CG1111: Engineering Principles and Practice I

Fundamentals of Electricity

NUS
National University of Singapore

What We'll Learn

- Basic electrical quantities

Electric charge

Electric current

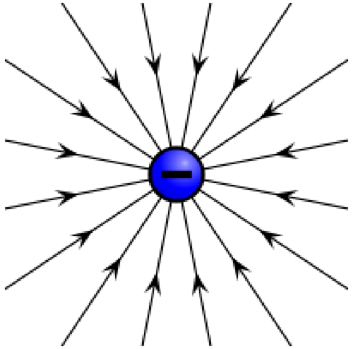
Power

Voltage

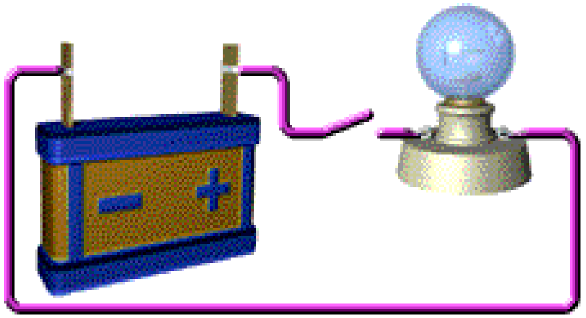
Electrical resistance

What is Electric Charge?

- Electric charge is the physical property of matter that causes it to experience a force when placed in an electromagnetic field
- Smallest charge that exists:
  - –Charge carried by an electron: $q_e = -1.602 \times 10^{-19} C$
  - –The SI derived unit of electric charge is coulomb (C)
- In a conductor, when under the influence of an electric field, electrons will move, giving rise to an electric current



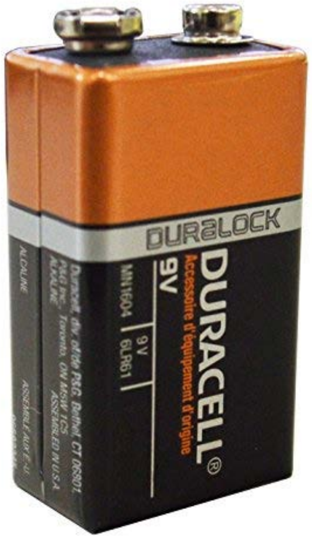
Voltage: The Pressure of Electricity



Credit: Picture from Intel

- There is something about the battery that pushes the electricity...

Voltage: The Pressure of Electricity

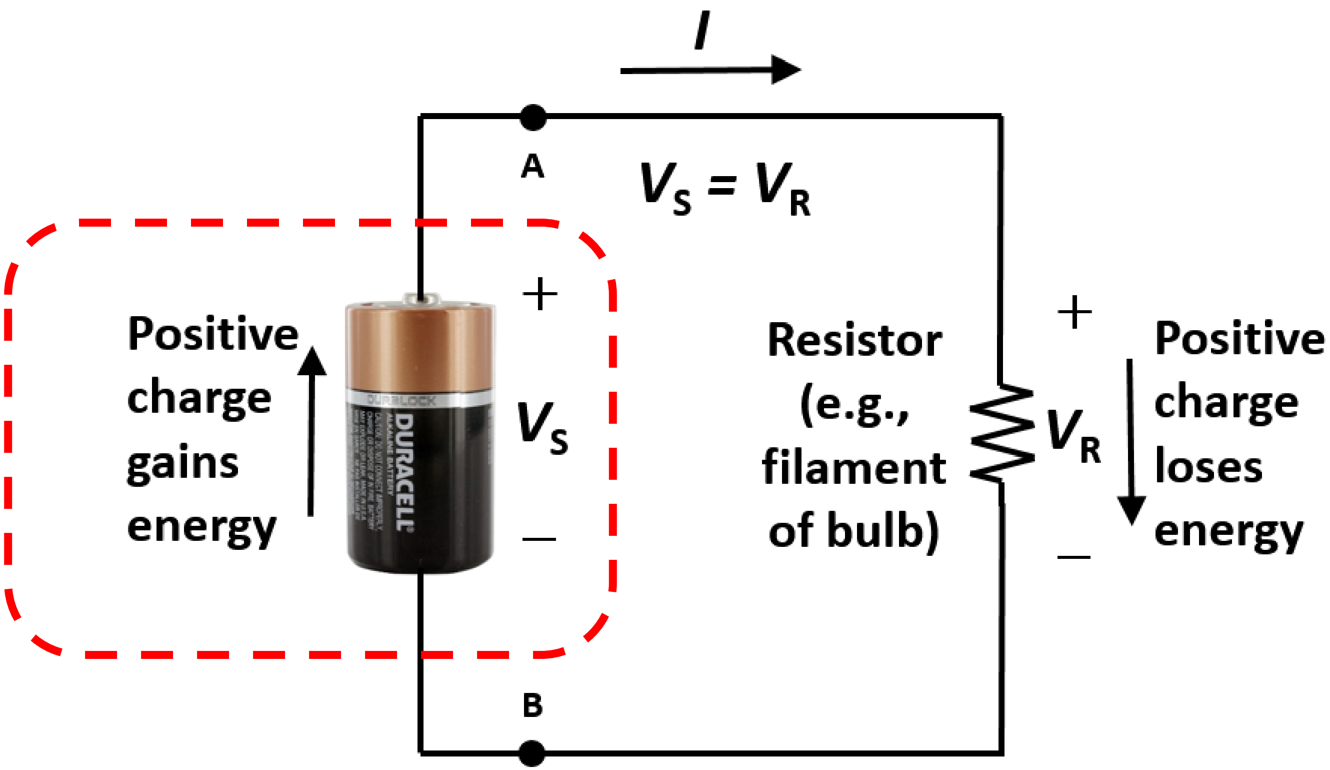


- Voltage: the amount of electrical pressure
- Unit of voltage: Volt (V)
- Also called electromotive force (EMF)

Voltage: A More Formal Definition

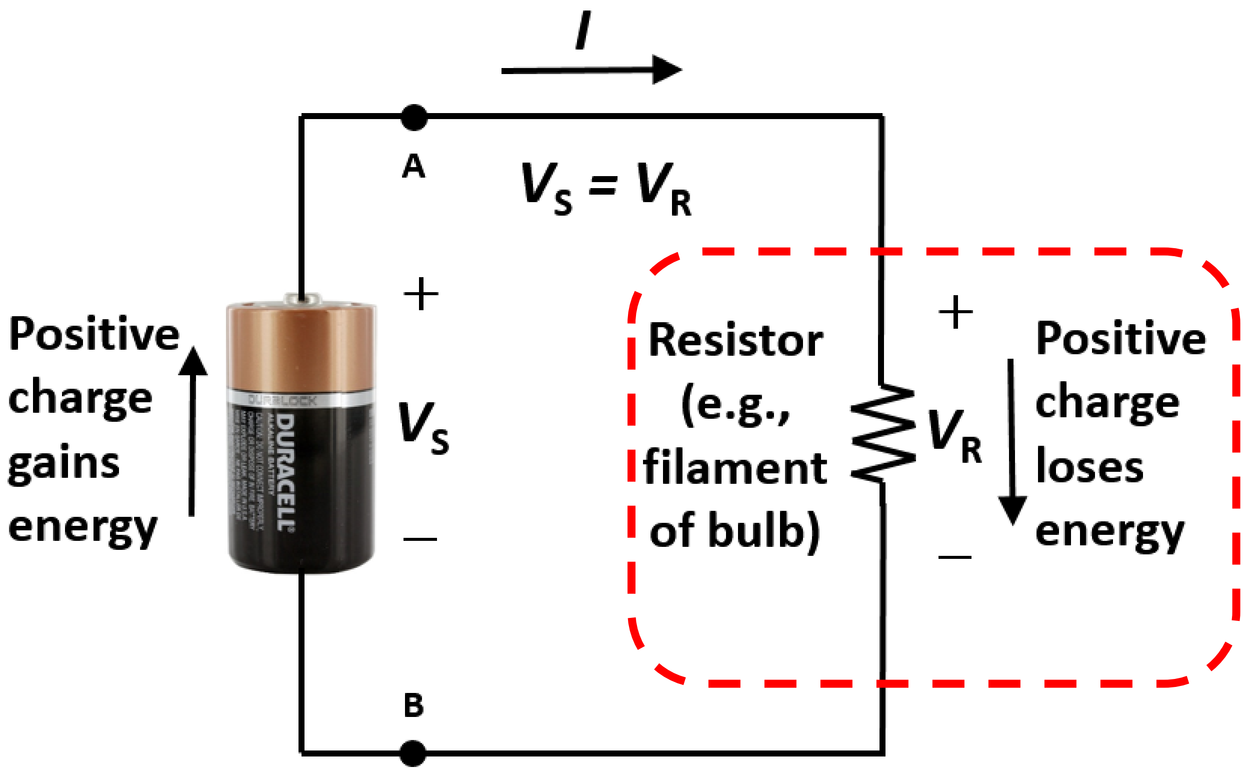
- It is a measure of the energy transferred per unit charge when the charge is moved from one point to another point
  - Unit: Volt (V), equivalent to Joules/Coulomb (J/C)
  - Voltage is always measured across two ends of an element with labeled polarities
  - The '+' terminal is at a higher energy level than the '–' terminal

Active Element (Source)



- If positive charge enters the negative polarity & exits the positive polarity of an element
  - The charge gains energy from the element
  - The element is a "source" (active element)

Passive Element (Load)



- If positive charge enters the positive polarity & exits the negative polarity of an element
  - The charge loses energy in the element
  - The element is a "load" (passive element)

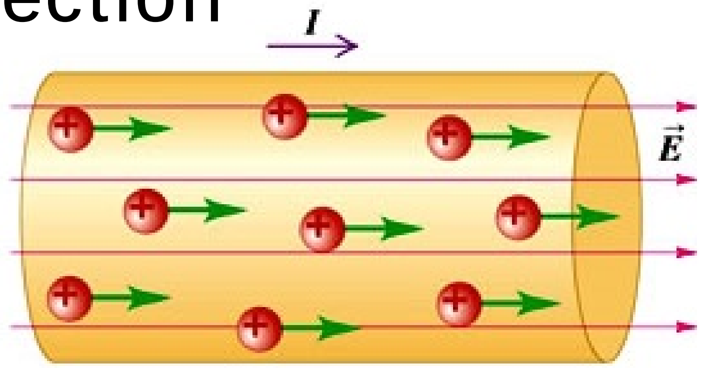
Electric Current

- Electric current = time rate of flow of electrical charges through an element
- Unit: Ampere (A)
- 1 Ampere = 1 Coulomb / second

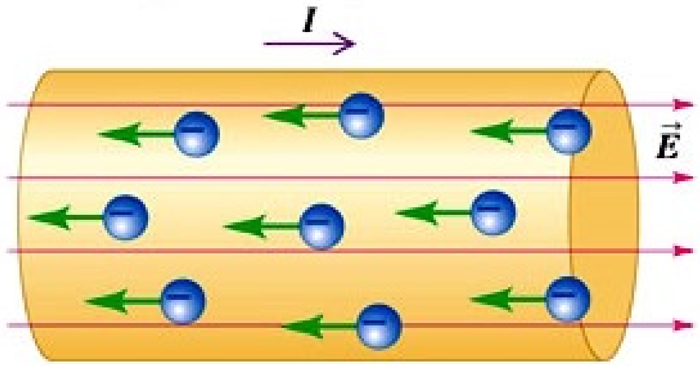
iPhone's charging current: ~1A

Electric Current Has Direction

- Direction of positive current = direction of flow of positive charges
  - –Regardless of whether the free charges in the conductor are positive, negative, or both
- For the case of negative moving charges (e.g., electrons in metals), the current is defined to be positive in the opposite direction



Positive moving charges



Negative moving charges

Electric Power

- Recall that
  - –Voltage = Energy transferred per unit charge
  - –Current = Charge per unit time
- Voltage x Current = Rate of energy transfer
  = Power
- Examining their units, we have

  V x A = (J/C) x (C/s) = J/s = W (Watts)

$$\boxed{P = V \times I}$$

Resistance & Ohm's Law

- When electric current flows through a wire or other circuit elements, it encounters some opposition
- Ohm's Law states that the voltage across an ideal resistor is proportional to the current through it
- The constant of proportionality is called "Resistance" (unit: Ohm)

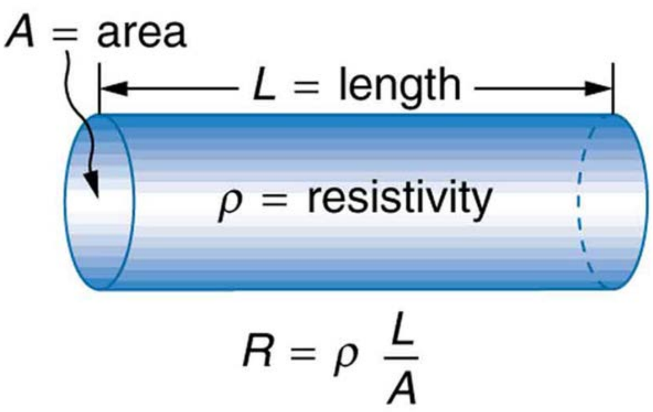
Ohm's Law: $\boxed{V = I \times R}$

Point to Note About Ohm’s Law

- Ohm’s Law is an empirical relationship, i.e., observed through experiments
- It is only an approximation
  - It does not hold at very high voltage & current values, as well as very low voltage & current values

Resistance

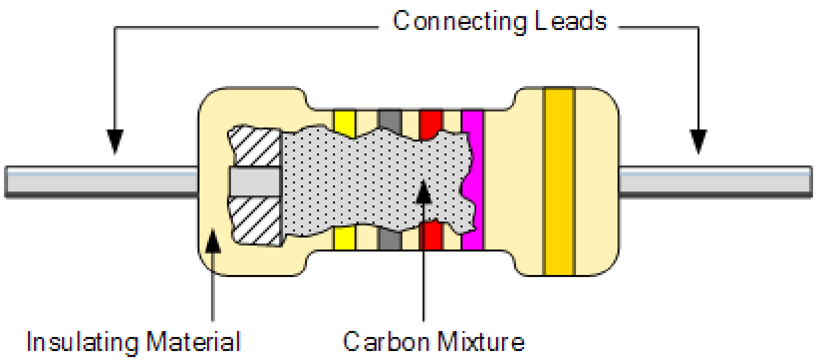
- Resistance depends on the material as well as the geometry of the element



Material	Resistivity ρ (Ωm)
Silver	1.629×10^{-8}
Copper	1.725×10^{-8}
Gold	2.271×10^{-8}
Aluminium	2.733×10^{-8}
Iron	9.98×10^{-8}

Practical Resistors

- Useful in electrical circuits because you can use them to control the behaviour in other parts of the circuit



- For example, a resistor can be used to limit the current flowing through an LED:
  - To control the desired brightness
  - To prevent it from burning out

What Happens When Current Flows Through Resistance?

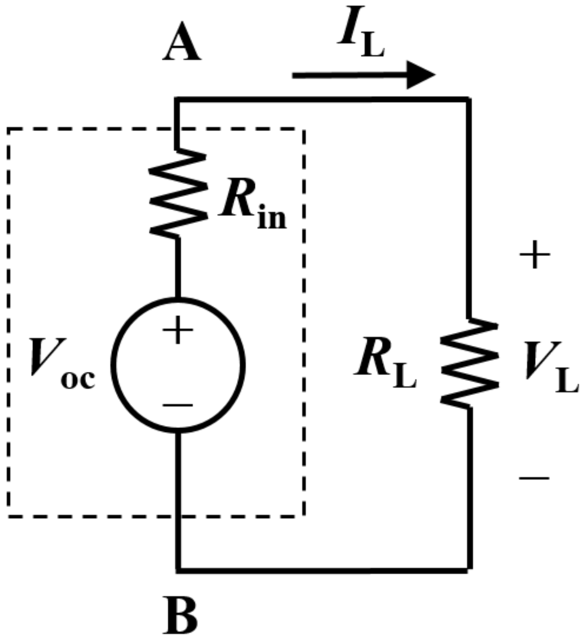
- Charge particles lose energy to the element $\rightarrow$ voltage drop
- Besides voltage drop, the energy loss also heats up the element
- Power loss $P_L = V \times I = (I \times R) \times I = I^2 \times R$
- Hence, $P_L \propto I^2$!!!
- Commonly used resistors in the lab $\rightarrow$ rated at 0.25 W

Practical Voltage Source

- In practice, voltage sources like batteries have internal resistance
  - There will be a voltage drop across this internal resistance (in series) when current is drawn
  - The higher the load current, the higher the voltage drop, & the higher the power loss

$$V_{AB} = V_{oc} - I_L R_{in}$$

$\cong$



Wires Must Have Sufficient Cross-Sectional Area!

- Recall that $R = \frac{\rho L}{A}$
- If $A \uparrow$, $R \downarrow$, and hence $P_L \downarrow$ for the same I
- Hence, the appropriate A for wires depend on the max current expected
  - –Notice that jumper cables used for jump-starting cars are thick because of the high current
  - –Otherwise wires start to melt!

THANK YOU