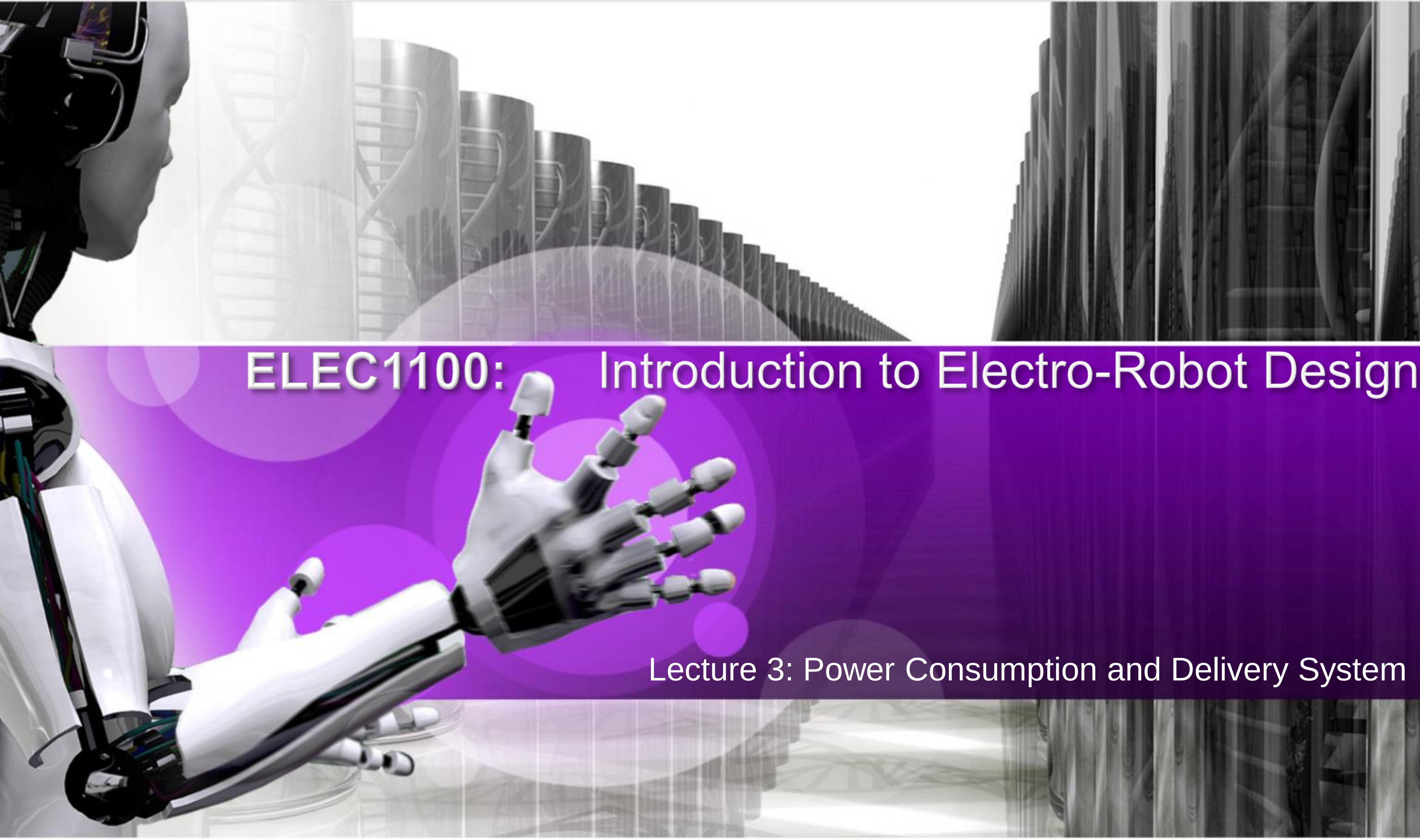
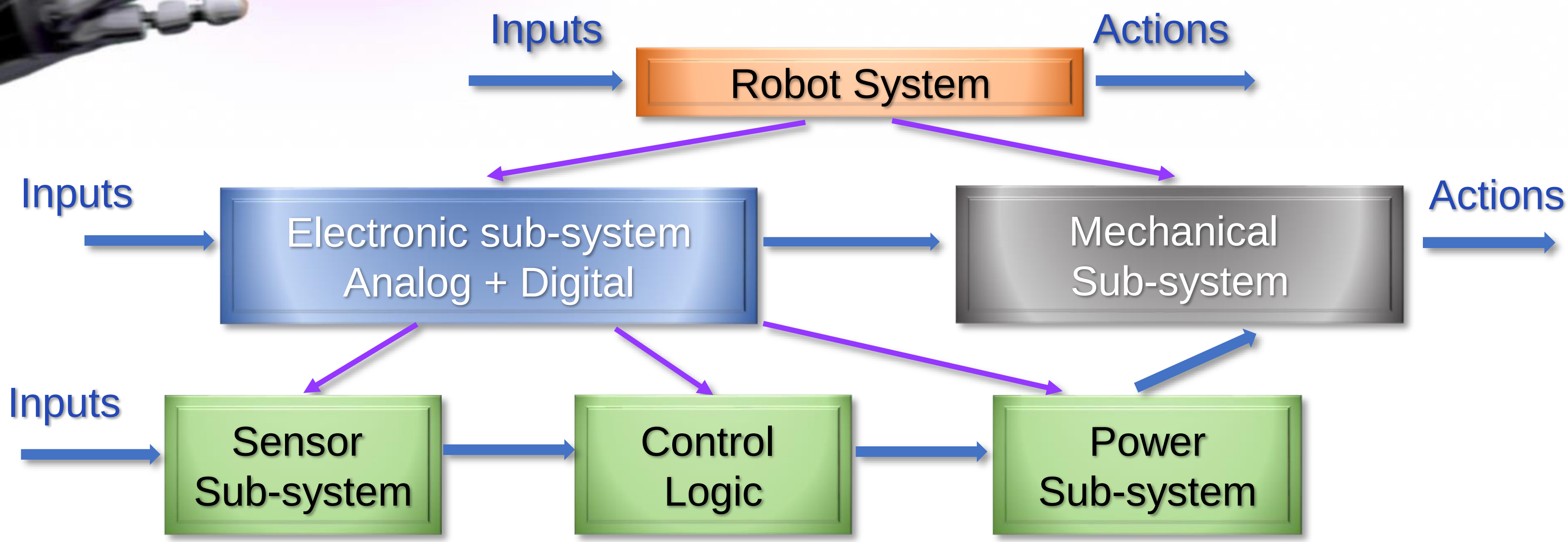


ELEC1100: Introduction to Electro-Robot Design

Lecture 3: Power Consumption and Delivery System

SONG Shenghui and MURCH Ross, Dept. of ECE, HKUST

ELEC1100 ROADMAP



Basic electronics:

Wk1: Basic Electronics - Charge/Current/Voltage/Resistor/

Wk2: Energy/Power and DC Sources

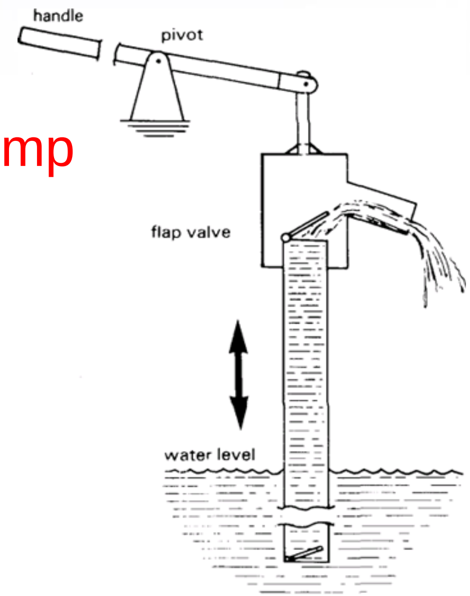
HOW DO WE GAIN ENERGY?

- How does a robot gain energy?

  Mostly, they rely on batteries.

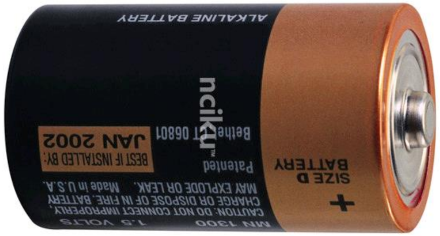
ANALOGIES: WATER SYSTEM AND CHARGE SYSTEM

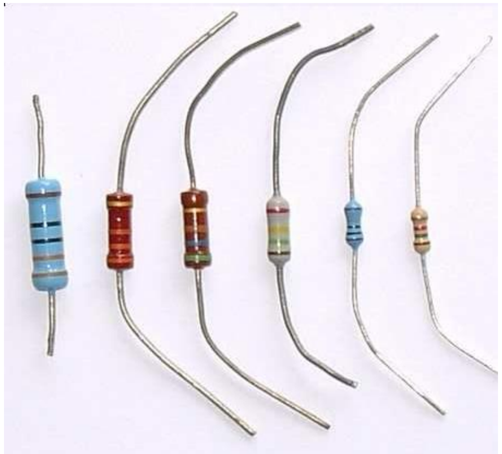
Water Pump



Water Pipe

Battery





Resistor

ENERGY

- Energy is an attribute of objects and systems
- Symbol: E
- Unit: Joule or J
- Forms of Energy:
  - Mechanical: Kinetic and potential
  - Thermal
  - Electrical
  - Chemical
  - ……

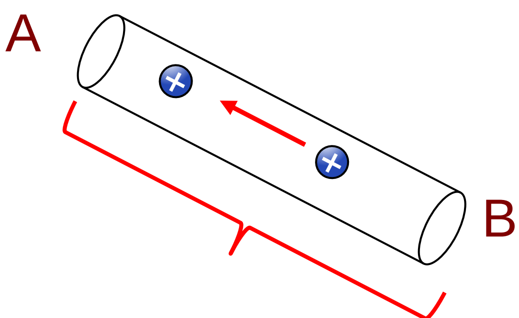
ENERGY CONSERVATION

- Energy can be converted from one form to another, but the total energy is conserved

- Example:
  - a ball falling from the Leaning Tower of Pisa gets its kinetic energy from potential energy
- Revision exercise:
  - a Porsche's mass = 2 tons, velocity = 100 km/h, how much kinetic energy does it have?

VOLTAGE, CURRENT AND ENERGY

- In order to have current flow between two points, we need to have a "voltage difference" between these two points
- A "positive charge" q gains energy when it moves from a point at lower voltage to a point with higher voltage



Voltage difference: V

$$E = q \times V \Rightarrow V = \frac{E}{q}$$

E in joule (J) and sometimes units of electron-volt (eV) are also used for the energy

- Current is the rate of electron flow $I = \dfrac{q}{t}$

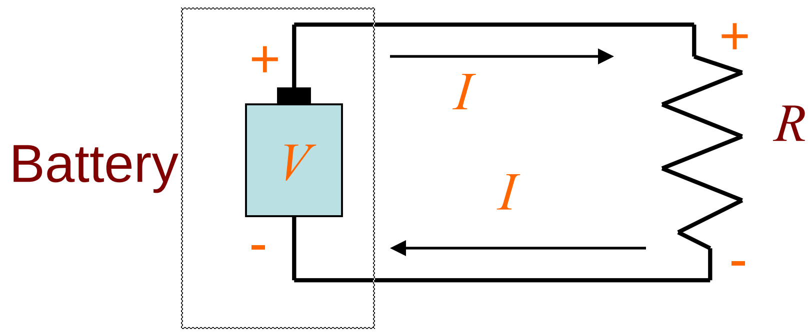
POWER

- Power is defined as the rate at which energy is produced/consumed/dissipated
- Symbol: P
- Unit: Watt or W or J/s

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

ELECTRICAL POWER

❖ Consider a battery supplying a voltage to drive the current through a resistor



$$P = \frac{E}{t} = \frac{E}{q}\frac{q}{t} = VI$$

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

POWER EXAMPLE

- A speaker converts electrical energy into vibration (sound energy)
- Power rating of a speaker is defined as the maximum power that can be delivered to it without damage
- Assume the internal resistance of a speaker is $16\ \Omega$ and the power rating is $100\ \mathrm{W}$. What is the maximum safe current that can be delivered to it?

POWER EXAMPLE

- A speaker converts electrical energy into vibration (sound energy)
- Power rating of a speaker is defined as the maximum power that can be delivered to it without damage

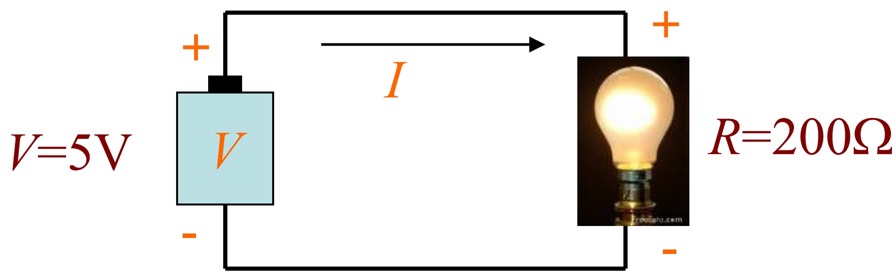
- Assume the internal resistance of a speaker is 16 Ω and the power rating is 100 W. What is the maximum safe current that can be delivered to it?

$$P = I^2 R$$

$$\Rightarrow I = \sqrt{\frac{P}{R}} = 2.5\text{A}$$

ANOTHER EXAMPLE

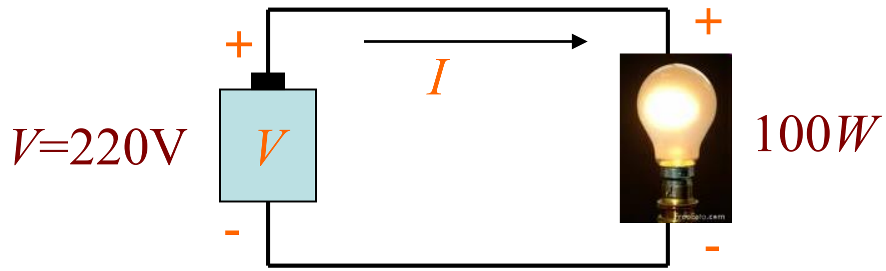
❖ Consider the simple resistor network below. What's the power dissipated by the bulb?



❖ Answer: $$P = \frac{V^2}{R} = 0.125\text{W}$$

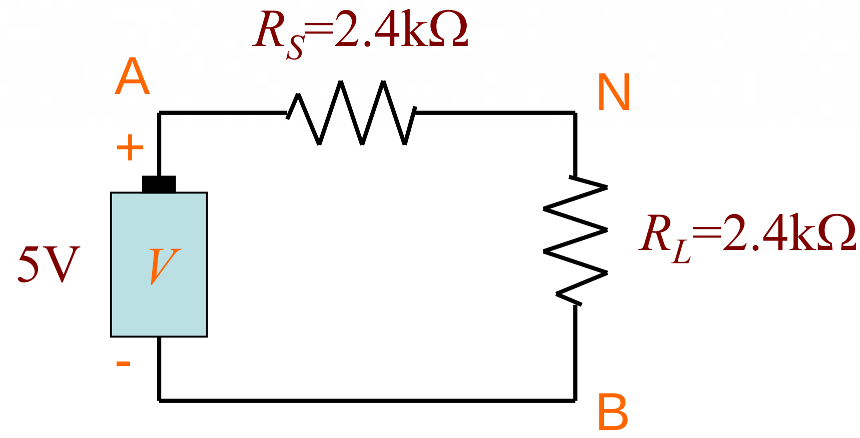
QUIZ [1] : POWER

- Consider the simple resistor network below applied to a light bulk with a given power rating. What is the resistance of the light bulb?



A LITTLE MORE CHALLENGING EXAMPLE

- Consider the simple resistor network below. What's the power dissipated by R_L?



- Answer (method 1):

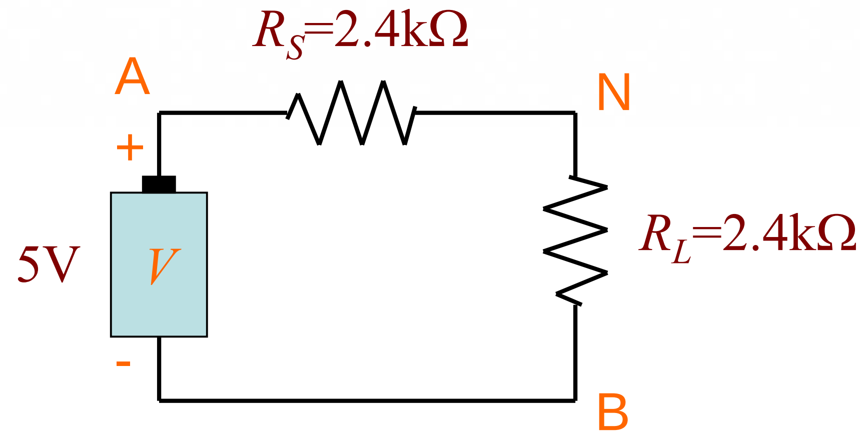
$$\text{total } R = 2.4\text{kW} + 2.4\text{kW} = 4.8\text{kW}$$

$$I = \frac{V}{R} = \frac{5V}{4.8\text{k}\Omega} = 1.04\text{mA}$$

$$P = I^2 R = 1.04\text{mA} \times 1.04\text{mA} \times 2.4\text{k}\Omega = 2.6\text{mW}$$

A LITTLE MORE CHALLENGING EXAMPLE

❖ Consider the simple resistor network below. What's the power dissipated by R_L?



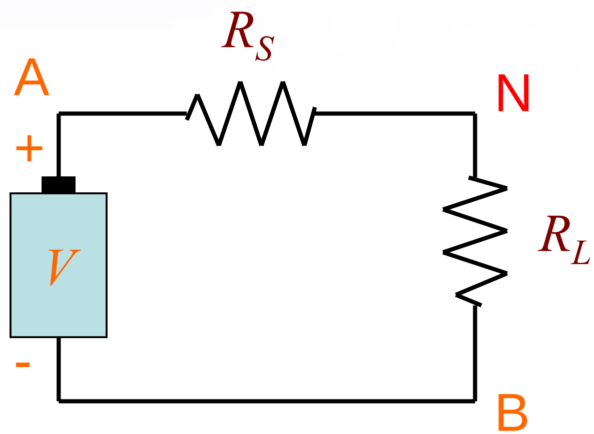
❖ Answer (method 2):

$$\text{total } R = 2.4\text{kW} + 2.4\text{kW} = 4.8\text{kW}$$

$$\text{total } P = \frac{V^2}{R} = \frac{5^2}{4.8\text{kW}} = 5.2\text{mW} \qquad P_{RL} = \frac{5.2\text{mW}}{2} = 2.6\text{mW}$$

VOLTAGE DIVIDER

- What is the voltage at node *N* in the circuit below?



$$\text{Total } R = R_S + R_L$$

$$I = \frac{V}{R} = \frac{V}{R_S + R_L}$$

$$\backslash \quad V_N = IR_L = \frac{R_L}{R_S + R_L} V$$

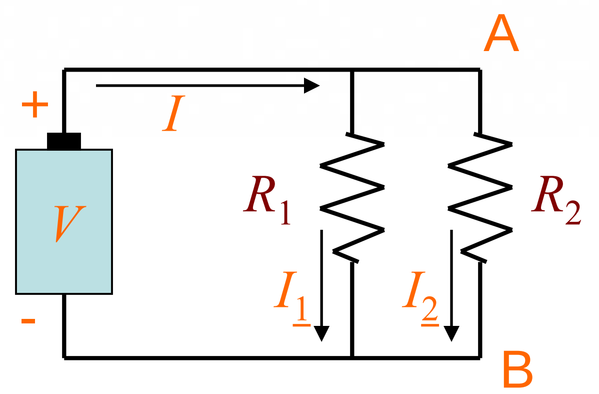
Q: What's implicitly assumed here?

An ideal wire has zero resistance

- Resistors in series, partition of the voltage according to the ratio of their resistances

RESISTORS IN PARALLEL [1]

- Consider the following circuit, what is the equivalent resistance given by R_1 and R_2?

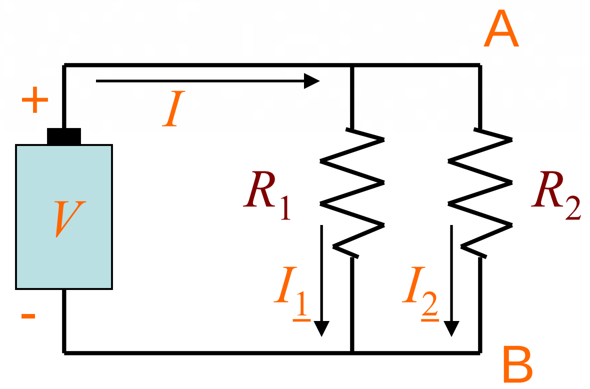


- **Answer:**

$$I_1 = \frac{V}{R_1} \qquad I_2 = \frac{V}{R_2}$$

$$I = I_1 + I_2 = \left(\frac{1}{R_1} + \frac{1}{R_2}\right)V = \frac{R_1 + R_2}{R_1 R_2}V = \frac{V}{R_{eq}} \qquad \backslash \quad R_{eq} = \frac{R_1 R_2}{R_1 + R_2}$$

RESISTORS IN PARALLEL [2]



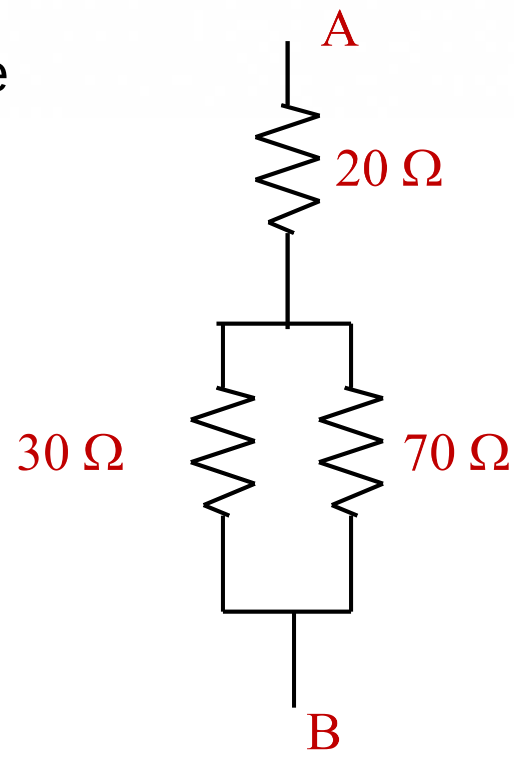
- The total resistance of two resistors in parallel becomes smaller than either one
- For more than 2 resistors in parallel

$$\frac{1}{R_{eq}} = \left(\frac{1}{R_1} + \frac{1}{R_2} \cdots \frac{1}{R_n} \right)$$

- The quantity $1/R$ is denoted as conductance having the unit of Siemens (S)
- Other units of conductance include Ω^{-1}, mho, ℧ etc.

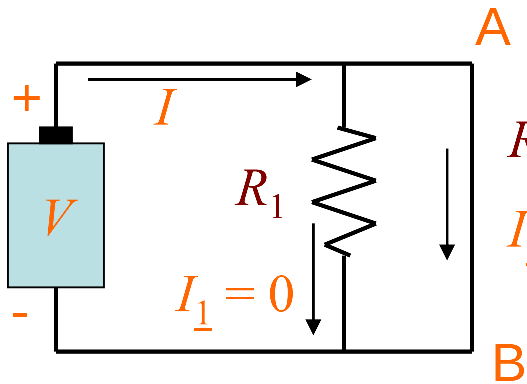
QUIZ [2]: TOTAL RESISTANCE

- For the resistor network given here, what is the equivalent resistance between nodes A and B in Ω?



SHORT CIRCUIT

- A circuit having a **short** is when a path in the circuit is formed with far less resistance (approximate to zero) than any of the pre-existing paths between the same nodes.



$R_2 = 0$ (replaced with a wire)

$I_2 = \infty$ (infinity)

- A short circuit has the potential to damage components!

ENERGY SOURCES

AC

Power Plant

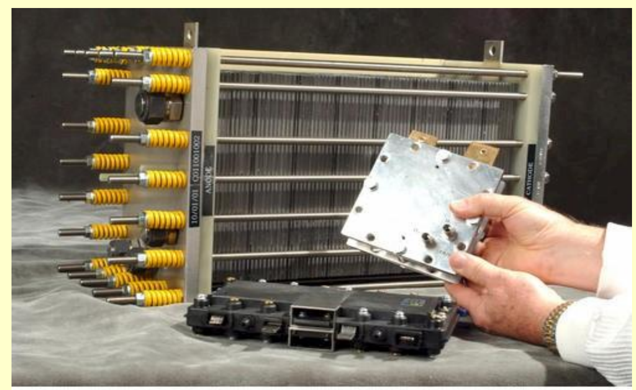
Power Generator

DC

Batteries

Energy Harvesting

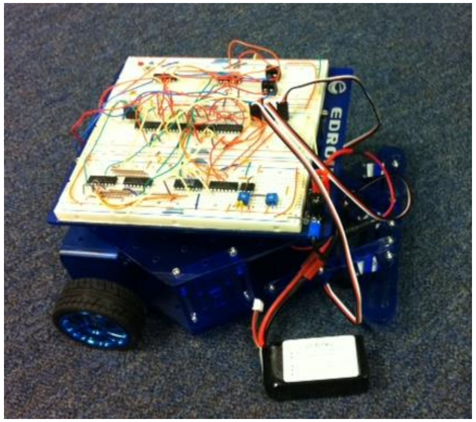
Solar Cell

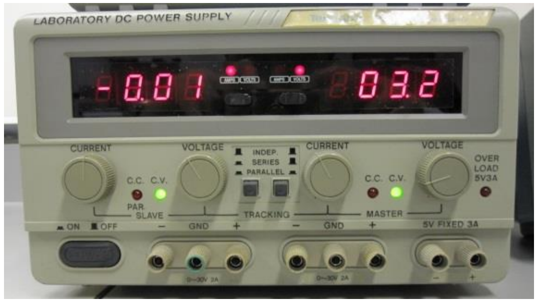


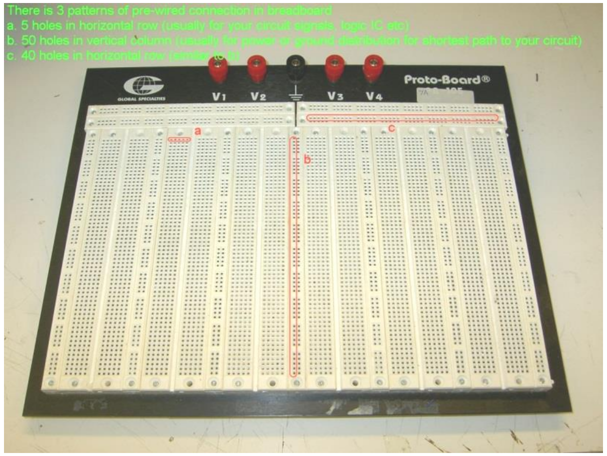
Courtesy of The National Renewable Energy Laboratory (NREL)

Fuel Cell

POWER SOURCES IN YOUR LAB





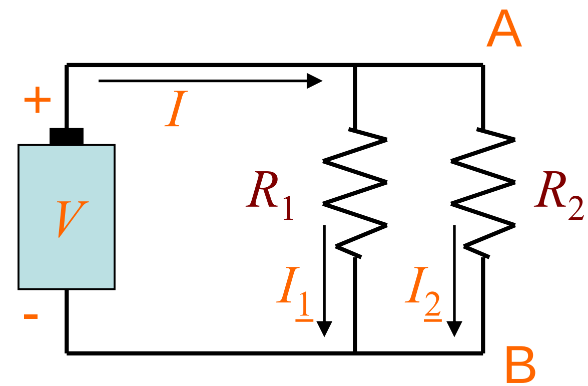


LECTURE SUMMARY

- Energy given by $E = q \times V$
- Power given by

$$\boxed{P = \frac{E}{t} = \frac{E}{q}\frac{q}{t} = VI} \quad \text{or} \quad \boxed{P = I^2 R = \frac{V^2}{R}}$$

- Power calculation in a circuit
- Calculating equivalent resistance in parallel resistors



$$R_{eq} = \frac{R_1 R_2}{R_1 + R_2} \quad \text{or} \quad \frac{1}{R_{eq}} = \left(\frac{1}{R_1} + \frac{1}{R_2} \cdots \frac{1}{R_n}\right)$$

NEXT LECTURE

- Battery characteristics
- DC sources
- Diodes and Voltage regulation

QUESTIONS?