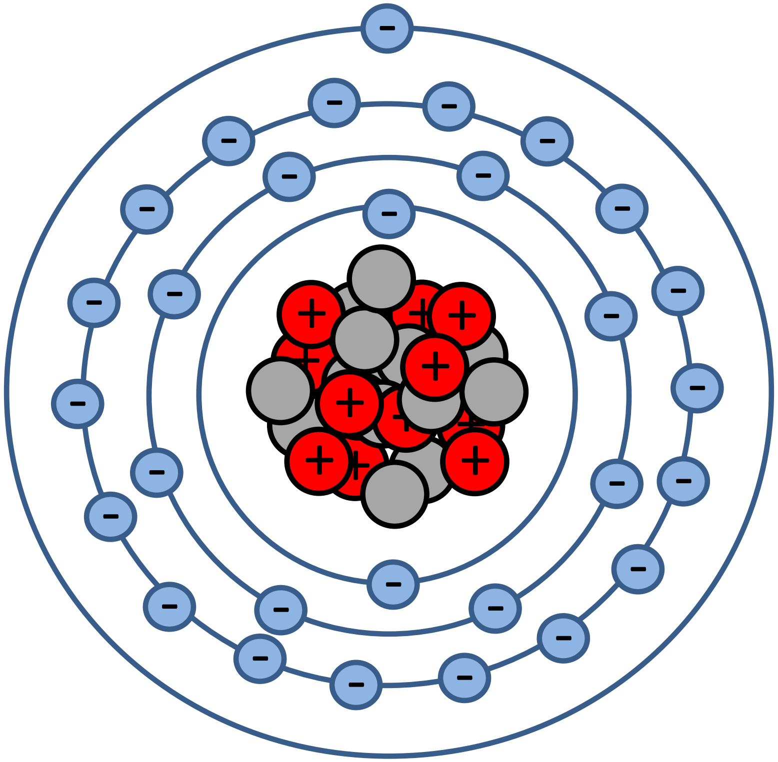
Quantities in Electric Circuits

In this module, we introduce basic concepts that form the foundation of electric circuits:

- ✓ Charge – associated with electrons
- ✓ Current – flow of electrons
- ✓ Voltage – work it takes to move charge
- ✓ Power – rate of work expended over time

What is Electricity?



Copper atom (Cu)

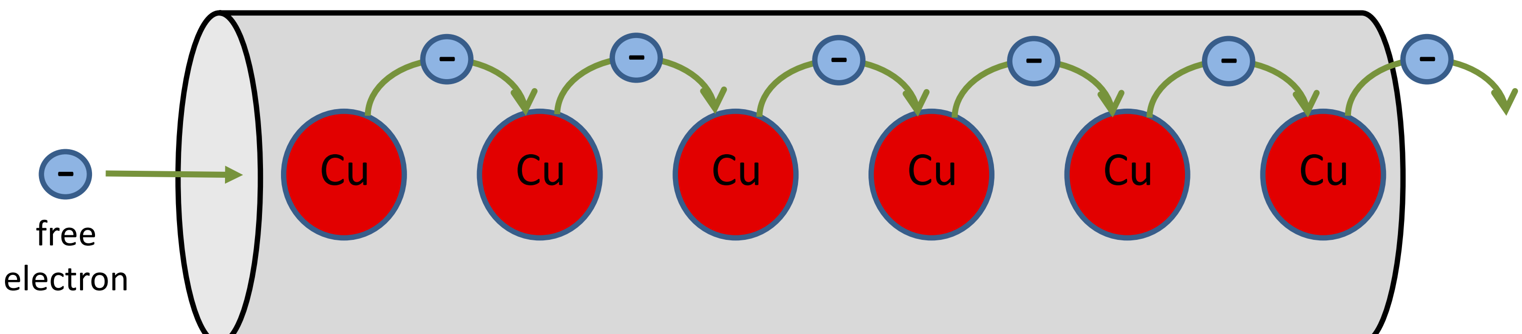
29 protons (+ charge)

35 Neutrons (neutral charge)

29 electrons (- charge)

Single electron in the outer shell makes it relatively easy to dislodge an electron from the CU atom.

⇨ good conductor of electricity

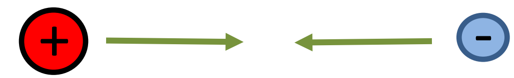


Copper wire

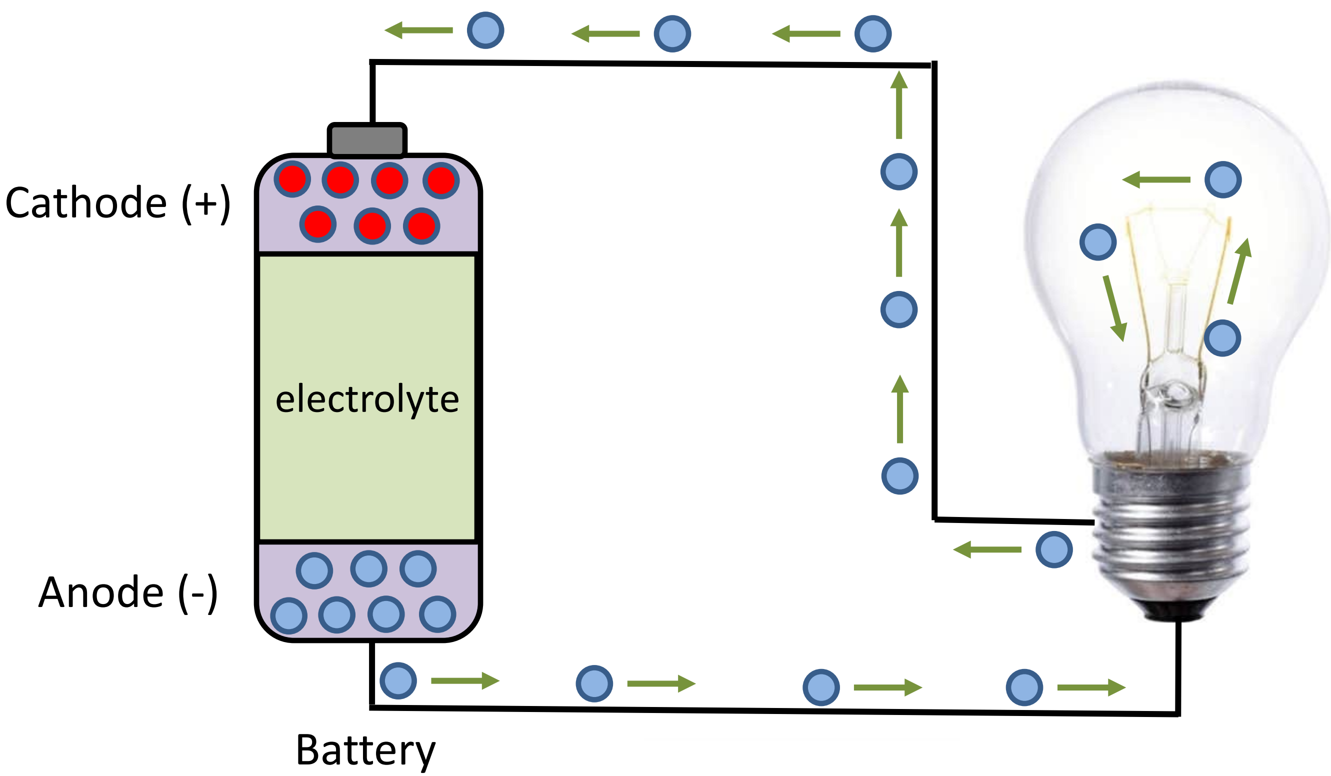
How do we make electrons move?

Particles with the same charge repel each other

Electromagnetic force



Particles with the opposite charge attract each other



Note: The physical flow of electrons (negatively charged current) is moving counterclockwise in this circuit.

Therefore, positively charged current (consisting of positive ions or what we sometimes call “holes”) is flowing clockwise.

Charge

Electric charge is the basis of describing all electrical phenomenon.

- Charge is bipolar (it can be positive or negative)
- Charge is discrete
  - Each electron carries a charge of 1.6022×10^{-19}C.
  - 1 Coulomb = 6.24×10^{19} electrons.
- Separation of charge creates an electric force
  - Voltage (Volts)
- Motion of charge creates an electric current
  - Current (Amps)

Current

- **Definition:** Electrical current is the rate of flow of charge.

$$I = \frac{dq}{dt}$$

I=current (Amps)

t=time (seconds)

q=charge (Coulombs)

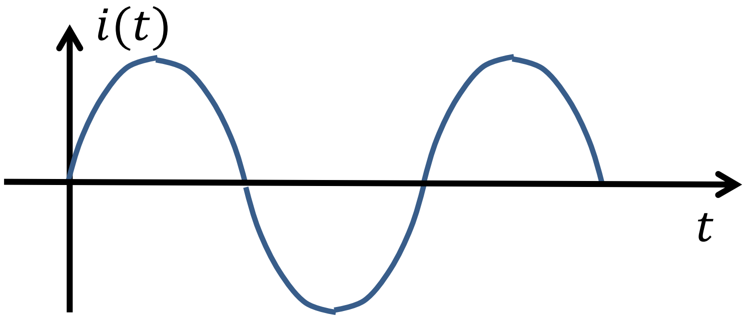
Units of current

1 Amp = $\frac{1 \text{ Coulomb}}{1 \text{ second}}$

= $6.24\text{x}10^{19}$ electrons/second

Don't forget – positive current is in the direction opposite of the physical flow of electrons.

Direct current (DC)



Alternating current (AC)

Voltage

- **Definition:** <u>Voltage</u> is the energy (work) required to move a unit of charge.

$$V = \frac{dw}{dq}$$

V=voltage (volts)

w=work or energy (Joules)

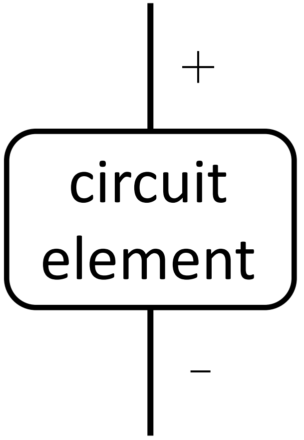
q=charge (Coulombs)

Units of voltage

$$1 \text{ Volt} = \frac{1 \text{ Joule}}{1 \text{ Coulomb}}$$

So in a 9V battery, each Coulomb of charge carries 9 Joules of potential energy.

In terms of electrical circuits, we will be concerned with the amount of energy required to move a unit of charge from one terminal of a circuit element to another.



Measuring AC Voltages/Currents

- We use the term AC (alternating current) to refer to sinusoidal voltages and currents.

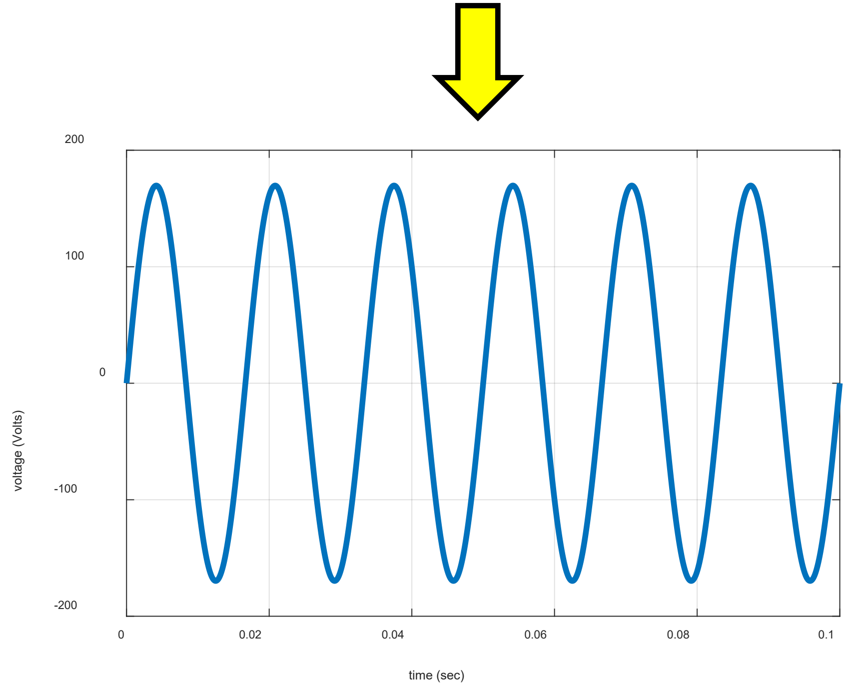
  Q: Since the voltage is always changing, at what point in time do we measure the voltage?

  A: Most equipment that measures AC voltages will specify the voltage in terms of its root-mean-square (RMS) value, V_{rms}.

- It is also common to refer to the peak-to-peak voltage, V_{pp}, of an AC voltage.

In the US, the voltage provided by your wall outlet has a voltage of 120V and a frequency of 60Hz.

It will look like this



Sinusoids

A sinusoidal voltage has the general form

$$v(t) = V_o \cos(\omega t + \theta)$$

and is described by three parameters

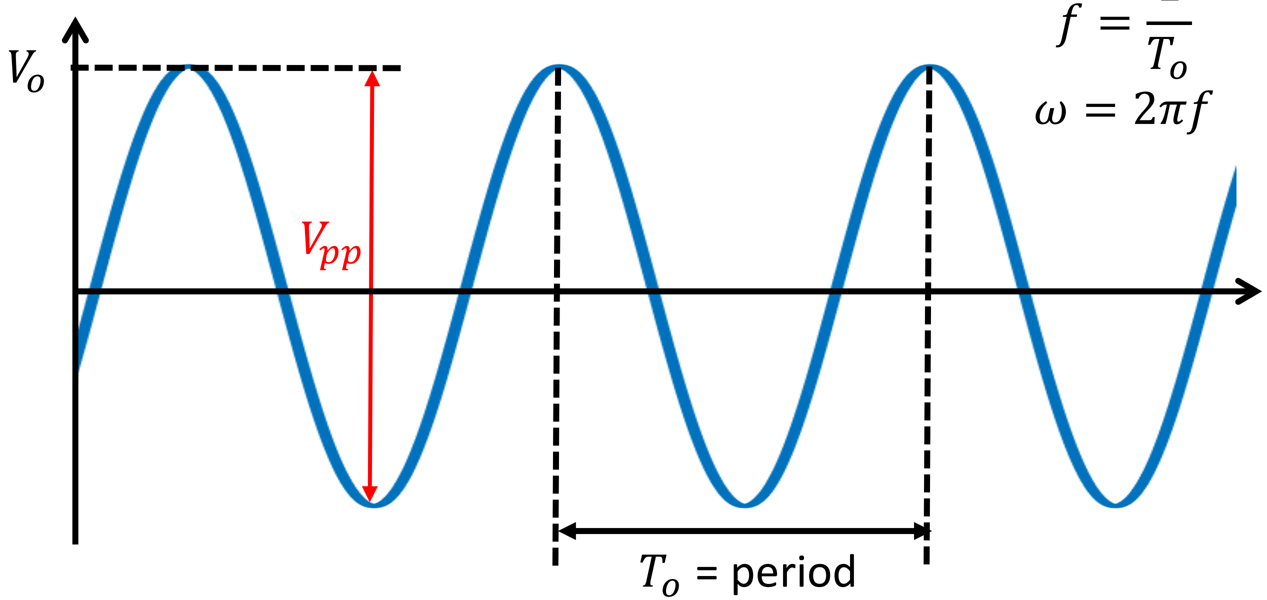
V_o = amplitude (volts)

θ = phase (radians or degrees)

ω = frequency (rad/sec)

or $f = \omega / 2\pi$ = frequency in Hz (cycles per sec)

Note: When we use the word "sinusoid," it doesn't have to mean just a sine. It could be a cosine or any time/phase shifted version.



$$f = \frac{1}{T_o}$$

$$\omega = 2\pi f$$

RMS Voltage (or Current)

It is common to describe a periodic waveform in terms of its "root mean squared" (RMS) value.

$$V_{rms} = \sqrt{\langle v^2(t) \rangle}$$

In the above definition, the angular brackets represent a time average:

$$\langle x(t) \rangle = \frac{1}{T_o} \int_{t_o}^{t_o+T_o} x(t)dt$$

where T_o is the period and t_o is any convenient starting point.

Try to prove this: For a sinusoidal waveform,

$$V_{rms} = \frac{V_o}{\sqrt{2}}.$$

That is, the RMS amplitude is the peak value divided by 1.414. Also,

$$V_{pp} = 2V_o \Rightarrow V_{rms} = \frac{V_{pp}}{2\sqrt{2}}.$$

You don't need to memorize the definition of RMS. The name tells you what to do. You just have to remember to do them in reverse order.

RMS=root, mean, square

1) Square the signal
2) Take the mean (average)
3) Take the square root.

Power

- **Definition:** Power is the rate of energy (work) expended per unit time.

$$\mathrm{P} = \frac{dw}{dt}$$

P=power (Watts)

t=time (seconds)

w=work or energy (Joules)

$$1 \text{ Watt} = \frac{1 \text{ Joule}}{1 \text{ second}}$$

- Note also that

$$P = \frac{dw}{dt} = \frac{dw}{dq} \cdot \frac{dq}{dt} = v \cdot i$$

1 Watt = (1 volt)(1 amp)

Units and Modifiers

- As engineers, we tend to use the metric system for measuring various quantities:

Quantity	Variable	Units
Voltage	V	Volts
Current	I	Amps
Energy (Work)	E (or W)	Joules
Power	P	Watts
Resistance	R	Ohms
Capacitance	C	Farads
Inductance	L	Henrys

- These units are then coupled with modifiers to adjust the range of values to commonly encountered levels:

Modifier	Letter	Value
pico	p	10^{-12}
nano	n	10^{-9}
micro	μ	10^{-6}
milli	m	10^{-3}
kilo	k	10^{3}
mega	M	10^{6}
giga	G	10^{9}
tera	T	10^{12}

Units and Modifiers

Examples:

Value	Scientific Notation	With Modifier	Alternative Modifier
0.00254A	2.54×10^{-3} A	2.54mA	2540μA
900,000,000Hz	9×10^{8} Hz	900MHz	0.9GHz
0.00000000059F	5.9×10^{-10} F	590pF	0.59nF

After you start using these modifiers, they will become second nature to you, but until then commit them to memory.

At least in electrical engineering, we almost never use modifiers that don't represent multiples of 1000 or 1/1000 (like centi- deca-, etc.)