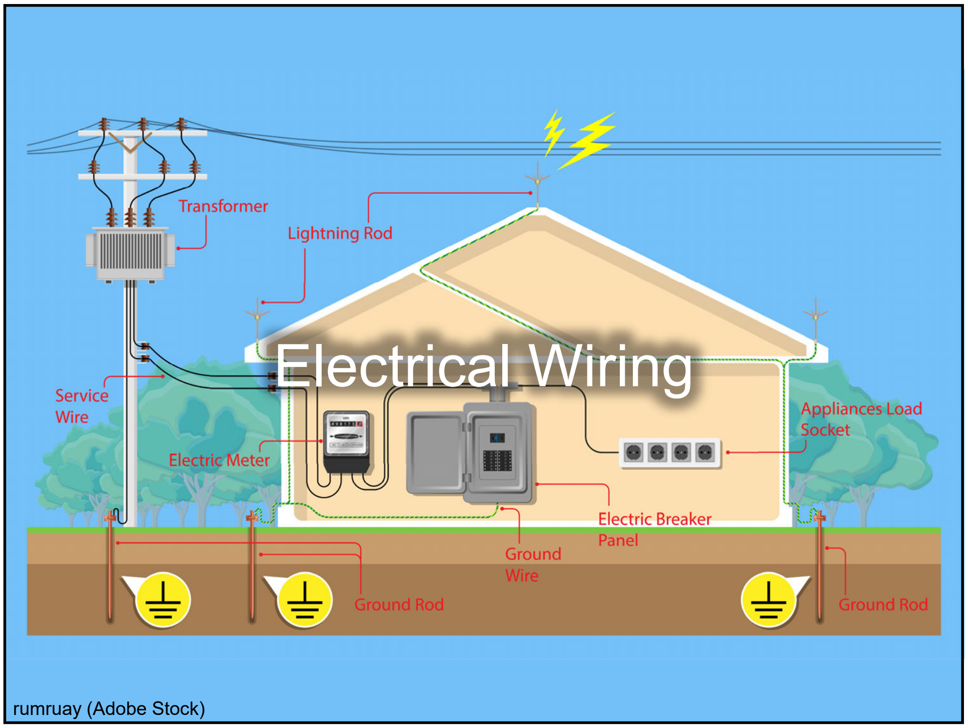
- **Voltage** adds

Parallel

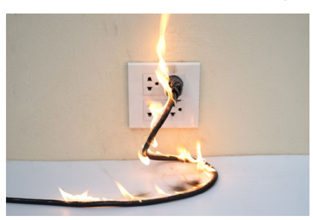
- **Voltage** is the **same**
- Increases Amp hour capacity
  - the amount of time the battery can deliver an amount of energy (voltage)



Charles Risen (Adobe Stock)



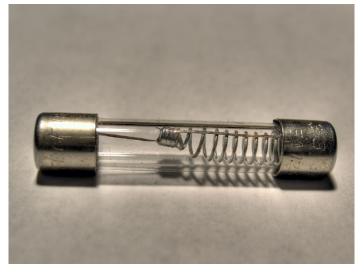
- Buildings are wired in parallel.
  - Voltage is the same for all appliances.
    - Consistent voltage everywhere throughout the country.
    - Appliances will work anywhere.
  - Each appliance added to the circuit increases the current in the circuit.
    - More charges flowing through the wire increases the number of collisions which increases rate of energy transformation to heat possibly resulting in a fire.



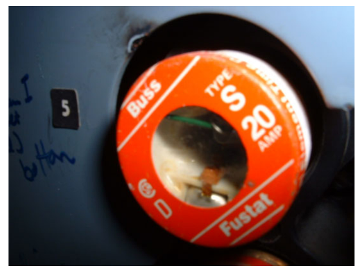
Thicha (Adobe Stock)

Safety

- Fuse
  - Limits the amount of current flowing in the circuit.
    - A thin wire in a sealed glass container.
    - Heat generated by resistance increases with current until the wire melts thus breaking the circuit.



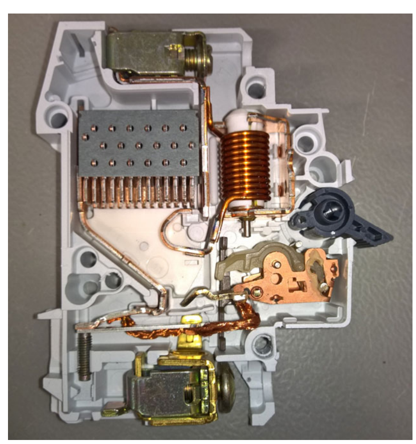
Fuse – Razor512 (CC BY 2.0)



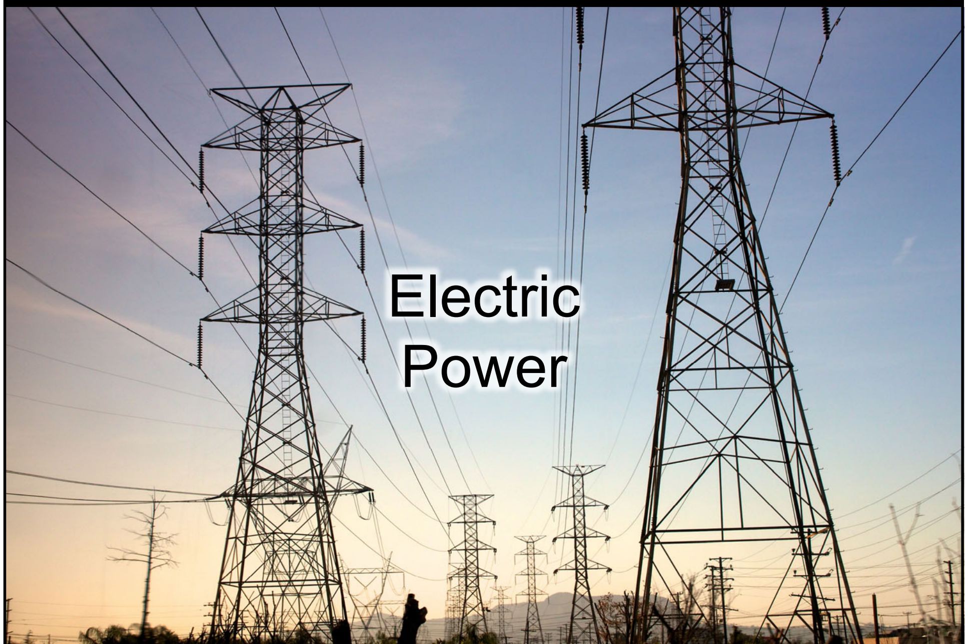
Fuse – David Loomer (CC BY-NC-ND 2.0)

- Circuit breaker
  - Limits the amount of current flowing in the circuit.
    - A switch and an electromagnet attached to the circuit.
    - The electromagnet gets stronger as the current increases until it attracts a metal lever on the switch causing it to turn off.

Lost_in_the_Midwest (Adobe Stock)



Circuit breaker – jarvelajussi (CC BY-NC 2.0)



Power transmission lines – Oran Viriyincy (CC BY-SA 2.0)

Power

- Rate at which energy is transferred.

$$\boxed{P = \frac{E}{t}}$$

P – power (watts, W)
E – energy (joules, J)
t – time (seconds, s)

- In an electric circuit, power can be related to current and voltage.

$$\boxed{P = IV}$$

P – power (watts, W)
I – current (amperes, A)
V – potential (voltage, V)

Example

- A 60 W light bulb dissipates (uses) 60 W of power. The voltage drop across the light bulb is 120 V.
  a) Calculate the current flowing through the bulb.
  b) How much energy does the bulb use in one hour?

a) current flowing through the bulb

$$P = IV$$
$$I = \frac{P}{V}$$
$$I = \frac{60\ \mathrm{W}}{120\ \mathrm{V}} = 0.5\ \mathrm{A}$$

b) energy the bulb uses in one hour

$$P = \frac{E}{t}$$
$$E = Pt$$
$$E = 60\ \mathrm{W}(1 \times 60 \times 60)\mathrm{s} = 216000\ \mathrm{J}$$

Cost of Electricity

- Electrical devices use power.
  - The amount of power depends on current (and voltage).
- The amount of energy used depends on the amount of time the device operates.
- A 60W light bulb uses 60 Watts of power or 60 Joules of energy each second.
  - In one minute (60 s), it will use 360 J.
  - In one hour (3600 s), it will use 216000 J.

- Power companies charge for the energy used.
- Using Joules as the units for energy would mean the numbers would be very large.
- A different unit of energy, kWh (kilowatt hour), was developed so that the energy numbers would be more manageable.

$$1\ \text{kWh} = 1000 \times 3600 = 3.6 \times 10^6 \text{J}$$

- Appliances often list how much power they use (in Watts, W)

- To calculate the amount of energy used (in kWh) in one hour

$$\frac{Power\ (W)}{1000} \times time\ (hours)$$

- A power meter measures the amount of energy used.

Red Power - Scott Robinson (CC BY 2.0)

Example 1

A household uses 900 kWh in one month. The cost of electricity is 9 ¢/kWh. Calculate the total cost for the month.

$$\text{Cost} = 900\ \text{kWh}\ \times \$0.09$$

$$\text{Cost} = \$81$$

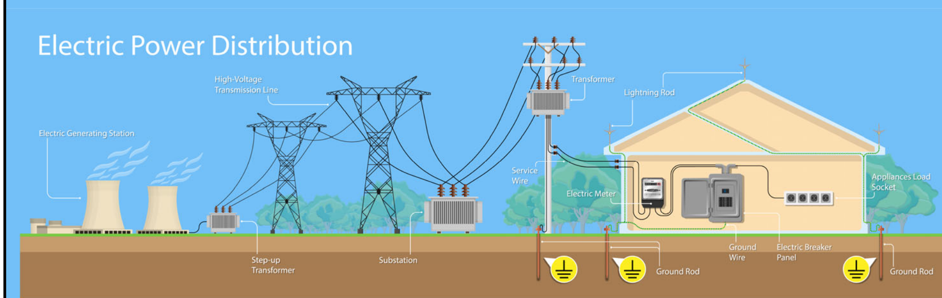
Example 2

A computer uses 385 W of power. What is the cost of letting the computer run all day if electricity is $0.09/kWh?

$$\text{Cost} = \frac{385\ \text{W}}{1000} \times 24\ \text{h} \times \$0.09$$

$$\text{Cost} = \$0.83$$

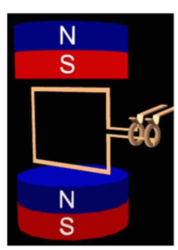
Where does the electricity that powers our lives come from?



rumruay (Adobe Stock)

Mechanical

- A generator uses electromagnetic induction to produce electricity.
  - A coil spinning in a magnetic field.



from PHYSCLIPS

- The generator is either driven directly or through a secondary process.

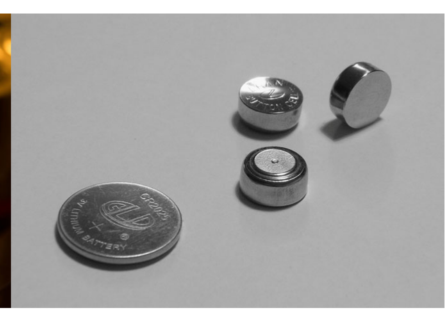
- Hydroelectric
  - Water directly drives the generator.
- Coal/Gas/Oil
  - Fuel is burned to boil water creating steam to drive the generator.
- Nuclear
  - Heat from a nuclear fission reaction used to boil water creating steam to drive the generator.

Manitoba Hydro Pointe du Bois Generator – Wtshymanki (Public Domain)

Hoover Dam generators – Jon Sullivan (Public Domain)

Chemical

- The moving electrons from a redox reaction can be harnessed to do work.
  - battery



Batteries at Attention – massmatt (CC BY 2.0)
Batteries – James Bowe (CC BY 2.0)

Light

- Photovoltaic cells absorb light energy, usually from the sun, and transfer it to electrons allowing them to flow creating an electrical current.

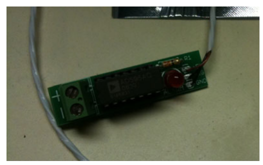
Solar Panel for Solar Highway – Portland General Electric (CC BY-ND 2.0)

Devices that Work by Generating Small Amounts of Electricity

snc10614 – Par Johansson (CC BY-SA 2.0)
Hamilton Khaki – James Case (CC BY 2.0)
Microphone – ngad (Adobe Stock)
Nest Learning Thermostat showing Celsius – Nest (CC BY-NC-ND 2.0)

Thermocouple

- Two wire legs made from different metals welded together at one end, creating a junction.
  - When the junction experiences a change in temperature, a voltage is created.
  - Used to measure temperature.



MakerBot Thermocouple Sensor – Andrew Plumb (CC BY-SA 2.0)
Easy To Read-Easy To Install – Jo Zimny Photos (CC BY-NC-ND 2.0)

Piezoelectricity

- The appearance of an electrical potential (voltage) across the sides of a crystal when you subject it to mechanical stress (by squeezing it).
  - microphone, quartz watch

Microphone – mipan (Adobe Stock)
Quartz Movement – Julie Jablonski (CC BY-NC 2.0)