Lecture 2 – Resistance

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Power

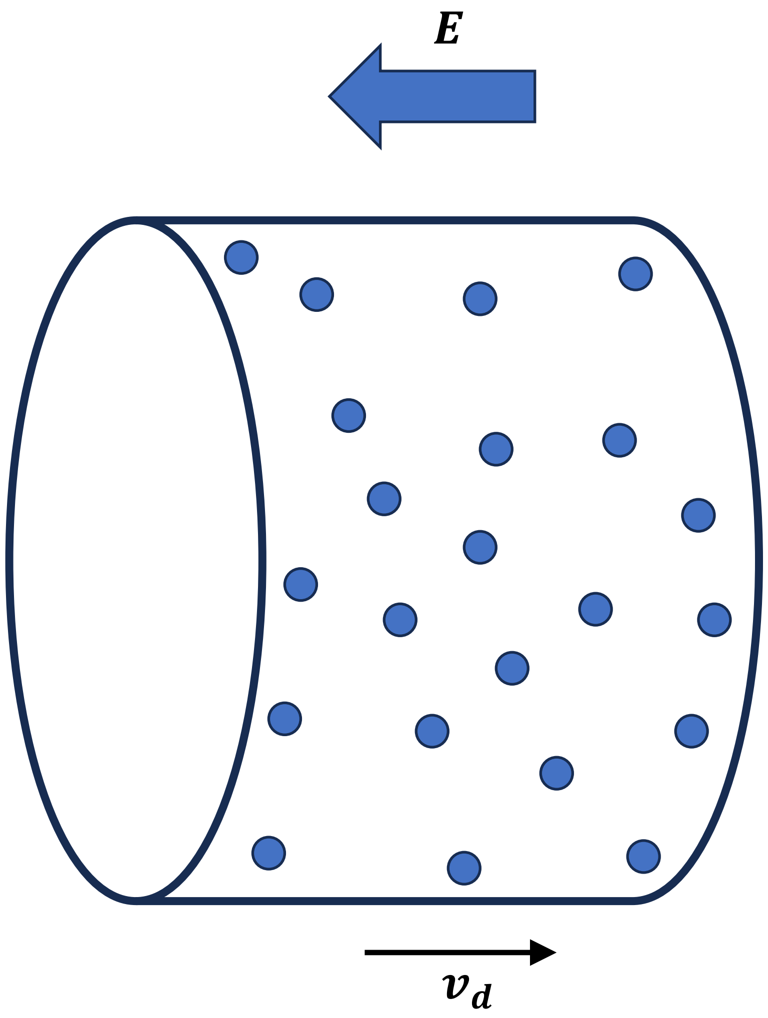
- Let us analyse the power being exerted by the electrons in motion

- We know that electrons are moving at terminal velocity:
  - Electric field force
  - Drag force due to material scattering

$$P = F\, v_d$$

$$P = eE\ \mu E$$

$$P = e\mu E^2$$



Power

$$P = e\mu E^2$$

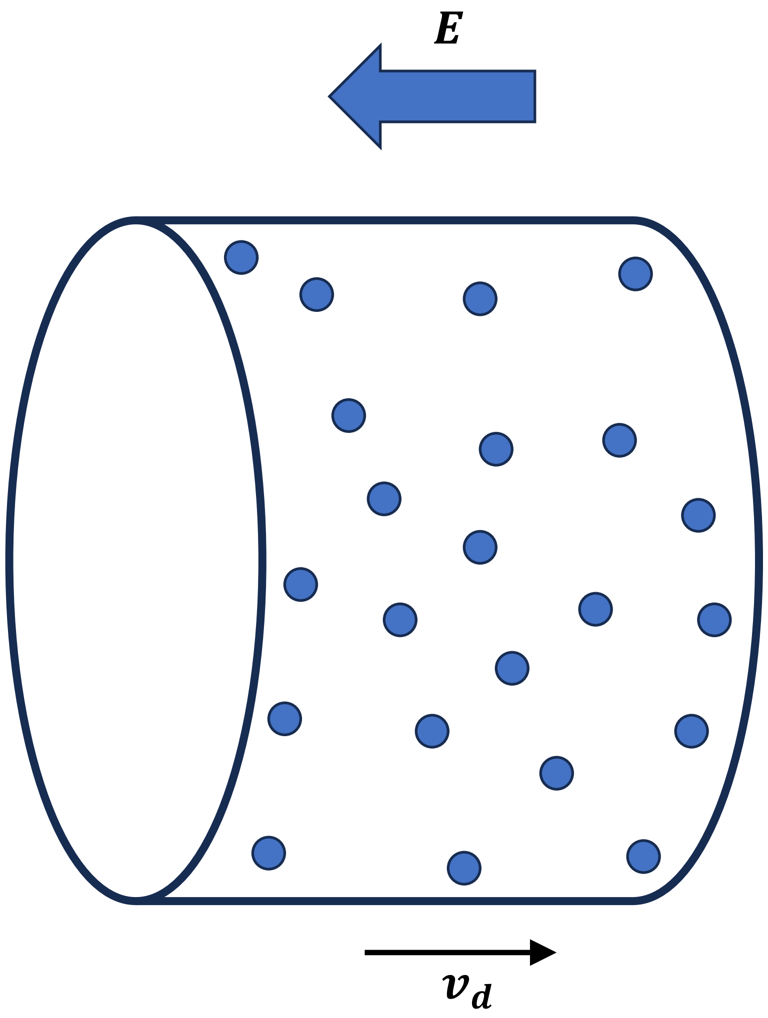
- This is the power exerted by one electron
- In the complete wire, the total power exerted by all electrons is:

$$P = nAL\, e\mu E^2$$

$$P = \frac{AL}{\rho} E^2$$

$$P = \frac{A}{\rho L} V^2$$

$$\boldsymbol{P = \frac{V^2}{R}}$$



Energy

$$\boldsymbol{P = \frac{V^2}{R}}$$

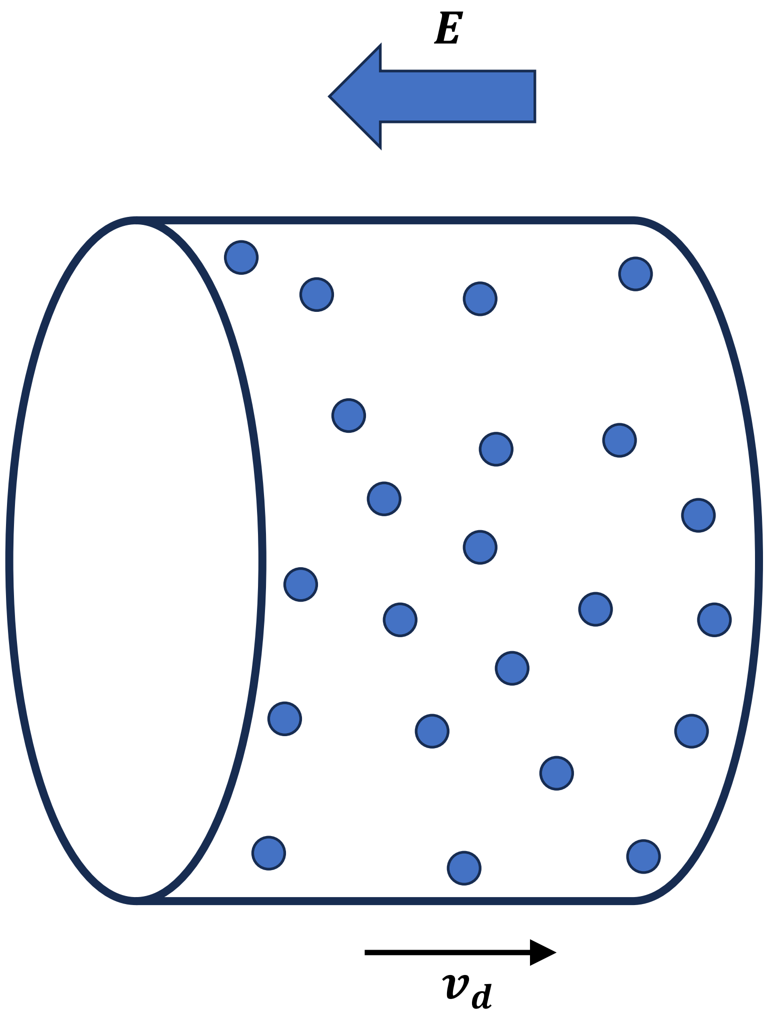
$$\boldsymbol{P = I^2 R}$$

$$\boldsymbol{P = IV}$$

- Power dissipated is constant
- Thus, energy dissipated linearly increases with time

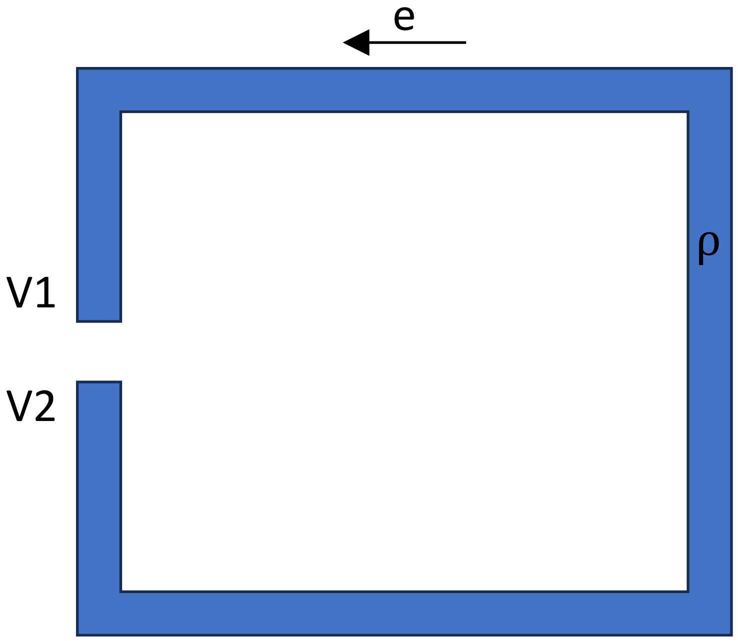
$$E = IVt$$

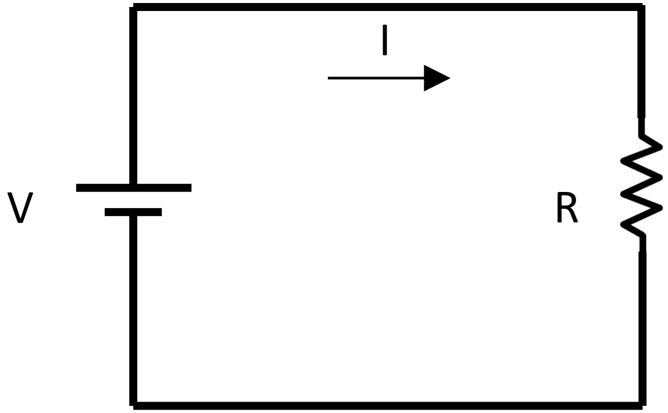
- Just like in case of drag, this energy gets dissipated as heat



The electrical circuit

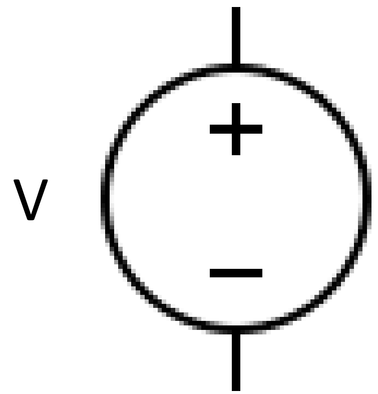
- A real electrical circuit looks like this
- However, this is difficult to analyse and scale, so we create a *mathematical model* of the circuit
- Whenever we talk about a circuit element, we are referring to this model, which is an approximation of the real thing
- This is the *lumped-element* model
  - The lines are ideal conductors ($\rho = 0$)
- The direction of current flow is taken to be from higher potential to lower potential
  - This is to match other observations in nature – like gravitational field, pressure etc.

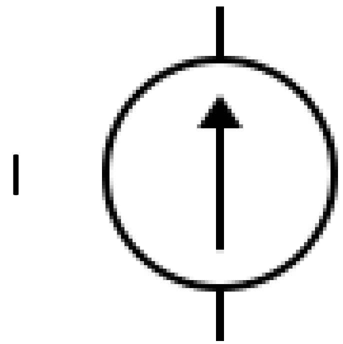




Voltage sources

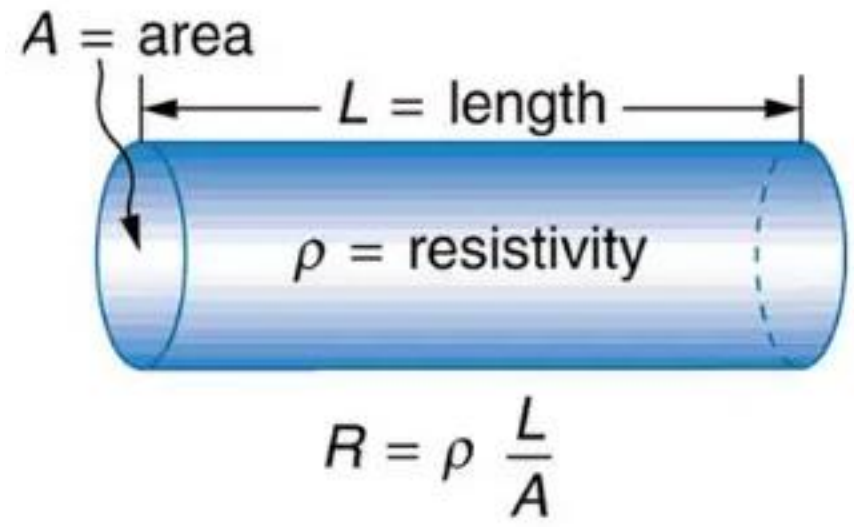
- In the lumped model, voltage sources are represented as a circuit element
- Early experimenters used Galvanic cell or Voltaic cell to produce voltage for their experiments
- These elements act as the source of energy for the circuit
- In some cases, it is more convenient to represent a source of energy as providing constant current, as a "constant current source"





Resistance

- Resistivity is a material property
- It depends on the number of free electrons and their effective mass
- Effective mass is based on the curvature of the E-k function of a specific band
  - This is calculated by solving the Schrodinger equation for a given lattice
- Number of free electrons depends on the energy distribution in the material, and on temperature
  - This is calculated using the Fermi-Dirac statistics
- To create a resistance of a specific value, we can use a material of known resistivity, area and length



Scattering

- Electrons in motion are scattered due to many reasons
- All these scatterings result in reduced mobility

1. Lattice scattering
2. Surface roughness scattering
3. Structural defect scattering
4. Electron-electron scattering

- If more than one source of scattering is present, it is a good approximation to combine their influences using “Matthiessen's Rule”

$$\frac{1}{\mu} = \frac{1}{\mu_l} + \frac{1}{\mu_{sr}} + \frac{1}{\mu_{sd}} + \frac{1}{\mu_{ee}} + \cdots$$

Temperature dependence

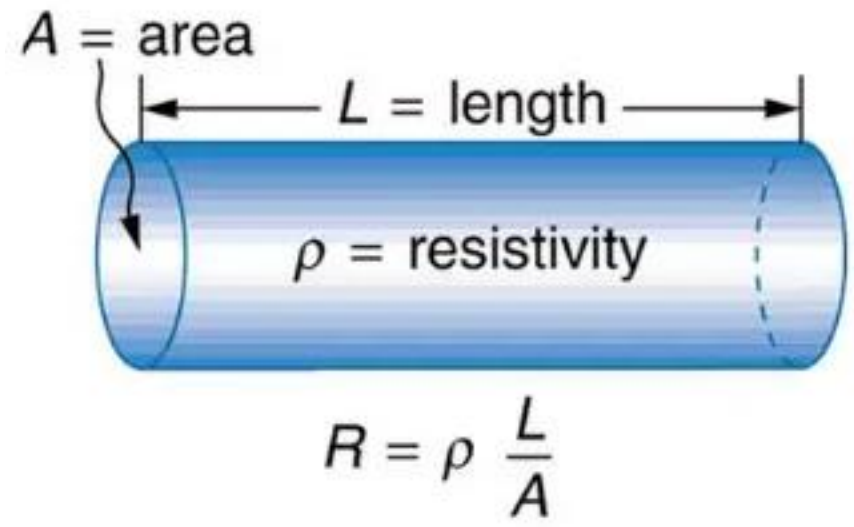
- Dependence on temperature is a key problem of resistors
- Increase is temperature causes increase in thermal oscillations inside a metal wire, with the number of free carriers being the same (approx.)
- Because of this, scattering from the atoms increases, increasing "drag", and causing resistivity to increase

$$\alpha = \frac{1}{\rho}\frac{d\rho}{dT}$$

- For small changes,

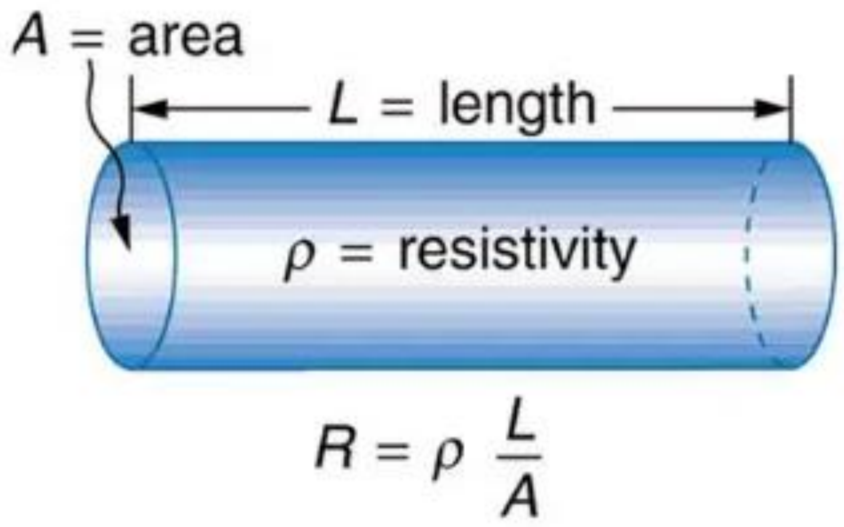
$$\rho_T = \rho_0(1 + \alpha\Delta T)$$

$$R_T = R_0(1 + \alpha\Delta T)$$



Resistance rating

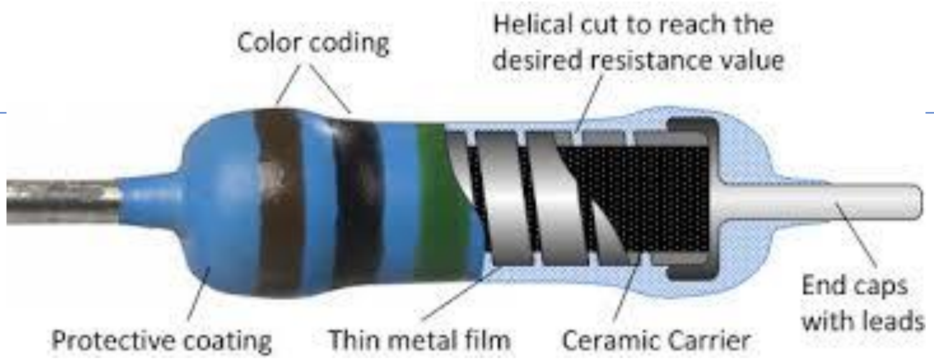
- The heat dissipated in a resistance causes its temperature to increase
- Thus, resistance increases slightly, before everything stabilizes when input power is equal to radiated power
- However, this is not true for very high levels of power
- Thus, resistors have a maximum current rating, i.e., they cannot be subjected to current more than a specific value [first real concept of the class!]
    - Typical rating is ¼ W, 1+ W is high power rating
- Further, resistances also have tolerances, i.e., what is the expected deviation in resistance value from the rate value
    - Typically in %, 1% is good, 10% is bad

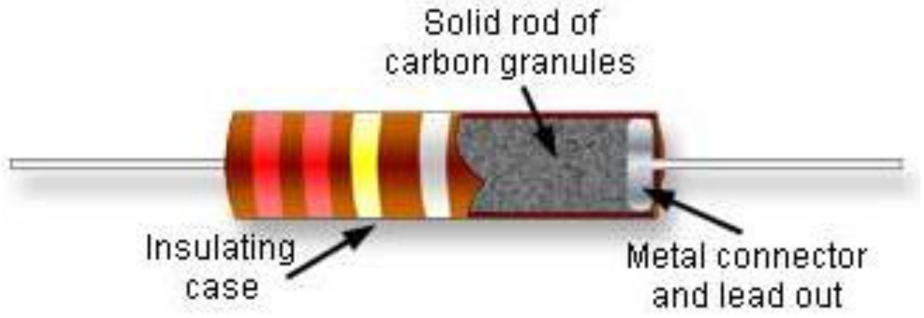


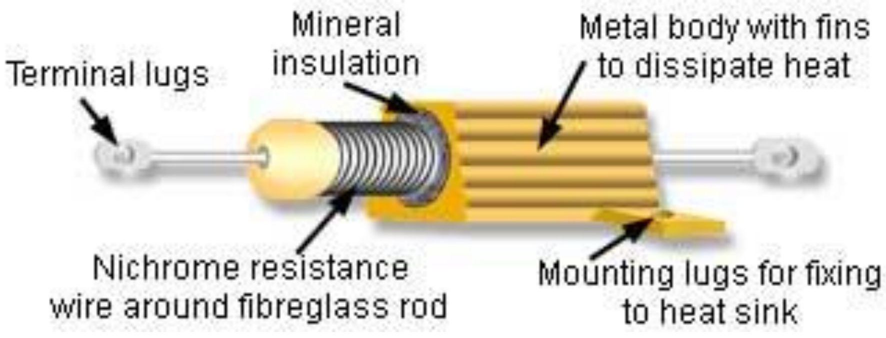
Making of a resistance

- Resistances are made:

1. Using a resistive thin film of specific dimensions, say a carbon, metal or tin oxide thin film
    - Very good tolerances
2. Using a composite of carbon particles (filler) in a non-conducting medium
    - The ratio of the filler particle determines the resistivity of the concoction
3. Using metal wire winding (nichrome etc)
    - Low resistance values
    - High power ratings

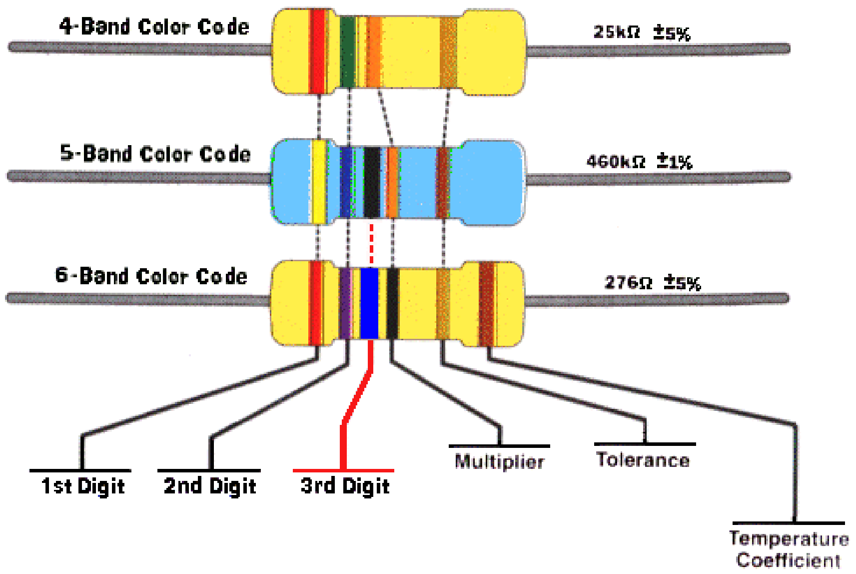






Colour code

- Resistances are coded with colour bands to identify their value and tolerance



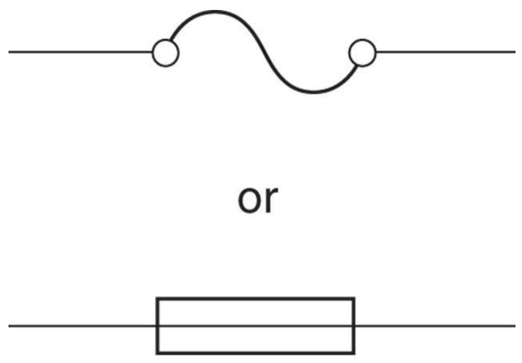
	Color	Value	Multiplier	Tolerance
Bad	Black	0	$\times 10^0$	± 20%
Beer	Brown	1	$\times 10^1$	± 1%
Rots	Red	2	$\times 10^2$	± 2%
Our	Orange	3	$\times 10^3$	± 3%
Young	Yellow	4	$\times 10^4$	- 0, + 100%
Guts	Green	5	$\times 10^5$	± 0.5%
But	Blue	6	$\times 10^6$	± 0.25%
Vodka	Violet	7	$\times 10^7$	± 0.10%
Goes	Gray	8	$\times 10^8$	± 0.05%
Well	White	9	$\times 10^9$	± 10%
Get	Gold	–	$\times 10^{-1}$	± 5%
Some	Silver	–	$\times 10^{-2}$	± 10%

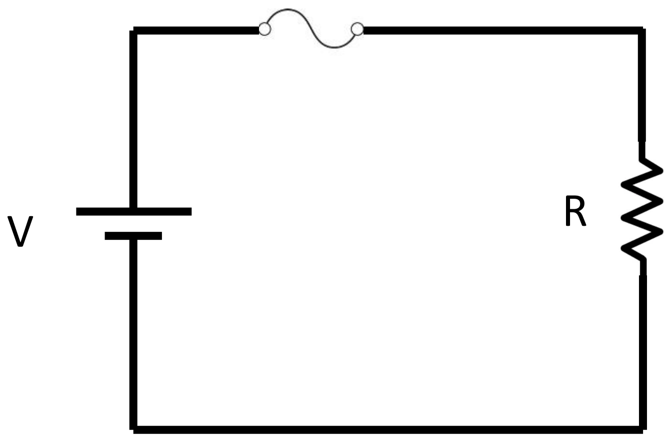
Fuse

- Fuse is a special resistor that is designed to malfunction!

- The design is such that if current more than a specific value is passed, the fuse should heat up so much that it melts/or malfunctions, and stops conducting (invented by Thomas Edison)

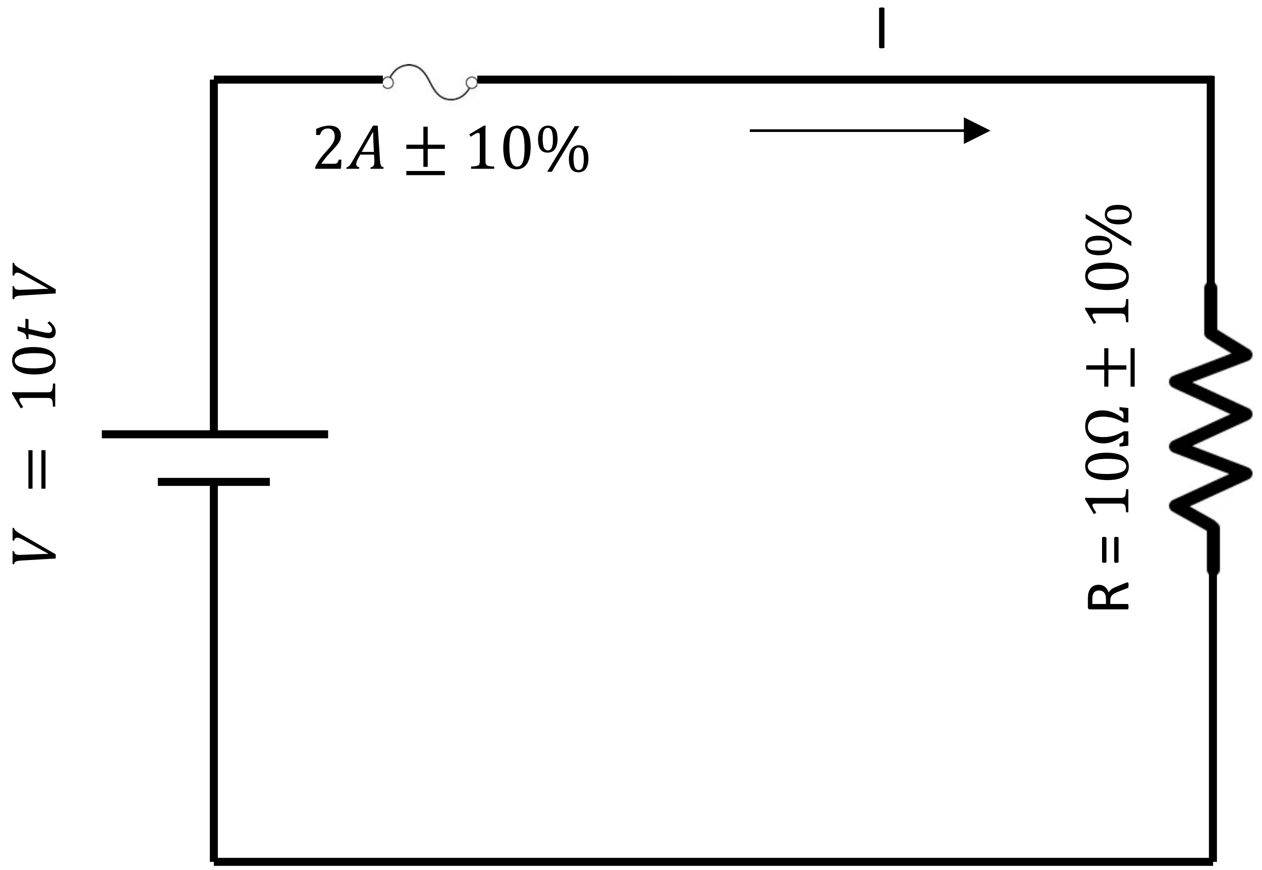
- This leads to isolation of the remaining circuit and can protect important devices





Example

- When will this circuit trip?
- What should be the power rating of the resistance?



Early applications of electricity

- First ever application of electricity was in medicine
  - In 1745, doctors in Geneva began to treat patients with electric shocks. A Swiss physician reported that victims of paralysis could sometimes be cured by repeated shocks to their muscles.
- In 1829, Joseph Henry used a large battery to build a powerful electromagnet. It could do heavy work, such as lifting hundreds of pounds of metal
- In 1850s, The Nollet generator was the first to be produced in large numbers by a manufacturing firm. They were used in electroplating, the first industrial operation to employ electricity
- In 1880s, EV cars!
  - In fact, 1899-1912, electric automobiles outsold gasoline-powered cars