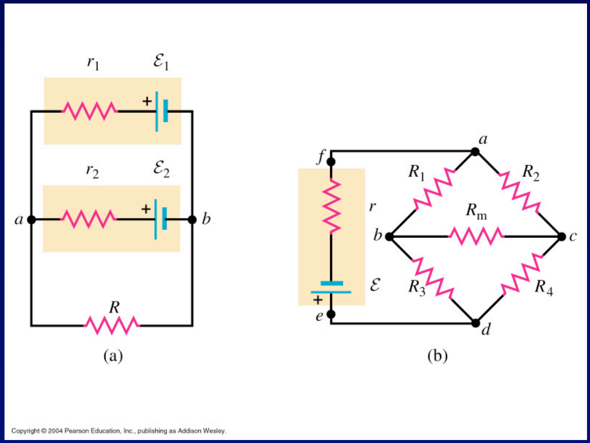
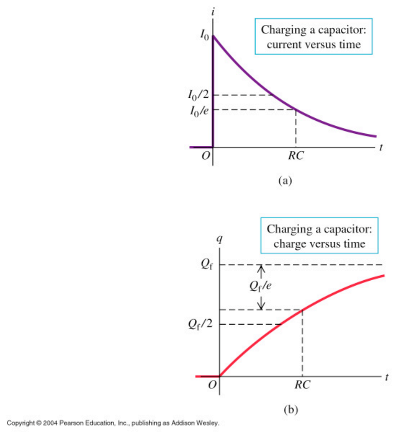
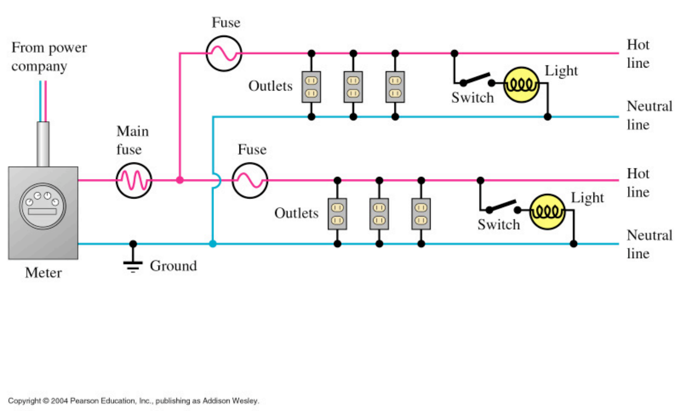
Chapter 26: Direct-Current Circuits (Part 2)

- Electrical measuring instruments (con'd)
- RC circuits
- Electrical Safety





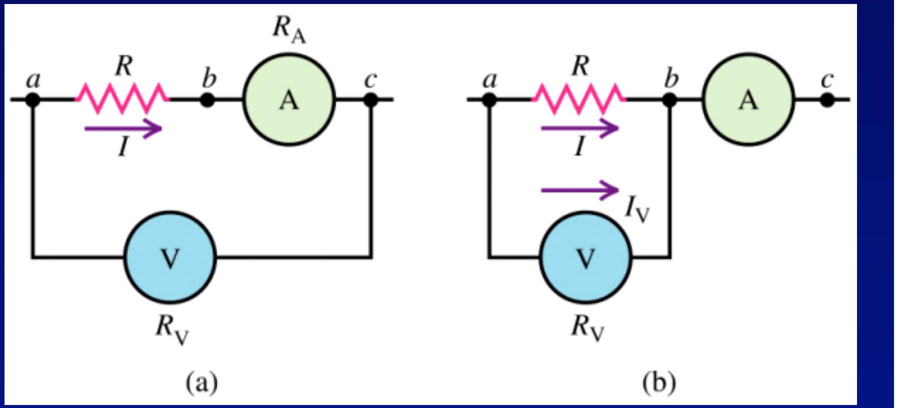


Electrical Measuring Instruments

New Topic

Example: Impact of Ammeter and Voltmeter on measurements

- Let's do the numbers.
  - Ammeter reading 0.1 A, resistance R_A=2.0 Ω.
  - Voltmeter reading 12.0 V, resistance R_V=10 kΩ



Ideal case (R_A=0, R_V=∞):
R=V/I=12/0.1=120 Ω

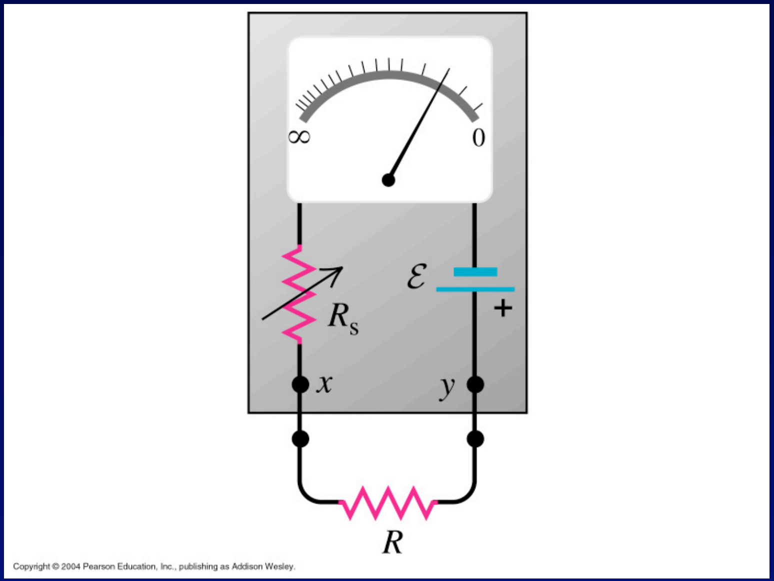
Case (a): voltage across R is less than 12V.
R_a=(12-0.1*2.0)/0.1=118 Ω

Case (b): Current in R is less than 0.1 A.
R_b=12/(0.1-12/10000)=121 Ω

Small difference, but must be taken into account in precision measurements.

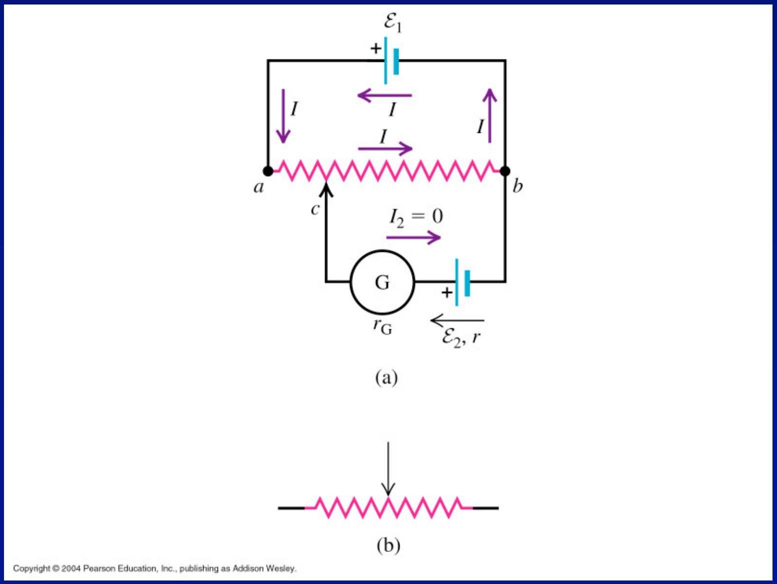
Ohmmeter

Open **between x and y, no deflection (R=∞).** Short between x and y: full-deflection (R=0). Any R in between is read directly.



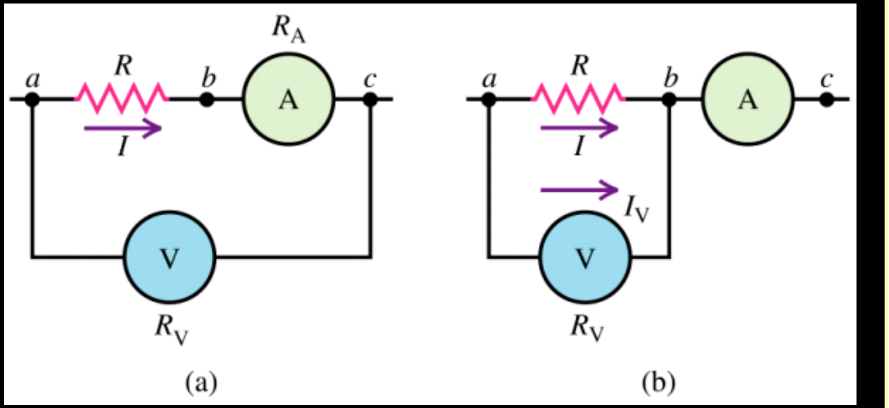
Potentiometer

A known voltage is balanced by sliding the contact c until the current through the unknown emf is zero: $\mathcal{E}_2=IR_{cb}$



ConcepTest 26.4 Ammeter and Voltmeter

- In the two circuits to measure an unknown resistance by R=V/I, the readings on the A and the V-meters are the same. Taking the resistance of the A and V-meters into account, what can you say about the resistance actually measured in each case?



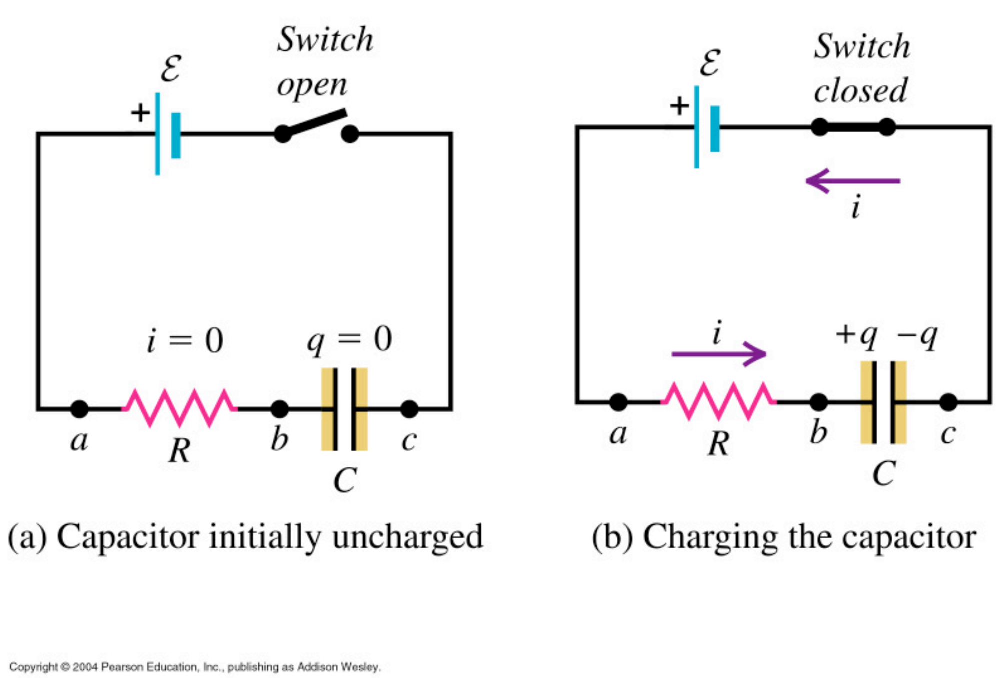
1) $R_a > R_b$ **2)** $R_a < R_b$ **3)** $R_a = R_b$

RC Circuit

New Topic

What happens if we add a capacitor in a DC circuit?

- Consider a charging circuit as shown.
- Charge will start to flow to the capacitor.
  - A current (recall $i=dq/dt$) flows in the circuit
- Voltage across the capacitor will increase
  - recall $V=q/C$
- The current decreases, eventually comes to a stop.
- Now the capacitor has maximum charge $Q=C\mathcal{E}$
- Now everything is quiet.



(a) Capacitor initially uncharged (b) Charging the capacitor

How to put it in more precise terms?

RC Circuit: charging

Apply loop rule:

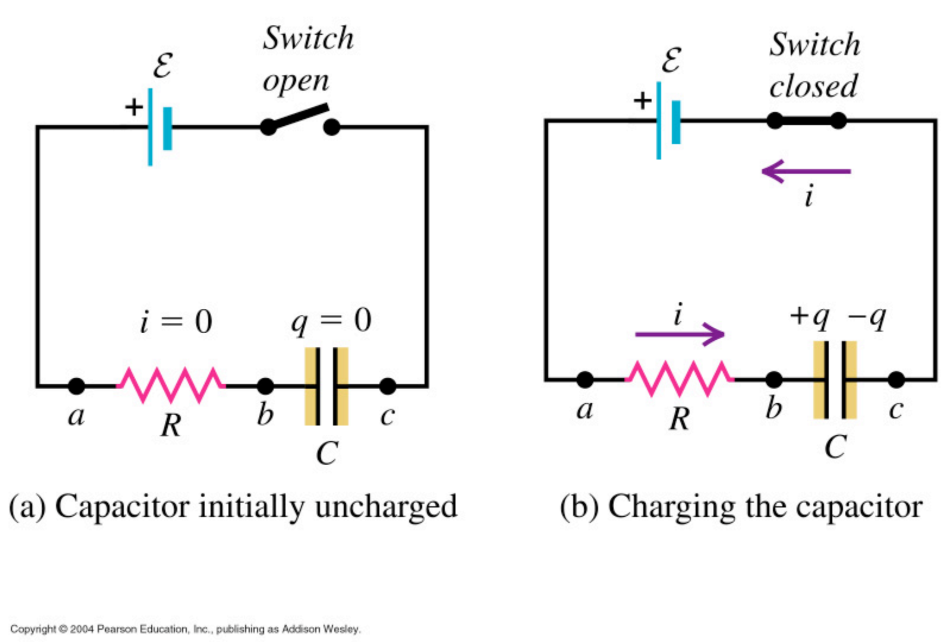
$$\varepsilon - iR - \frac{q}{C} = 0$$

This is a differential equation for q (with the initial condition q=0 at t=0):

$$R\frac{dq}{dt} + \frac{q}{C} - \mathcal{E} = 0$$

Solution: $q(t) = C\mathcal{E}\left(1 - e^{-t/RC}\right)$

$$i(t) = \frac{dq}{dt} = \frac{\mathcal{E}}{R}e^{-t/RC}$$



(a) Capacitor initially uncharged (b) Charging the capacitor

Conclusion:

a) Exponential time dependence

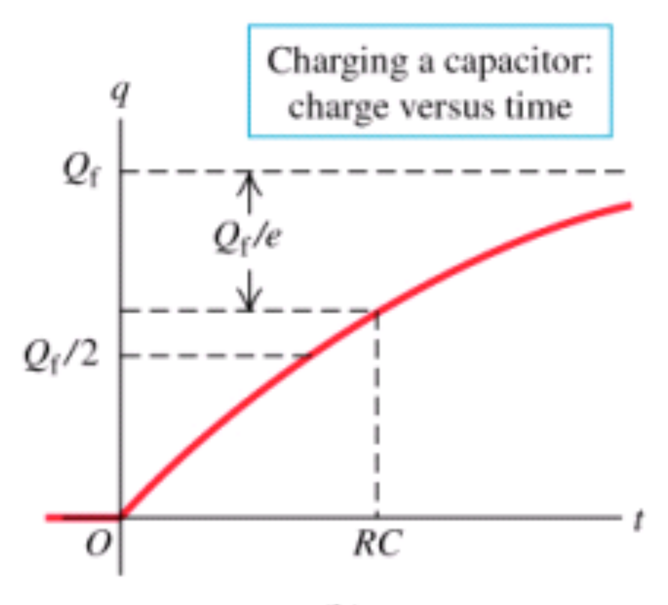
b) Time constant RC=τ

Example: For R=10 kΩ and C=5 μF, the time constant is 50 ms.

RC Circuit: charging

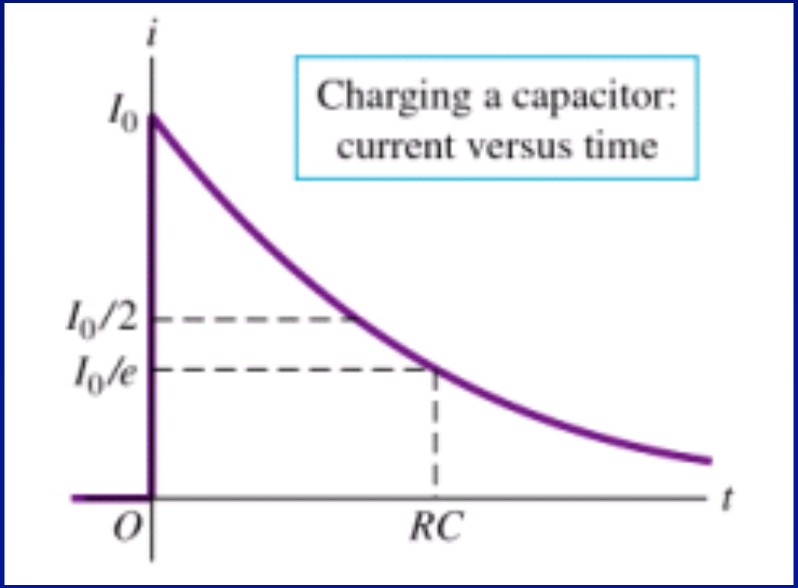
$$q(t) = C\mathcal{E}\left(1 - e^{-t/RC}\right)$$

At t=RC, charge increases to 63% of its maximum value. (recall e=2.713)



$$i(t) = \frac{dq}{dt} = \frac{\mathcal{E}}{R}e^{-t/RC}$$

At t=RC, current decreases to 37% of its maximum value.



RC Circuit: discharging

Apply loop rule:

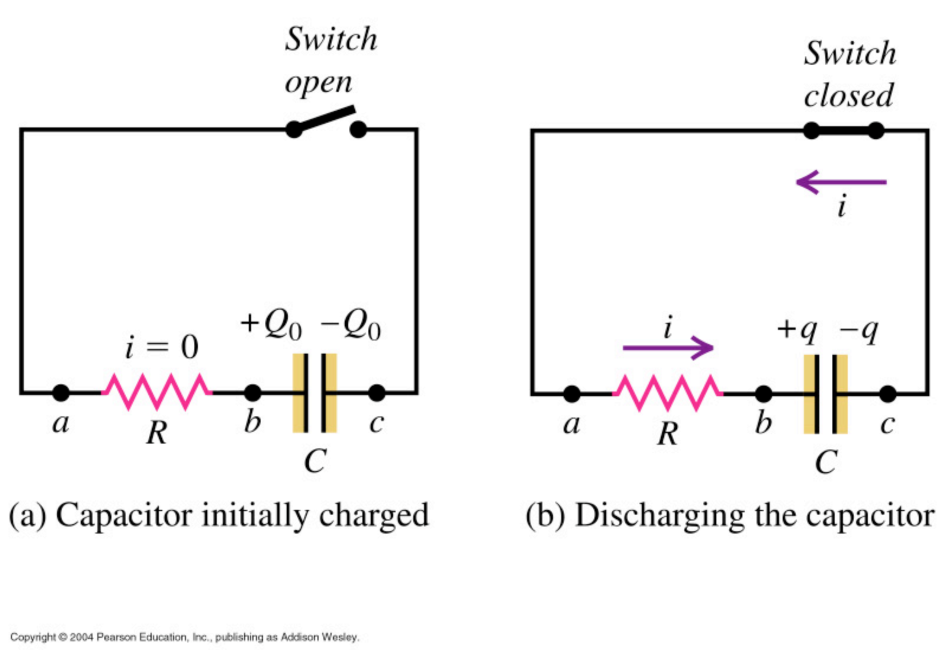
$$-iR-\frac{q}{C}=0$$

This is a differential equation for q (with the initial condition q=Q_0 at t=0):

$$R\frac{dq}{dt}+\frac{q}{C}=0$$

Solution: $q(t)=Q_0e^{-t/RC}$

$$i(t)=\frac{dq}{dt}=-\frac{Q_0}{RC}e^{-t/RC}$$



(a) Capacitor initially charged (b) Discharging the capacitor

Conclusion:

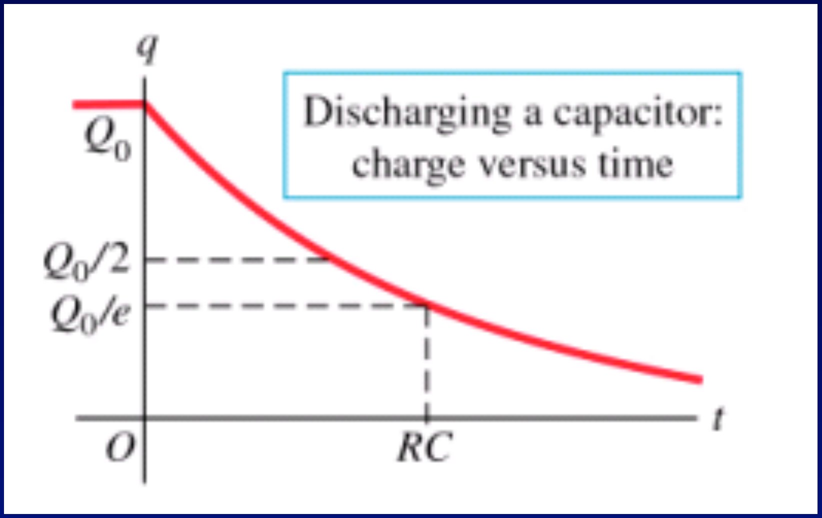
a) Same exponential time dependence

b) Same time constant RC=τ

RC Circuit: discharging

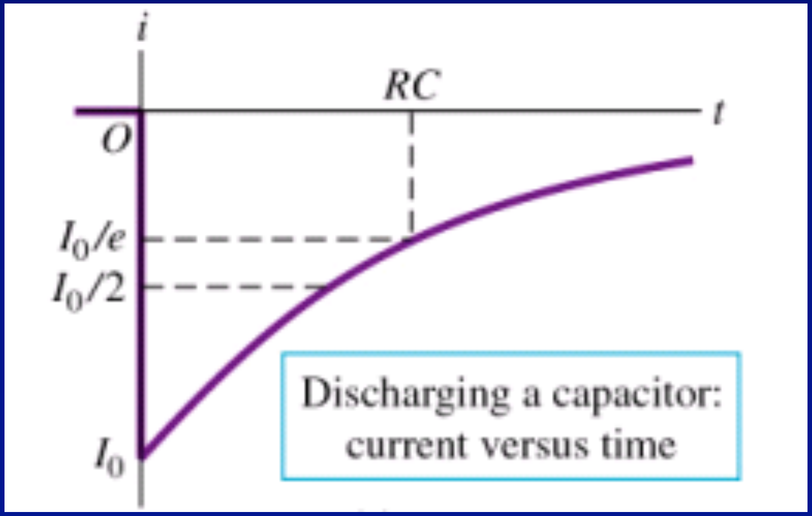
$$q(t) = Q_0 e^{-t/RC}$$

At t=RC, charge decreases to 37% of its maximum value.



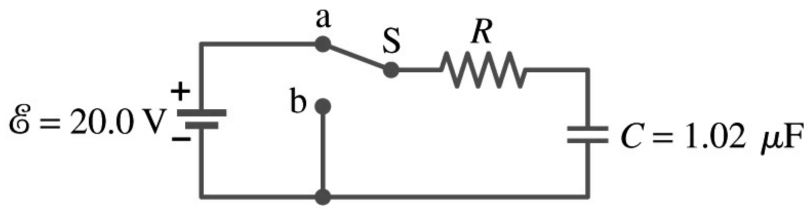
$$i(t) = \frac{dq}{dt} = -\frac{Q_0}{RC} e^{-t/RC}$$

At t=RC, current increases to 37% of its maximum value.



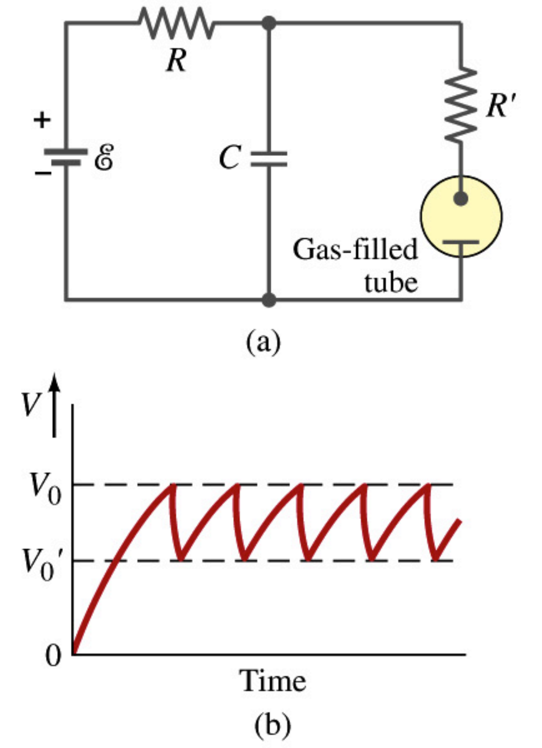
Example: discharging RC circuit

- In the RC circuit shown, the battery has fully charged the capacitor. Then at t=0, the switch is thrown from a to b. The current is observed to decrease to ½ of its initial value in 40μs.
    - What is R?
    - What is Q, the charge on the capacitor, at t=0?
    - What is Q at t=60μs



Application of RC Circuits

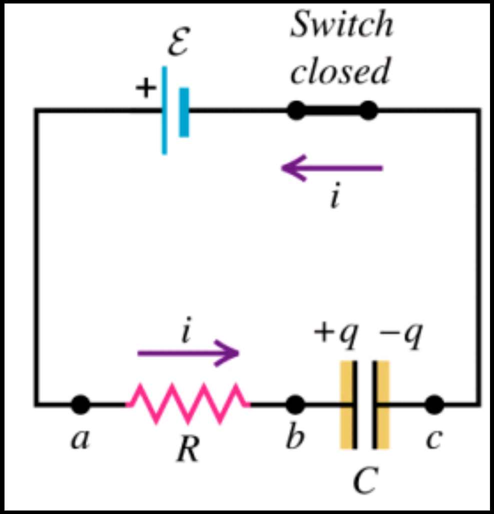
- The time dependence and time constant $\tau=RC$ for charging and discharging provides a means to change voltage with a adjustable frequency: the sawtooth voltage
  - automobile turn signal
  - intermittent wiper
  - traffic flashing light
  - heart pacemaker
  - and more



ConcepTest 26.5 RC Circuits

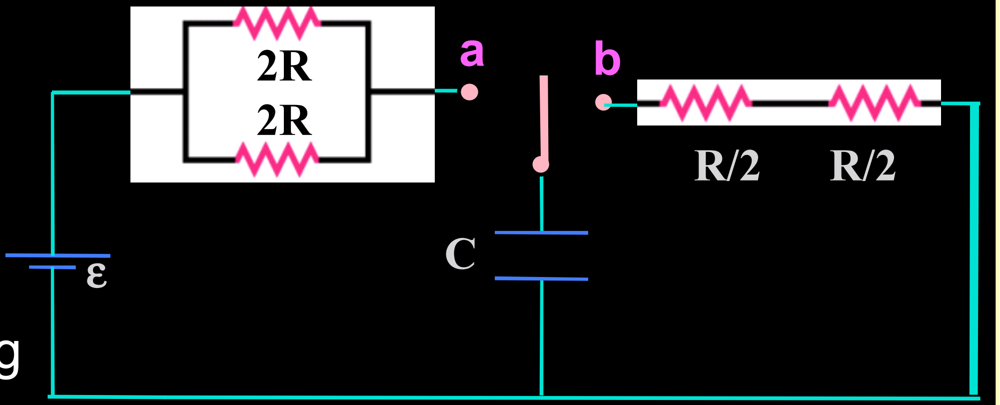
- **In charging a capacitor, how much total energy (in terms of Ɛ, R, C) is delivered by the battery?**

(a) $\mathcal{E}^2/R$ (b) $\mathcal{E}^2/(2R)$ (c) $C\mathcal{E}^2$ (d) $C\mathcal{E}^2/2$



ConcepTest 26.6 RC Circuits

- In the circuit shown, the switch is first thrown to position a to charge the capacitor, then to position b to discharge it. What is the relationship between the charging time constant (τ_1) and discharging time constant (τ_2) ?



(a) $\tau_1 < \tau_2$ (b) $\tau_1 = \tau_2$ (c) $\tau_1 > \tau_2$

Electrical Safety

New Topic

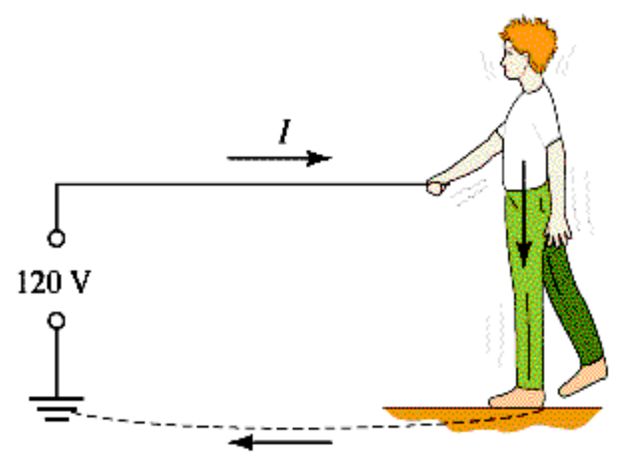
Injuries through Electricity

- If we touch a charged conductor:
  - potential difference between conductor and ground
  - your body becomes a part of the circuit for current!
- Extent of injury depends on **current** flow through your body

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

usually 120 V

resistance of the body



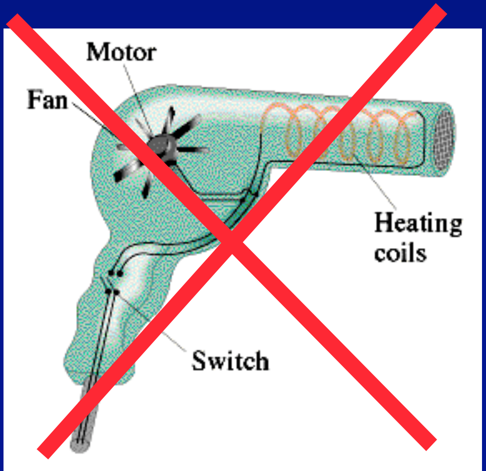
R = 0.5 x 10^6 Ω (for dry skin) ➡ I = 0.24 mA

R = 0.5 x 10^4 Ω (for wet skin) ➡ I = 24 mA

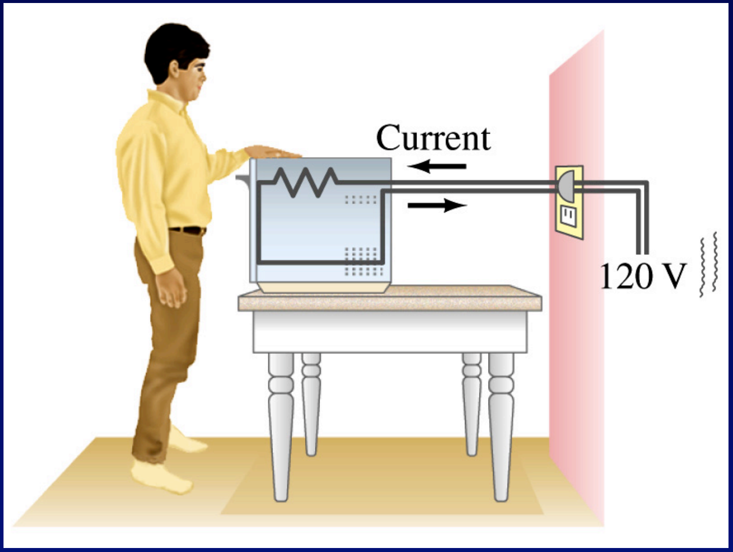
Injuries through Electricity

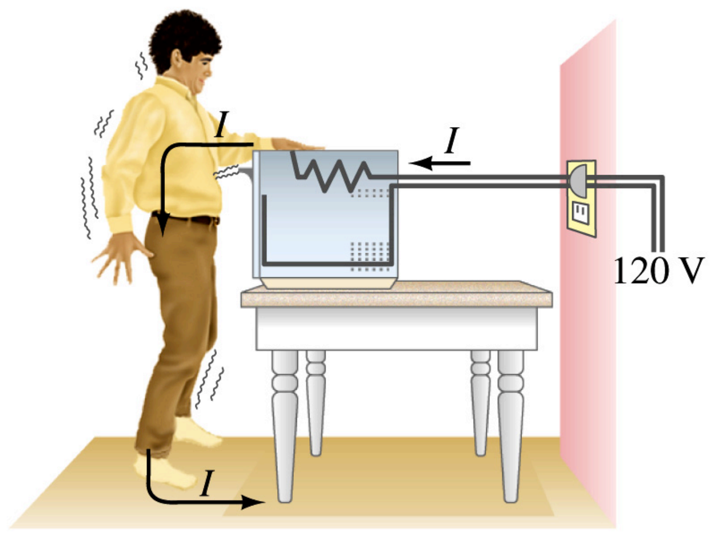
Current	Effect	Fatal?
1 mA	mild shock	no
5 mA	painful	no
10 mA	paralysis of motor muscles	no
20 mA	breathing stops	minutes
100 mA	heart stops	seconds
1000 mA	serious burns	instantly

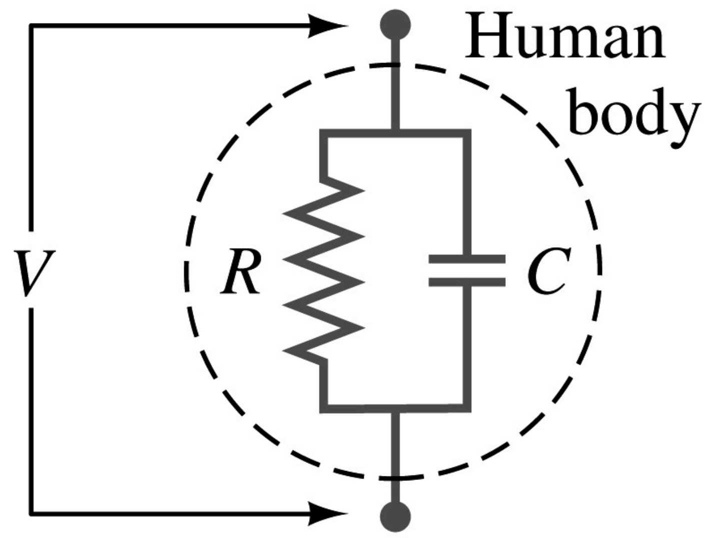
So don’t dry your hair in the bathtub!

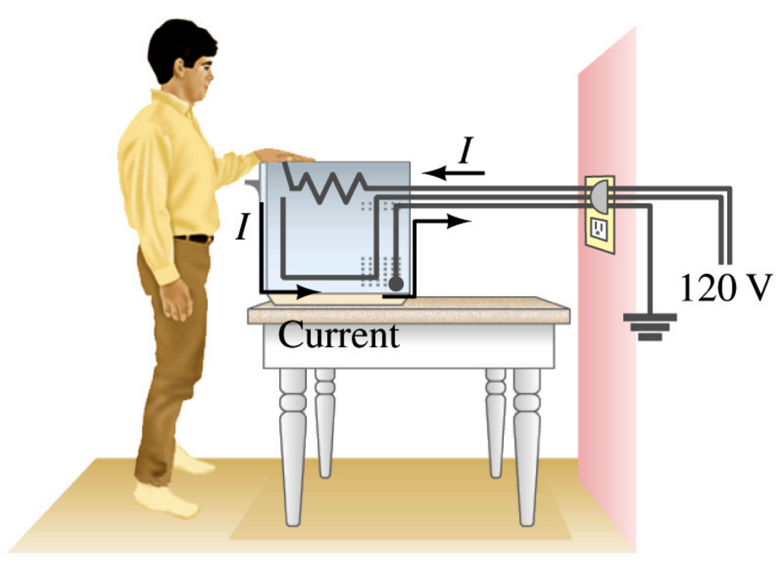


Grounding of Devices









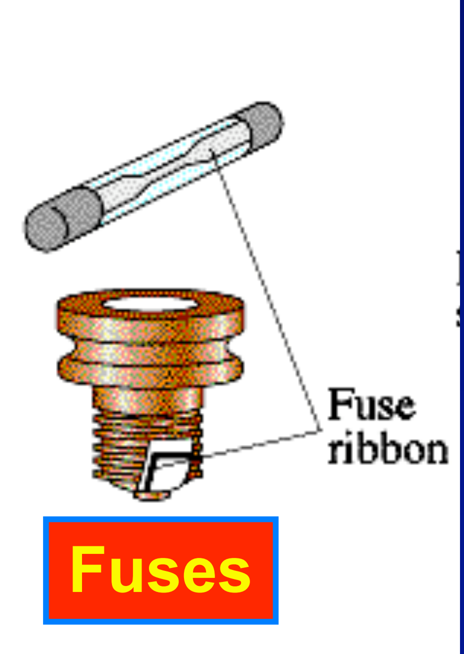
Artificial Respiration

- A current of around 70 mA passing through the body for a second or more can cause the heart to beat irregularly (ventricular fibrillation)
  - If it lasts long, death results.

- A much larger current of about 1 A can bring the heart to a standstill. Upon release of the current, the heart returns to its normal rhythm. This shock may not be a bad thing.
  - Defibrillator: a device to restart the heart by applying a high voltage (therefore high current) shock.

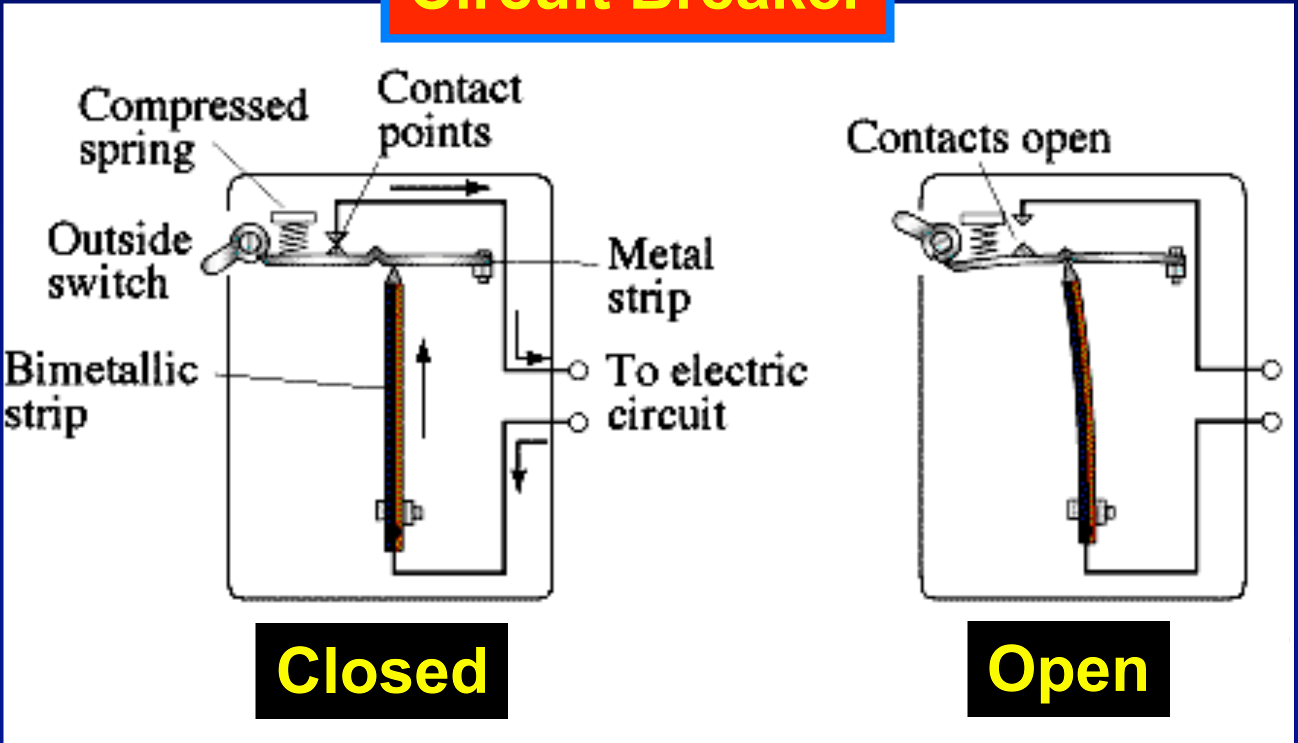
Fuses and Breakers

- Too many devices in the circuit can require more current than the wires can handle -- overheating of wires is a fire hazard !
- If an electric circuit gets “overloaded” (too much current) fuses or circuit breakers interrupt the flow of current.



Fuses

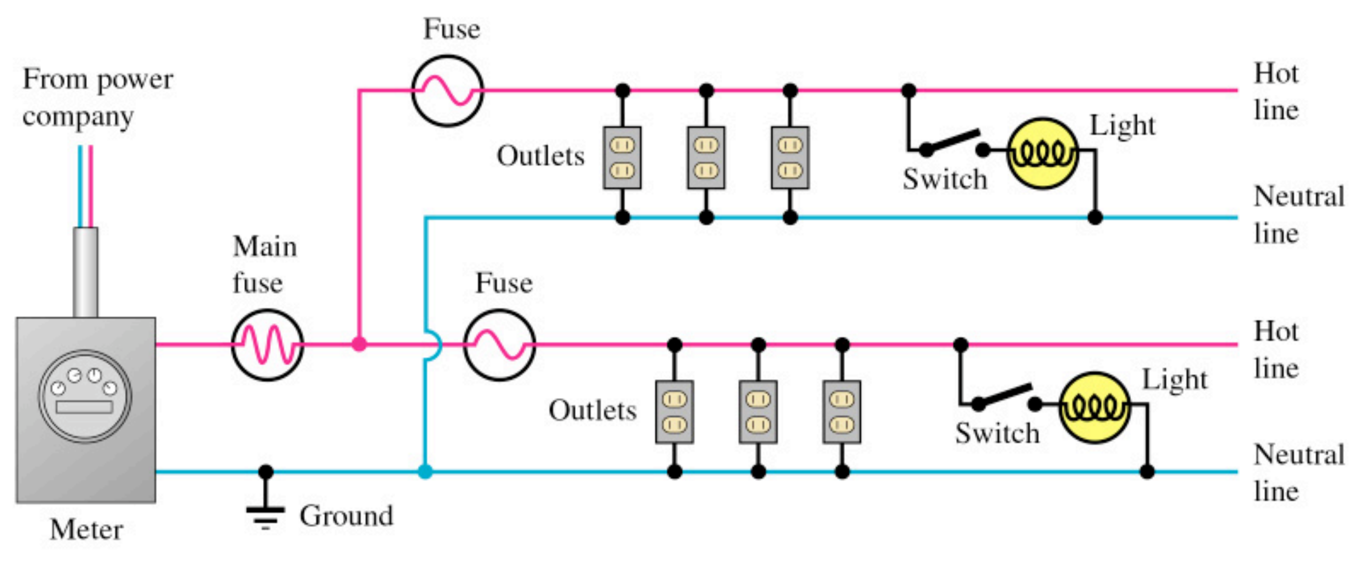
Circuit Breaker



Closed

Open

Power Distribution System



Example: Will the fuse blow?

- The circuit shown is designed for a 20-A fuse. Determine the total current drawn by all the devices shown in the circuit.

I = P / V

100/120=0.8 A

1800/120=15 A

350/120=2.9 A

1200/120=10 A

The total is 28.7 A.

So it blows if all the devices are used at the same time.