Electric power and Joule heating

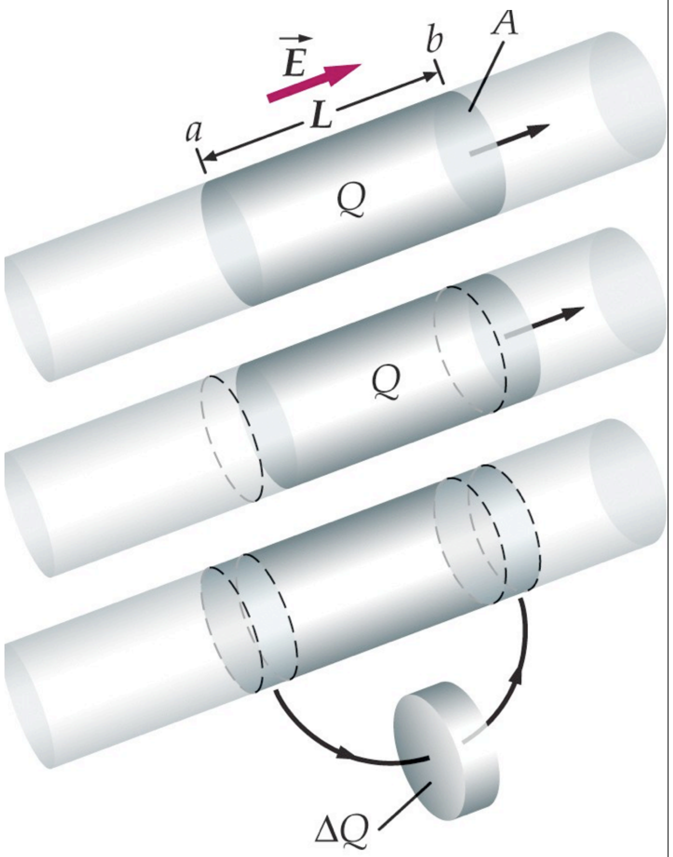
- As a charge moves from *a* to *b*, the change in electric potential energy is:

$$\Delta U = \Delta Q(V_b - V_a)$$

- Since $V_a > V_b$ it is a loss
- Rate of potential energy loss=power dissipated in conductor:

$$-\frac{\Delta U}{\Delta t} = \frac{\Delta Q}{\Delta t}\Delta V = I\Delta V$$

$$\wp = I\,\Delta V = I^2 R = \frac{V^2}{R}$$



Power companies transmit electricity at high voltages and low currents on power lines to minimize power losses despite higher risk

Electricity distribution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In North America, the power is delivered by a sinusoidal frequency 60 Hz, in Europe 50 Hz.

Early distribution systems used a voltage of 2200 volts, increased to 2400 volts. As cities grew, most 2400 volt upgraded to 2400/4160 Y three-phase systems.

Most cities now have been converted higher voltage systems.

European systems used higher voltages, generally 3300 volts to ground, in support of the 220/380Y volt power systems used in those countries. In the UK, urban systems progressed to 6.6 kV and then 11 kV (phase to phase), the most common distribution voltage.

North American and European power distribution systems also differ in that North American systems tend to have a greater number of low-voltage, step-down transformers located close to customers' premises. For example, in the US a pole-mounted transformer in a suburban setting may supply 1-3 houses, whereas in the UK a typical urban or suburban low-voltage substation might be rated at 2 MW and supply a whole neighborhood. This is because the higher voltage used in Europe (380 V vs 230 V) may be carried over a greater distance with acceptable power loss. An advantage of the North American setup is that failure or maintenance on a single transformer will only affect a few customers. Advantages of the UK setup are that the transformers may be fewer, larger and more efficient, and due to diversity there need be less spare capacity in the transformers, reducing power wastage.

Sources of EMF

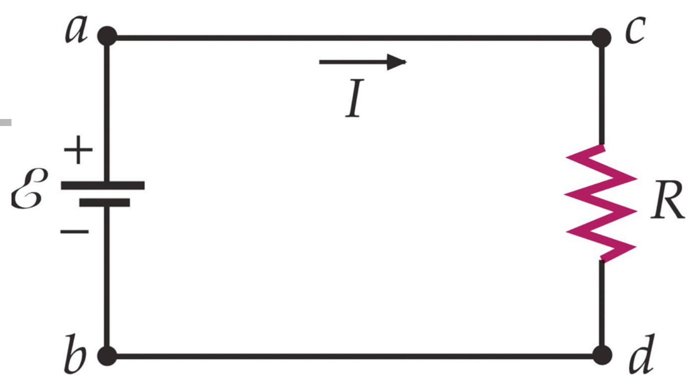
- Battery: source of electromotive force = device that supplies electrical energy to a circuit
- Ideal battery: maintains a constant voltage diff. between its terminals independent of the current through it

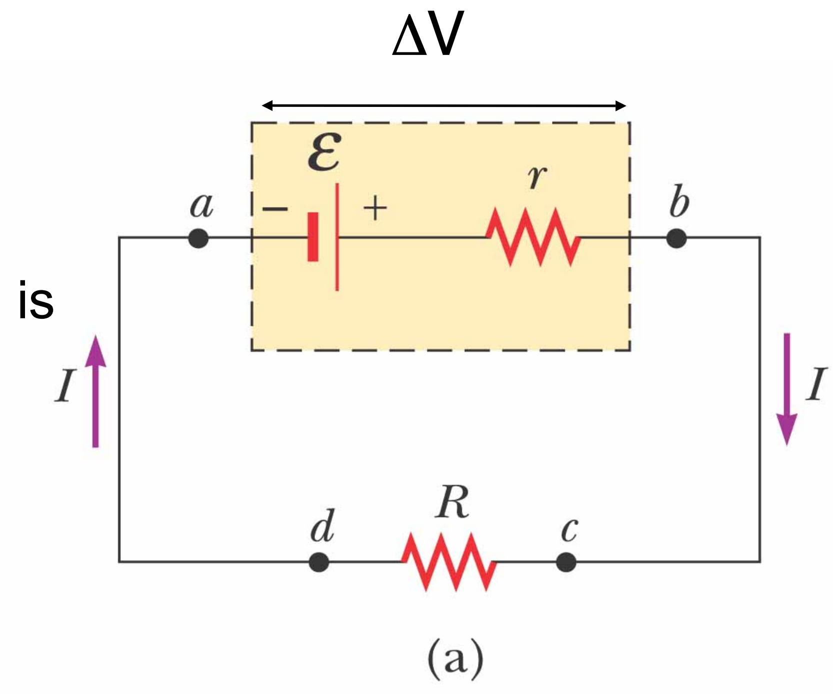
$$\varepsilon = RI$$

- In a real battery, there is internal resistance, *r* and the terminal voltage is

  $\Delta V = \varepsilon - Ir$

  Hence ε *is equivalent to the open circuit voltage (I=0)*

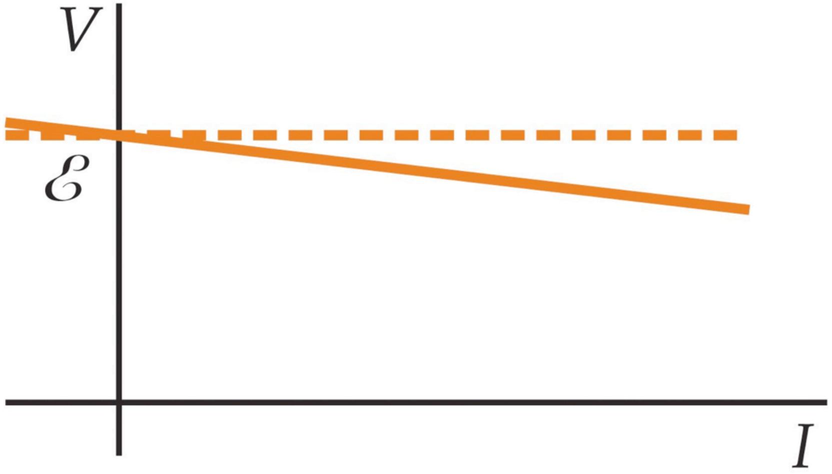




(a)

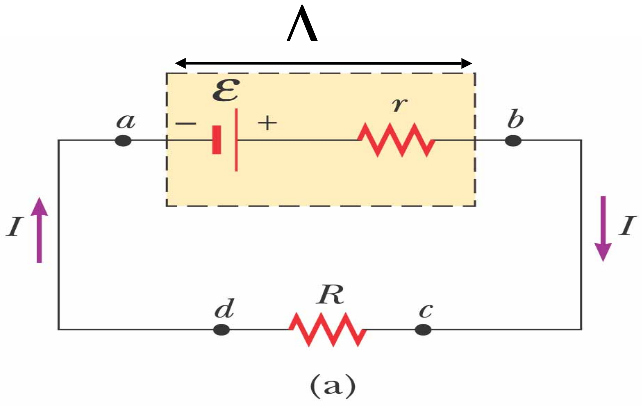
Real battery

- In a real battery the terminal voltage depends on the current through the battery



$$\Delta V = \varepsilon - Ir = RI$$

For an ideal battery: $I = \varepsilon / R$
Notice: I =ε/(r+R)



(a)

- $P = I\varepsilon = I^2 R + I^2 r$

Question:

- find the value of R to be placed at the terminals of a battery to obtain the max delivered power

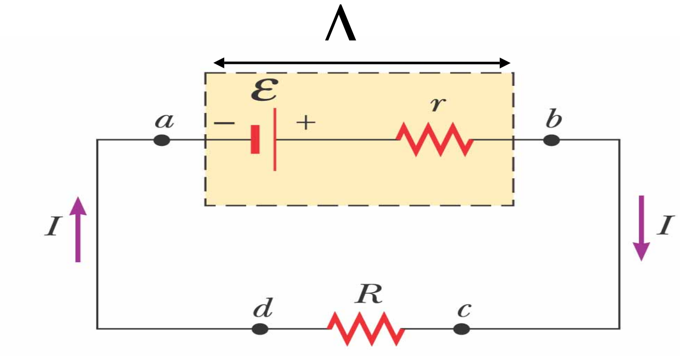
$$I = \frac{\varepsilon}{(r+R)}$$

$$P = RI^2$$

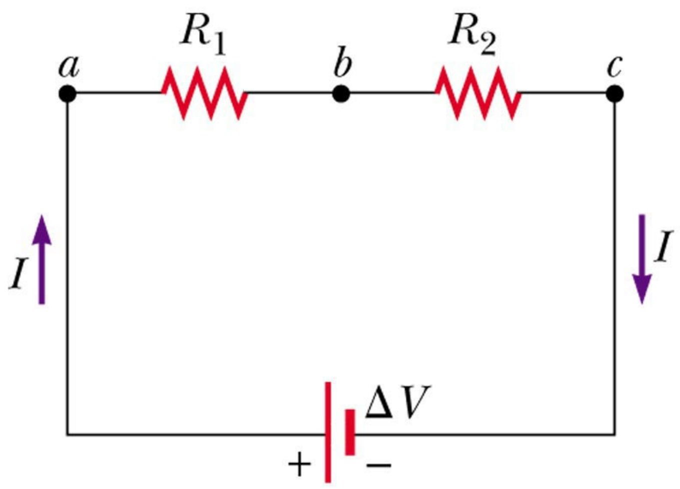
$$\Downarrow$$

$$R = r$$

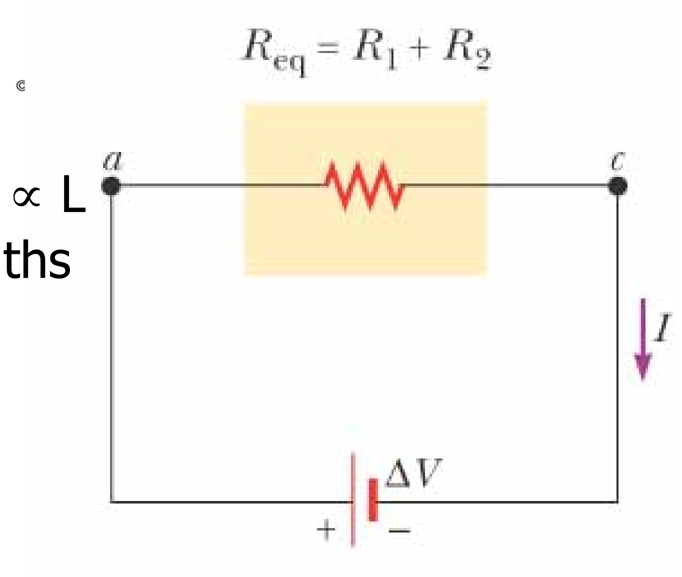
Impedance matching
load

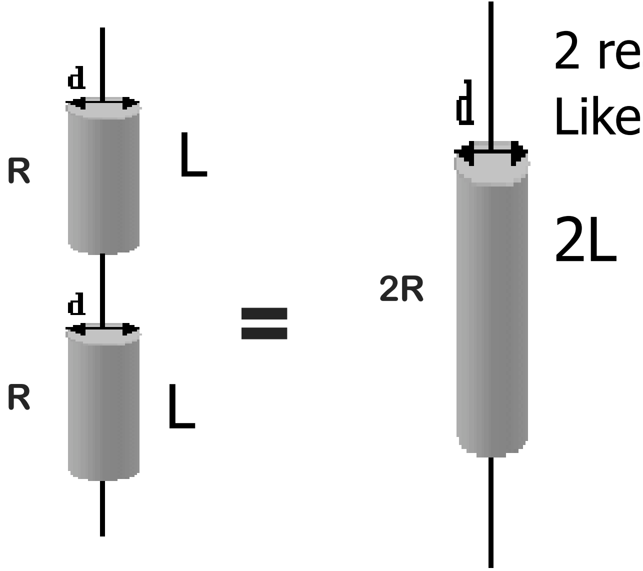


Resistors in Series



- $I_1 = I_2 = I$
- Potentials add
  - $\Delta V = \Delta V_1 + \Delta V_2 = IR_1 + IR_2 =$
    $= I\,(R_1+R_2)$
- The equivalent resistance $R_{eq} = R_1+R_2$



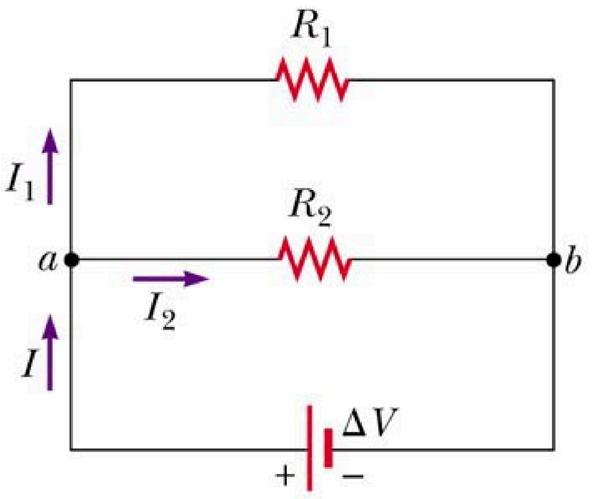


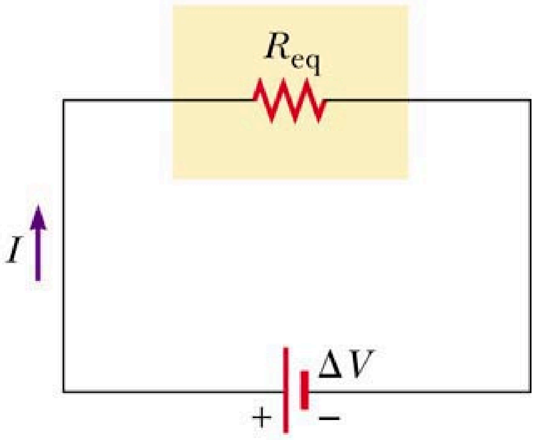
2 resistors in series: R ∝ L
Like summing the lengths

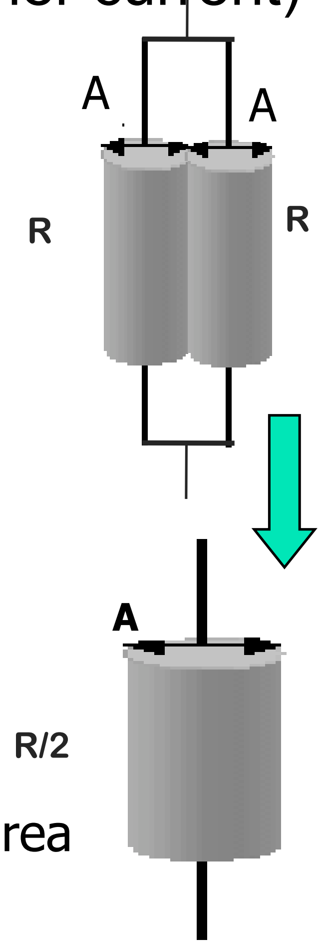
$$R = \rho \frac{L}{A}$$

Resistors in Parallel

- $\Delta V = \Delta V_1 = \Delta V_2$
- $I = I_1 + I_2$ (the lower resistance path will have higher current)
- Equivalent Resistance $$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2}$$



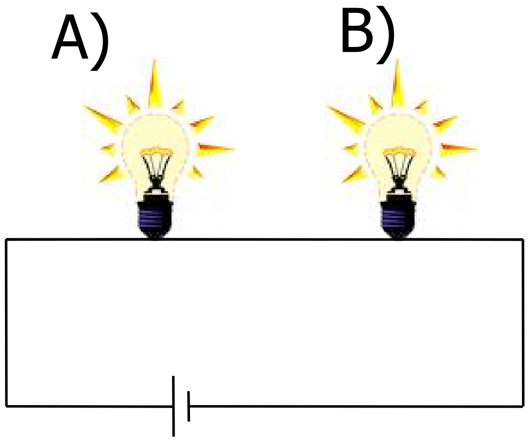




$$R = \rho \frac{L}{A}$$

2 resistors in parallel: effectively adding area and $R \propto 1/A$ so $1/R$ add

2 Identical Light Bulbs in parallel and series

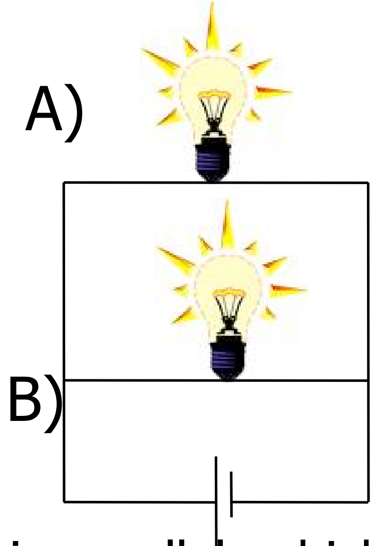


Light Bulbs in series: which is more luminous?

A)

B)

[✓ A) and B) have the same luminosity]



Light Bulbs in parallel: which is more luminous?

A)

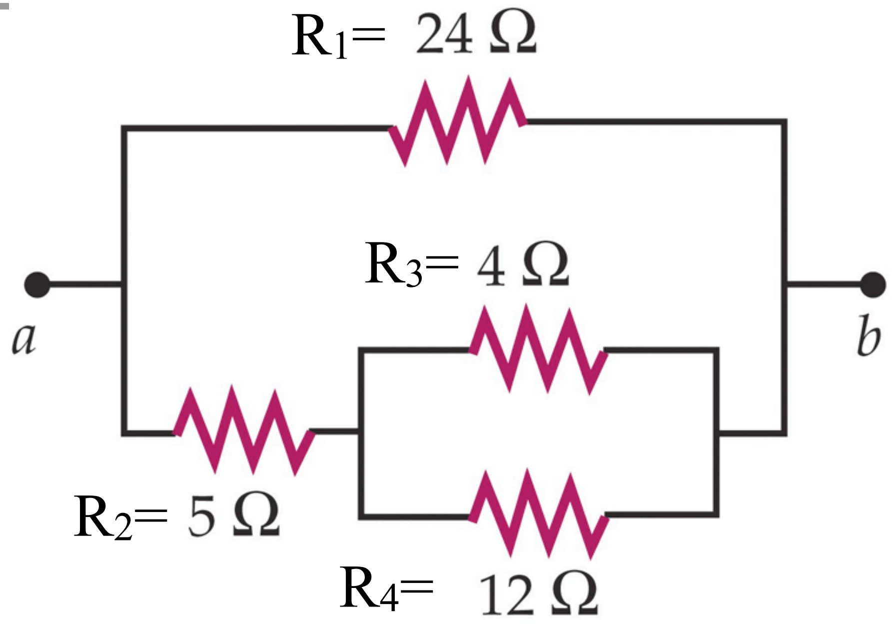
B)

[✓ A) and B) have the same luminosity]

In which of the 2 cases the bulbs will be more luminous?

[✓ - parallel] - series

A combination of resistors



$$R_{eq} = \frac{R_1\left(R_2 + \frac{R_3R_4}{R_3 + R_4}\right)}{R_1 + R_2 + \frac{R_3R_4}{R_3 + R_4}}$$