# Electricity and Magnetism

- Physics 259 – L02
- Lecture 34

UNIVERSITY OF CALGARY

# Chapters 26 & 27

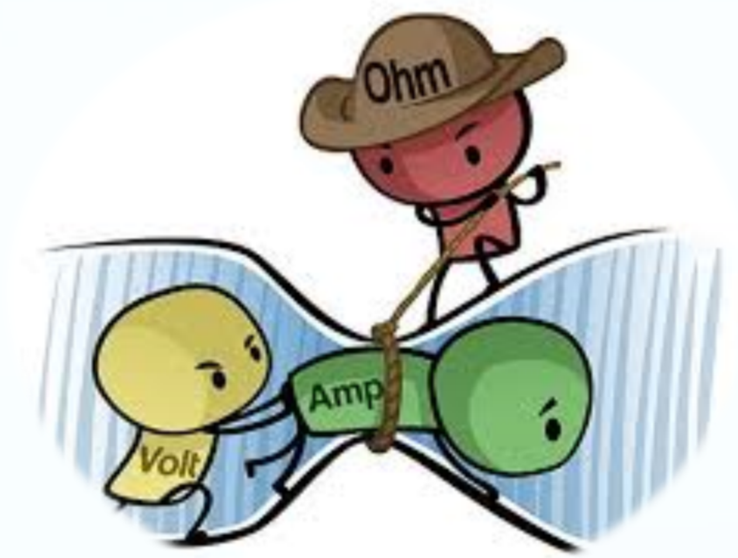
# Last time

- Chapter 25- Capacitance

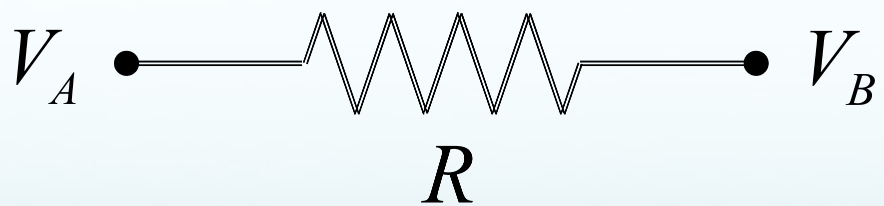
## This time

- Chapters 26 and 27

# 26-4 Ohm's Law




When a voltage difference $\Delta V$ is applied across a resistor $R$, the voltage difference causes electrons to flow through the resistor




This flow of electrons is the electric current $I$. These quantities are related by Ohm's Law:

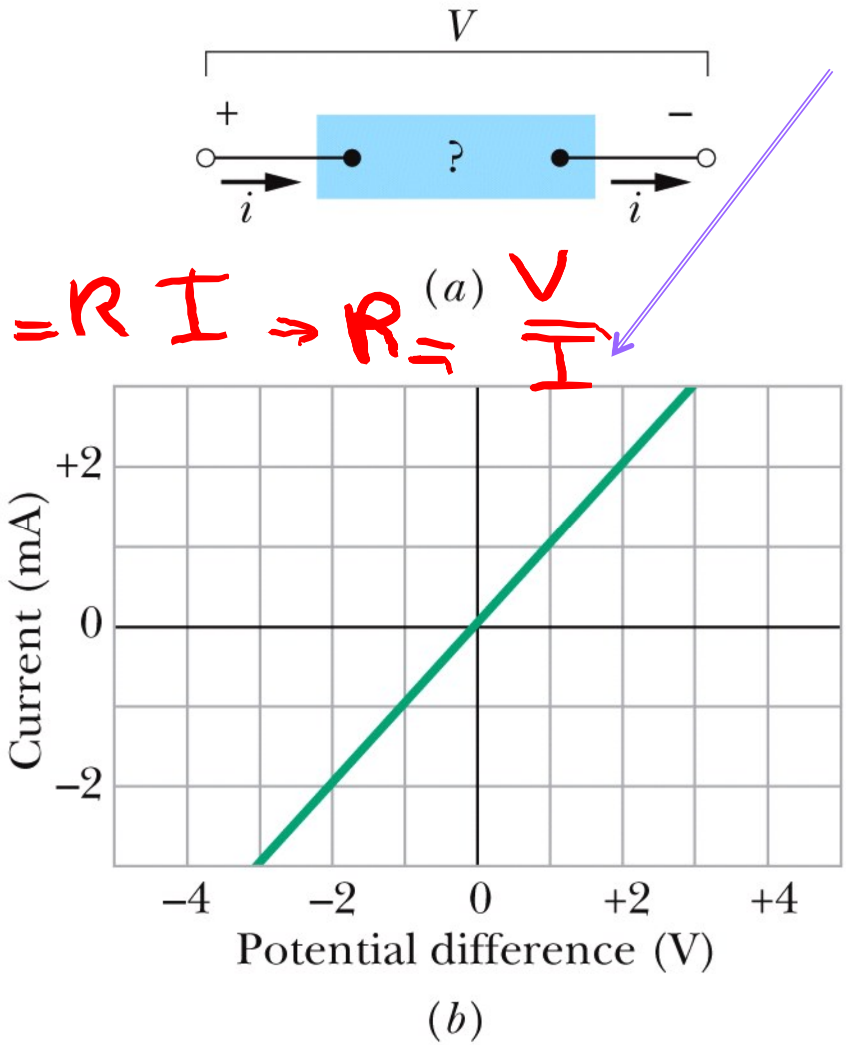
$$\boxed{\Delta V = IR}$$

# Ohmic vs non-Ohmic devices

Materials with isotropic electrical properties

Materials with anisotropic electrical properties (pn junction diode)

$V = RI \rightarrow R = \frac{V}{I}$



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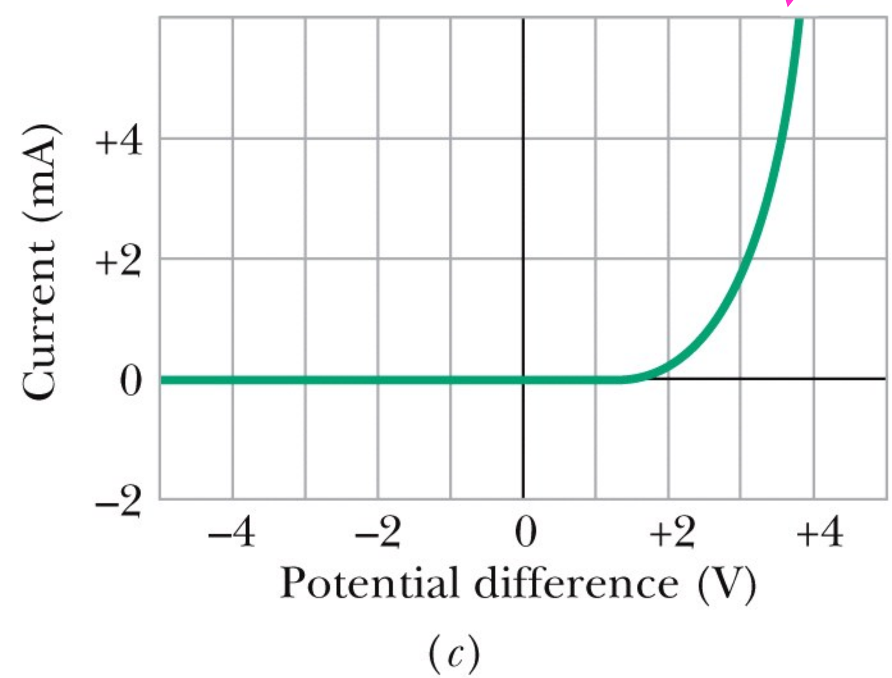


(c)



halliday_10e_fig_26_11

# TopHat Question

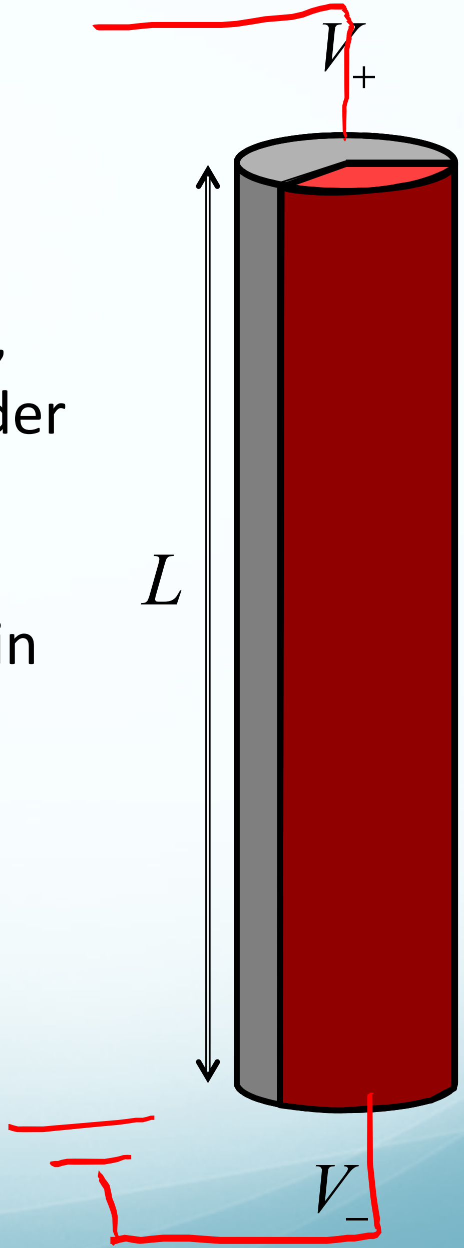
A cylindrical resistor is composed of 1/3 copper and 2/3 Tungsten as shown ($\rho_{Cu}$ = 1.69x$10^{-8}$ Ωm, and $\rho_W$ = 5.25x$10^{-8}$ Ωm). The radius of the cylinder is R = 0.105 mm, and it is L = 5.26 cm long.

Each piece has a resistance. Are these resistors in series or in parallel?

A. Series

B. Parallel

C. Neither



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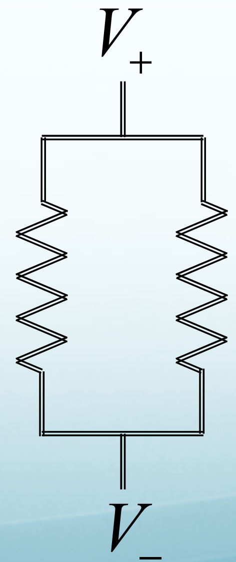
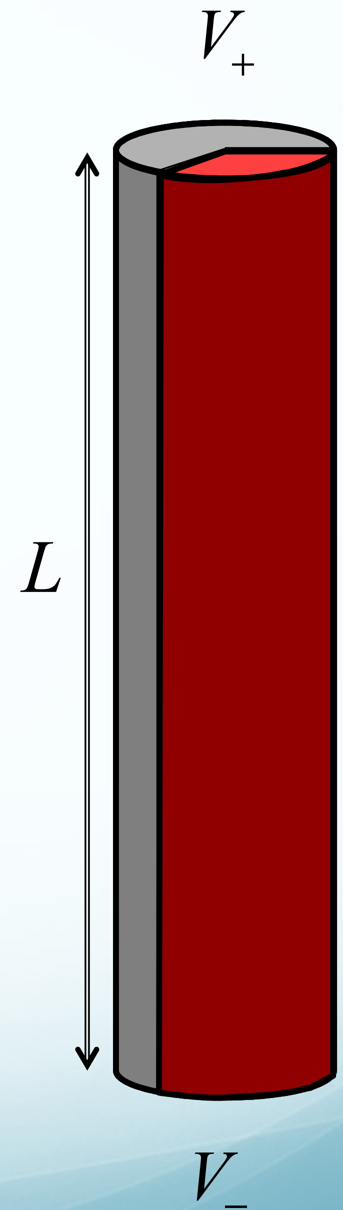
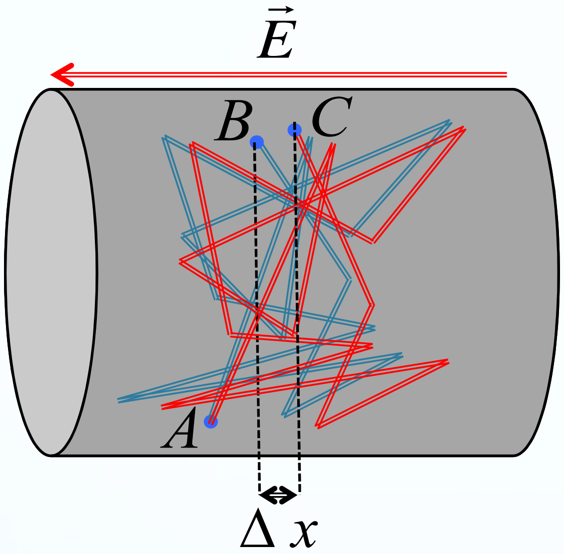


# Microscopic view of Ohm's law (resistivity)




Electrons bounce around inside the metal at speeds very high speeds on the order of 0.5% light speed.

When an electric field is applied in the conductor, there is a net force on the electrons, leading to "drift speed"

$$v_d = \frac{J}{ne}$$

microscopic picture of resistivity:

$$\boxed{\rho = \frac{m}{ne^2\tau}}$$

$$\boxed{\rho - \rho_0 = \rho_0 \alpha \left(T - T_0\right)}$$

# Temperature Dependent Resistance

$$\boxed{R - R_0 = R_0\left(\tfrac{2}{3}\alpha\right)\left(T - T_0\right)}$$

**Proof: Appendix 2-Chapter 26**

$$\boxed{\rho - \rho_0 = \rho_0 \alpha \left(T - T_0\right)}$$

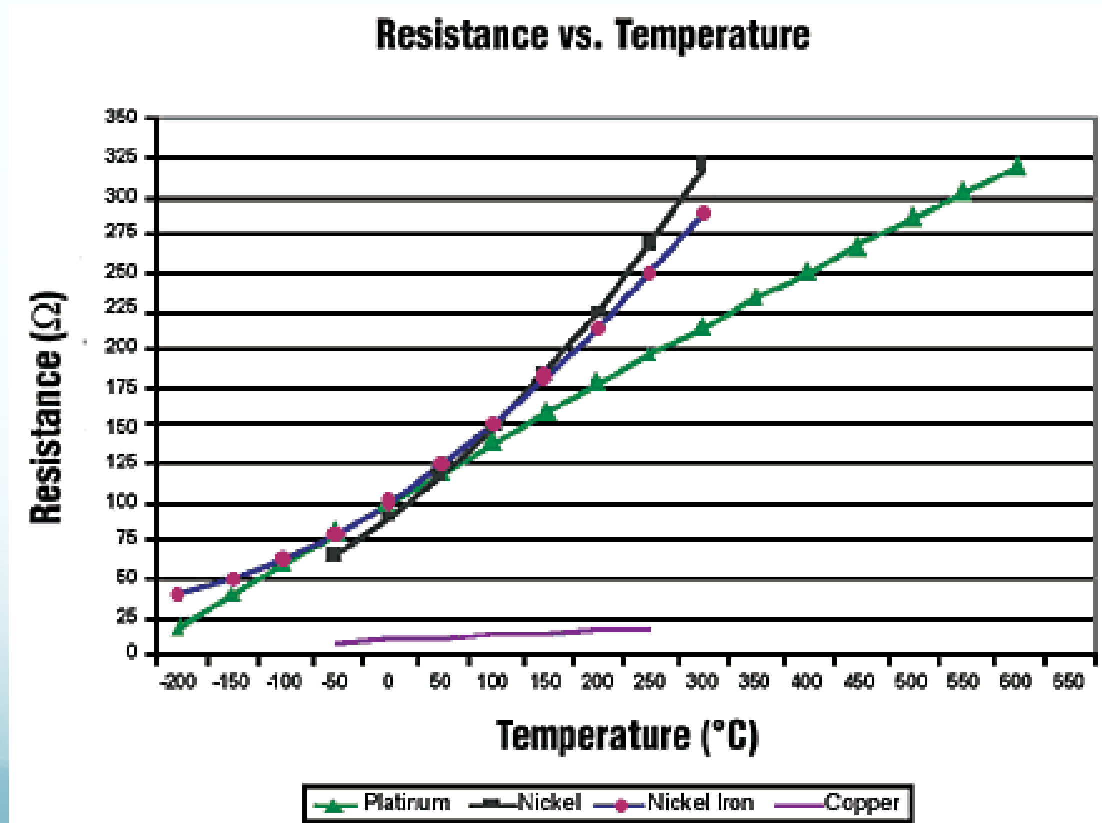



Image from http://archives.sensorsmag.com/articles/0503/52/main.shtml

# 26-5 Power in circuits

Recall that **POWER** is the **rate at which work is done**

$$P = \frac{W}{\Delta t}$$

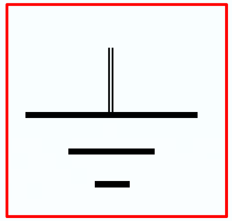
A battery with voltage $\Delta V$ raises the **potential energy** of a single charge $q$ by an amount $q\,\Delta V$. This is the **work done** by the battery. For $N$ charges

$$P = \frac{Nq\quad V}{\Delta t} = \left(\frac{Nq}{\Delta t}\right) V = IV$$

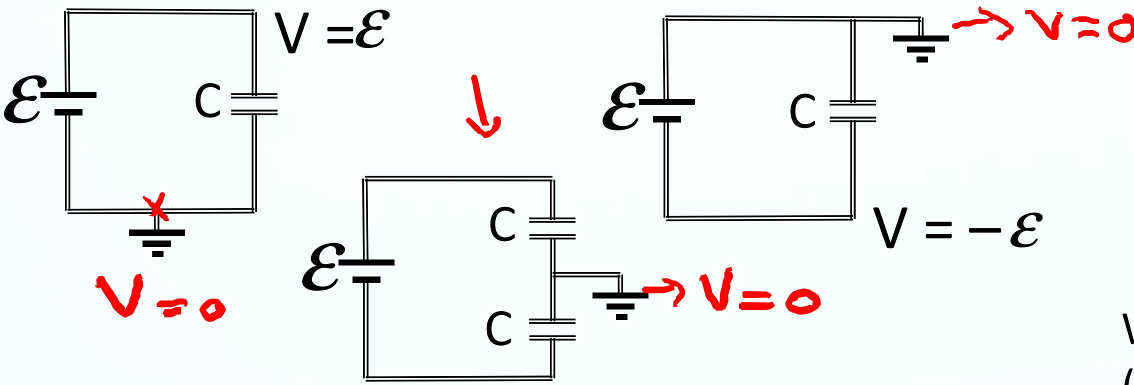
**Power in circuits→** $\boxed{P = I\,V = RI^2 = \frac{V^2}{R}}$

# 27 Circuits:
## continue of last section

# Grounding

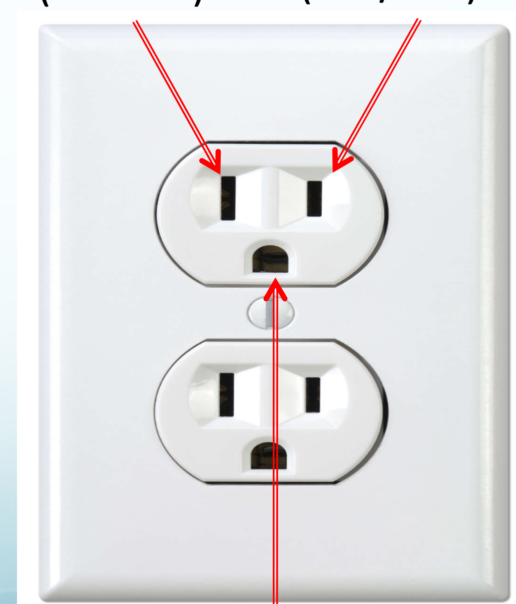


**This symbol is called "ground" and it represents the place in the circuit where V=0.**



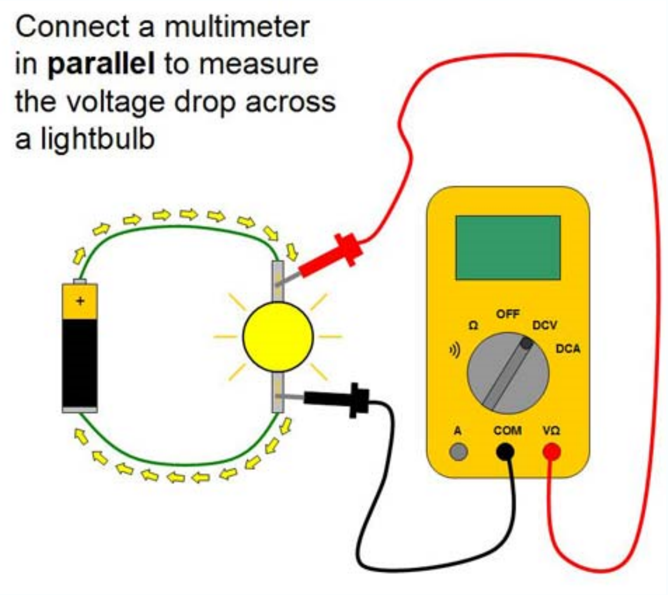

Wide slot (neutral)

Narrow slot (hot/live)

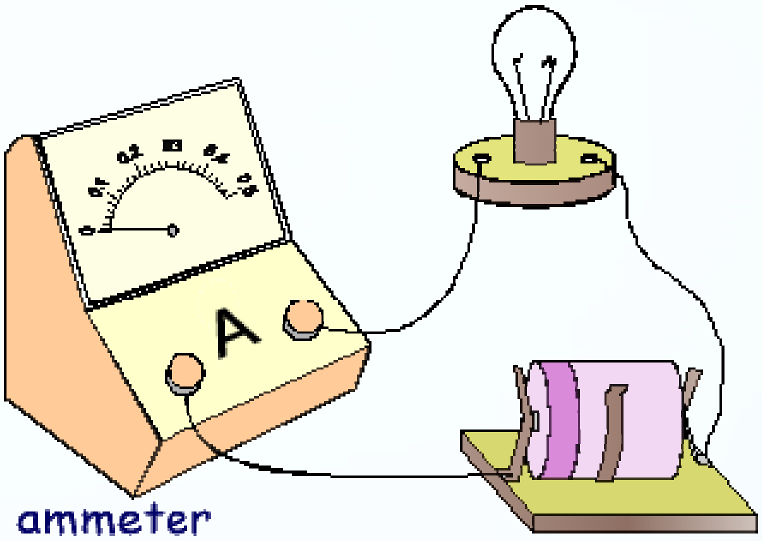


Ground

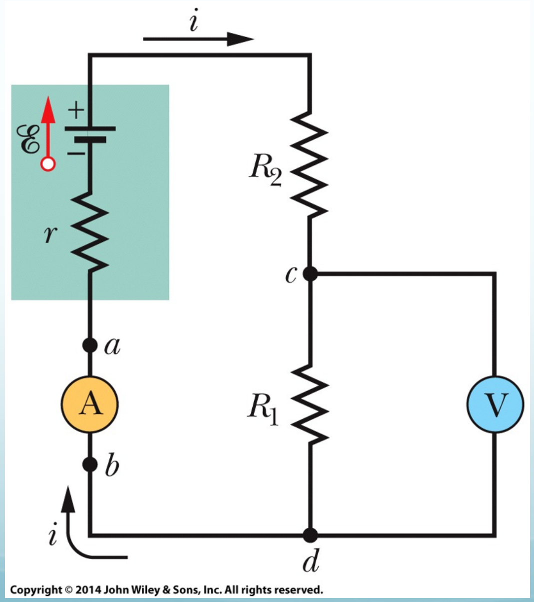
# 27-3 The Ammeter and The Voltmeter




https://tinyurl.com/zpbg36w




https://tinyurl.com/jlktro3

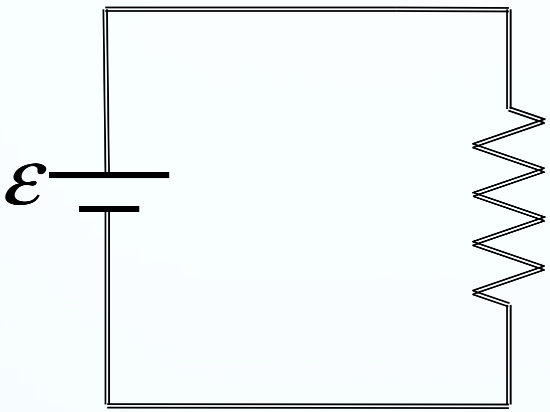


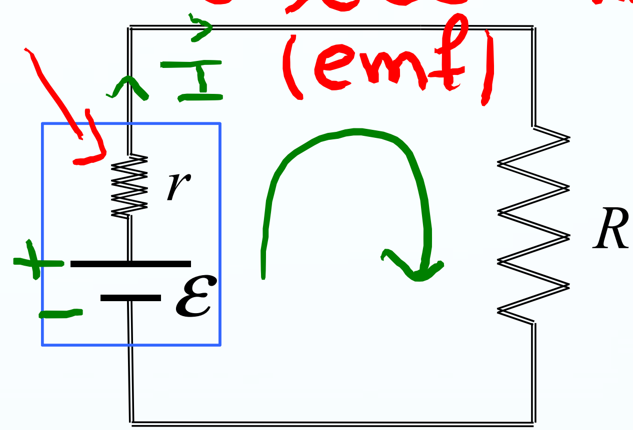
# Non-ideal Batteries: internal resistance

## Appendix 2-Chapter 26

Every voltage source has **some** internal resistance to it. Usually this can be ignored but not always.

$\mathcal{E} \rightarrow$ electromotive force (emf) (V)




**The internal resistance simply acts as a resistor in series with the rest of the circuit.**

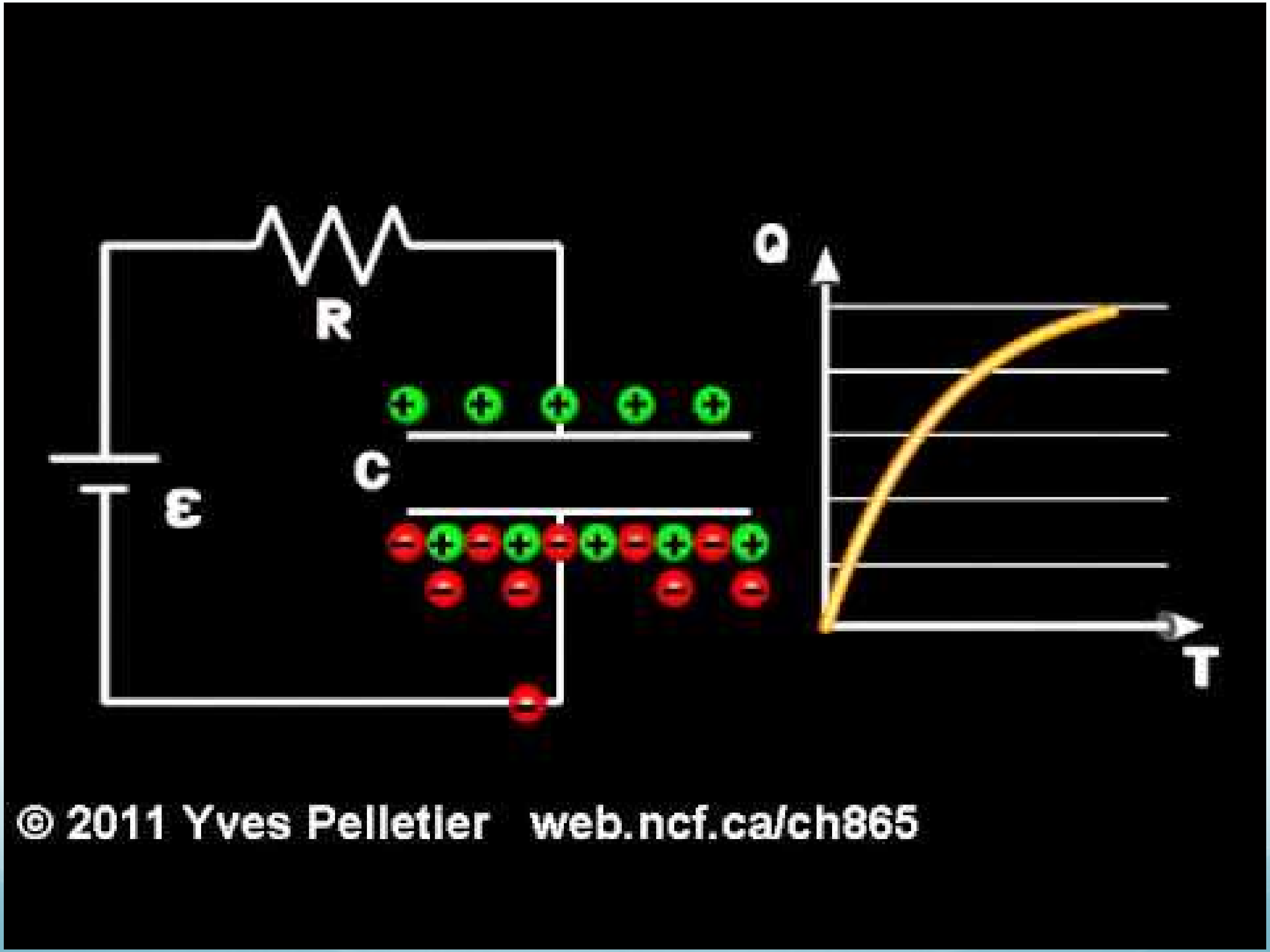
$$\varepsilon - Ir - IR = 0 \rightarrow I = \frac{\varepsilon}{(r+R)} \rightarrow$$

$$\varepsilon - I(r+R) = 0$$

$$P_\varepsilon = \overset{IV}{I\varepsilon} = \frac{\varepsilon^2}{R+r}$$

$$P_R = I^2 R = \frac{\varepsilon^2 R}{(R+r)^2}$$

# 27-4 RC Circuits (resistors + capacitors)

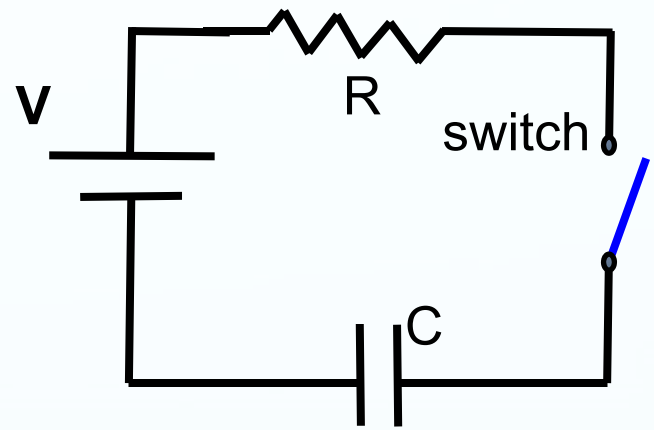


**Until now→ steady and continuous currents**

many important circuit applications use a combination of capacitors and resistors to produce **time dependent currents**

*Examples: wireless signals in a cordless phone, remote control, etc.*

Simple RC Series Circuit




Open switch→

- ✓ no current can flow
- ✓ charge and voltage on capacitor → Zero

Closed switch for a long time→

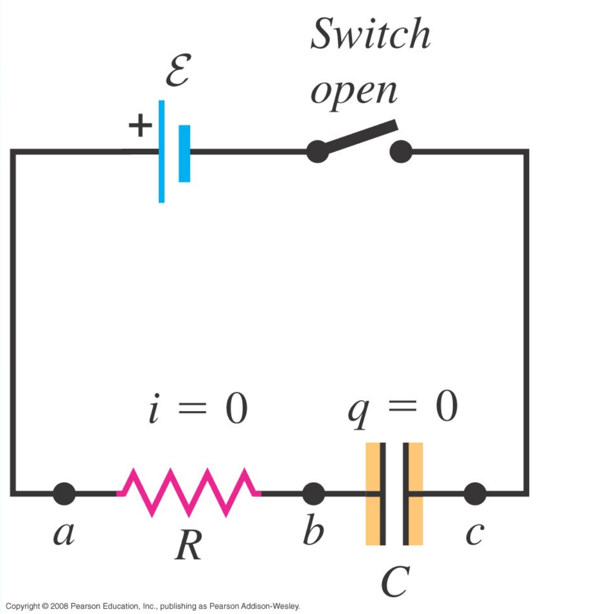
- ✓ Charge on capacitor $Q = CV$
- ✓ Voltage across capacitor is *V* and no current flows in the circuit.

**What happens immediately after switch is closed or opened?**

**We get time dependent currents!**

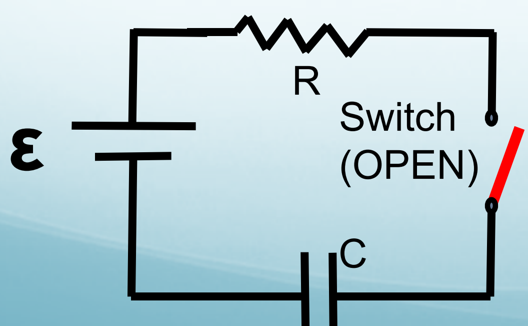
# Case 1: Charging a capacitor

(a) Capacitor initially uncharged

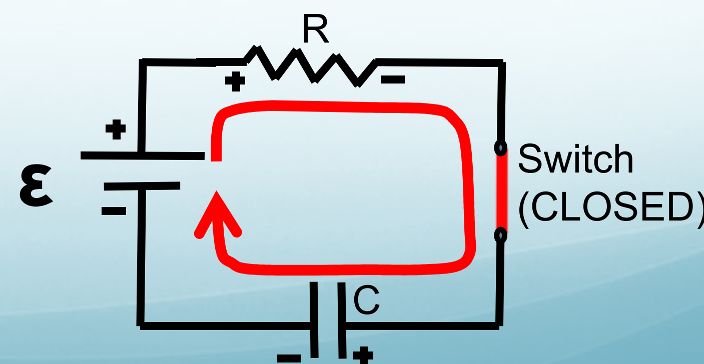



R could be the internal resistance of the battery, resistance of the connecting wires, an actual resistance in the circuit or combination of all the above.

**Switch is open for a long time before t=0**

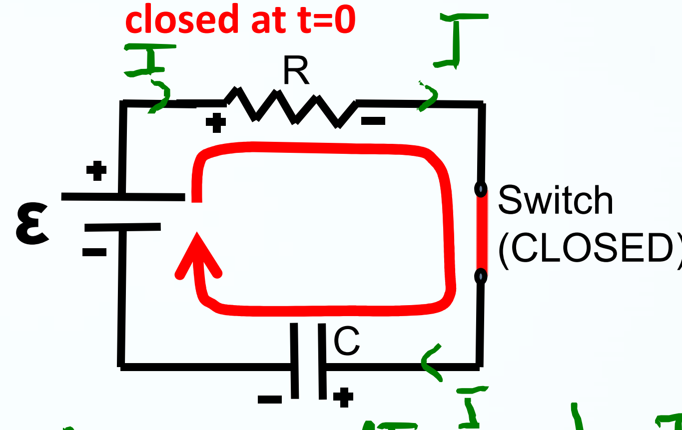



**Switch is suddenly closed at t=0**



# Case 1: Charging a capacitor

**Switch is suddenly closed at t=0**




$$\varepsilon - IR - \frac{q}{C} = 0 \rightarrow \frac{d}{dt} \rightarrow$$

$$\cancelto{0}{\frac{d\varepsilon}{dt}} - R\frac{dI}{dt} - \frac{1}{C}\underbrace{\frac{dq}{dt}}_{I} = 0$$

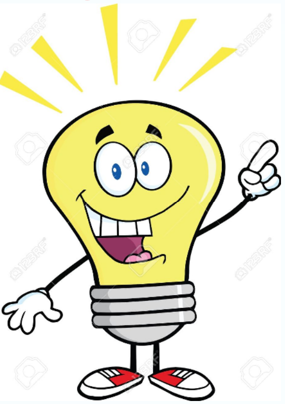
$$-R\frac{dI}{dt} - \frac{1}{C} I = 0 \rightarrow -R\frac{dI}{dt} = \frac{1}{C} I \rightarrow \frac{dI}{dt} = -\frac{1}{RC} I$$

$$\rightarrow \frac{dI}{I} = -\frac{1}{RC}\,dt \xrightarrow{\text{integral}} \boxed{I = \frac{V}{R} e^{-(t/RC)}}$$

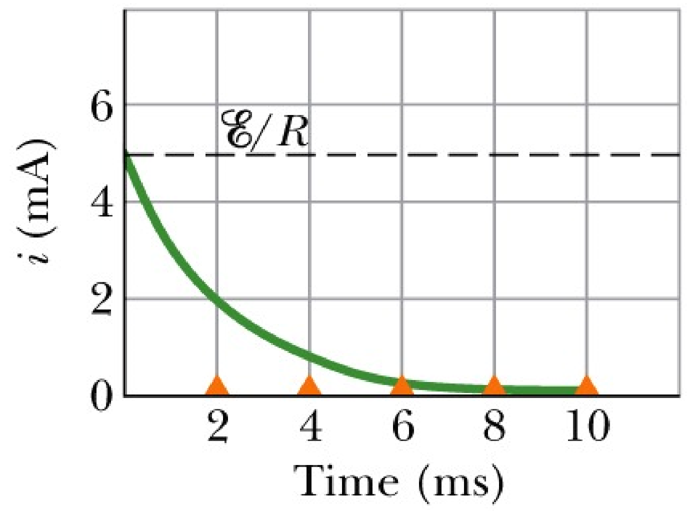
$$I = \frac{dq}{dt} \rightarrow q = \int I\,dt \rightarrow \boxed{q = CV\left(1 - e^{-t/RC}\right)}$$

Proof → Appendix 2 - chapter 26

# Case 1: Charging a capacitor



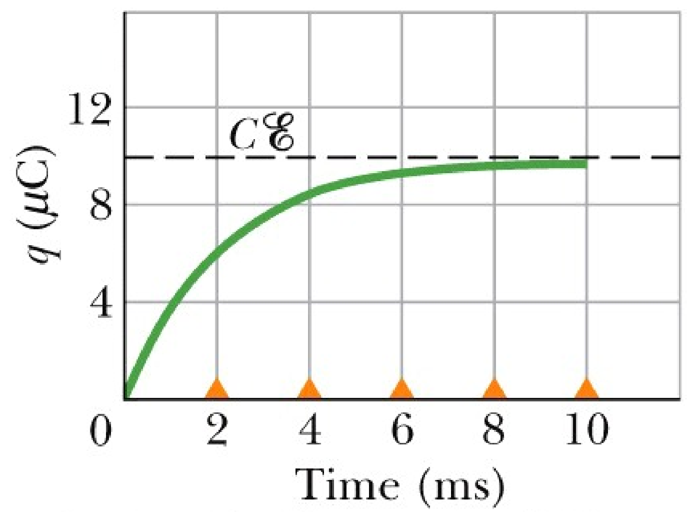
$$i = i_0 e^{-t/RC}$$





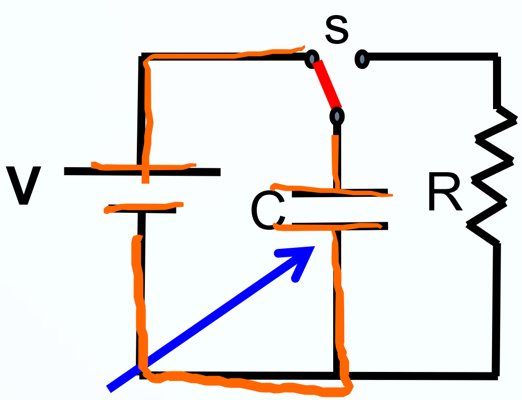

$$q = \varepsilon C\left(1 - e^{-t/RC}\right) = Q_f\left(1 - e^{-t/RC}\right)$$

↳ $\Delta V$ of battry



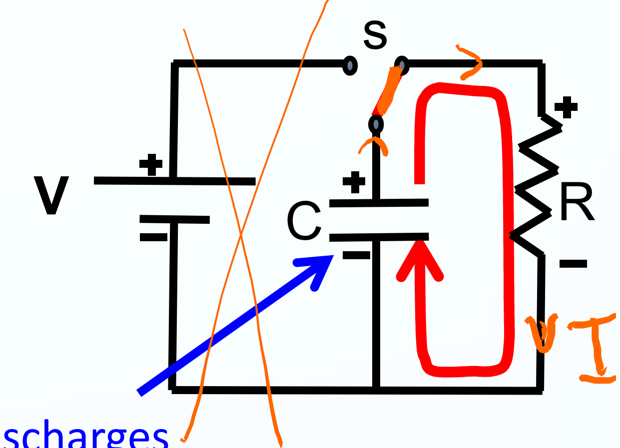
# Case 2: Discharging a capacitor

Switch is connected to the left for a long time until t=0-




Capacitor charges up to voltage V

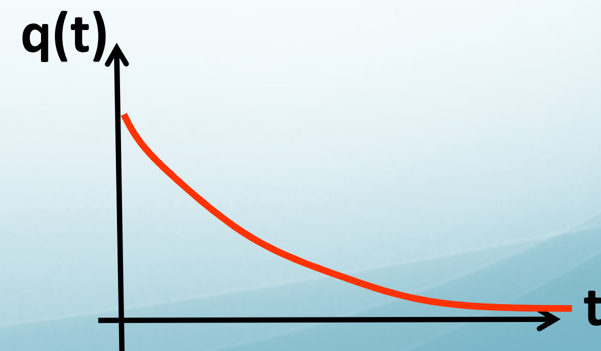
Switch is suddenly flipped to the right at t=0+




Capacitor discharges

Once the switch is flipped to right → $\frac{q(t)}{C} - iR = 0 \rightarrow \boxed{\frac{q}{RC} = i} = -\frac{dq}{dt}$

NOTE here dq < 0




Solving for the charge q(t) on the capacitor→

$$\boxed{q(t) = q_0 e^{-t/RC}}$$

$$\boxed{i(t) = i_0 e^{-t/RC}}$$

$$q_0 = CV$$

# Top Hat Question

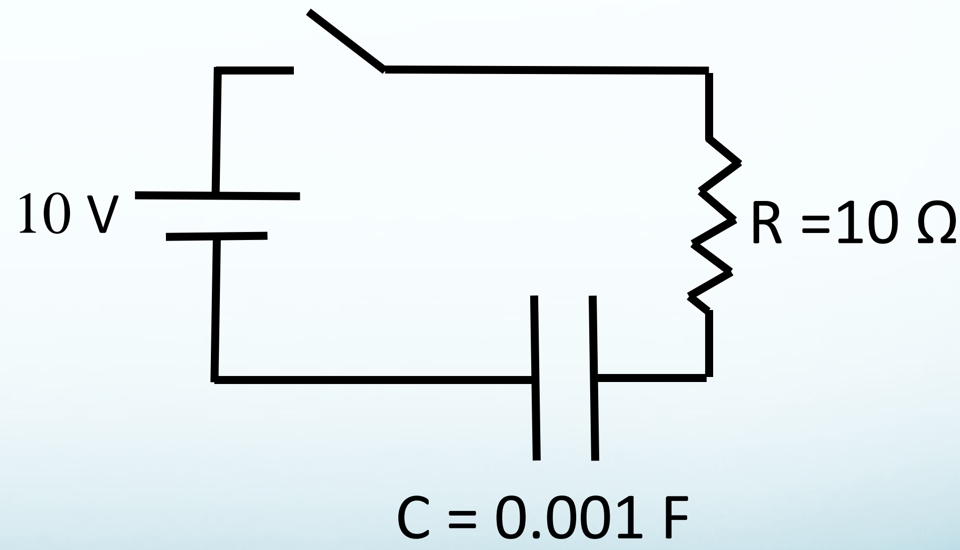
An RC circuit is shown below. Initially the switch is open and the capacitor is uncharged. At time t=0, the switch is closed. What is the voltage across the capacitor ***immediately*** after the switch is closed (time = 0+)?

A. 0.0 V

B. 10 V

C. 5.0 V

D. 1.0 V



This section we talked about:

Chapters 26 and 27

See you on Thursday