Chapter 19: DC Circuits

- **EMF and Terminal Voltage**

- **Resistors in Series and in Parallel**

- **Kirchhoff's Rules**

- **EMFs in Series and in Parallel; Charging a Battery**

- **Capacitors in Series and in Parallel**

- **RC Circuits – Resistor and Capacitor in Series**

- **Electric Hazards**

- **Ammeters and Voltmeters**
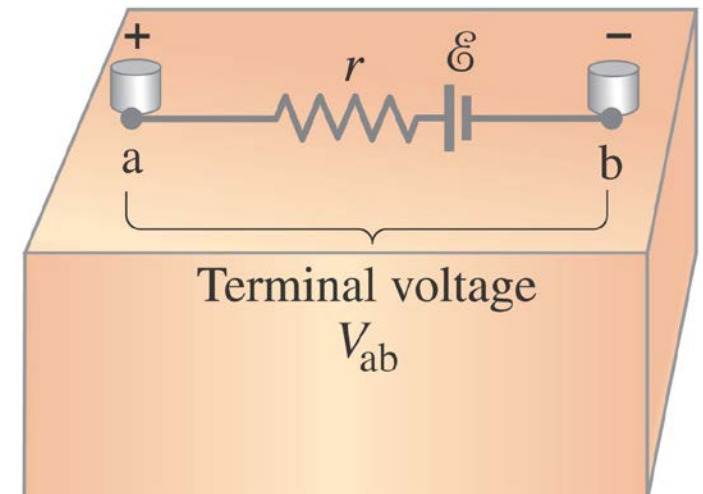
19.1 Electro Motive Force (EMF) and Terminal Voltage

—⋀⋀— **Resistor**

+ |⊢ − **Battery**

⊢| **Capacitor**

Batteries have an internal resistance (r), which behaves as though it were in series with the emf.

$$V_{ab} = \mathscr{E} - Ir$$

So the terminal voltage drops when a load is applied.

R is negligible only when Ir < amp.hr rating /10

Terminal voltage
V_{ab}

Internal Resistance of Batteries

As current flows from the battery, the voltage across its terminal falls.

If the voltage drop is too great, the battery will not be able to produce enough power.

Also since battery has its own resistance, it wastes or dissipates power according to $P = I^2 R$

This is why your laptop battery scorches your leg, and why you can't start a car with a handful of AAA's

Typically r = 0.01-0.1 Ohms (higher for smaller cells)

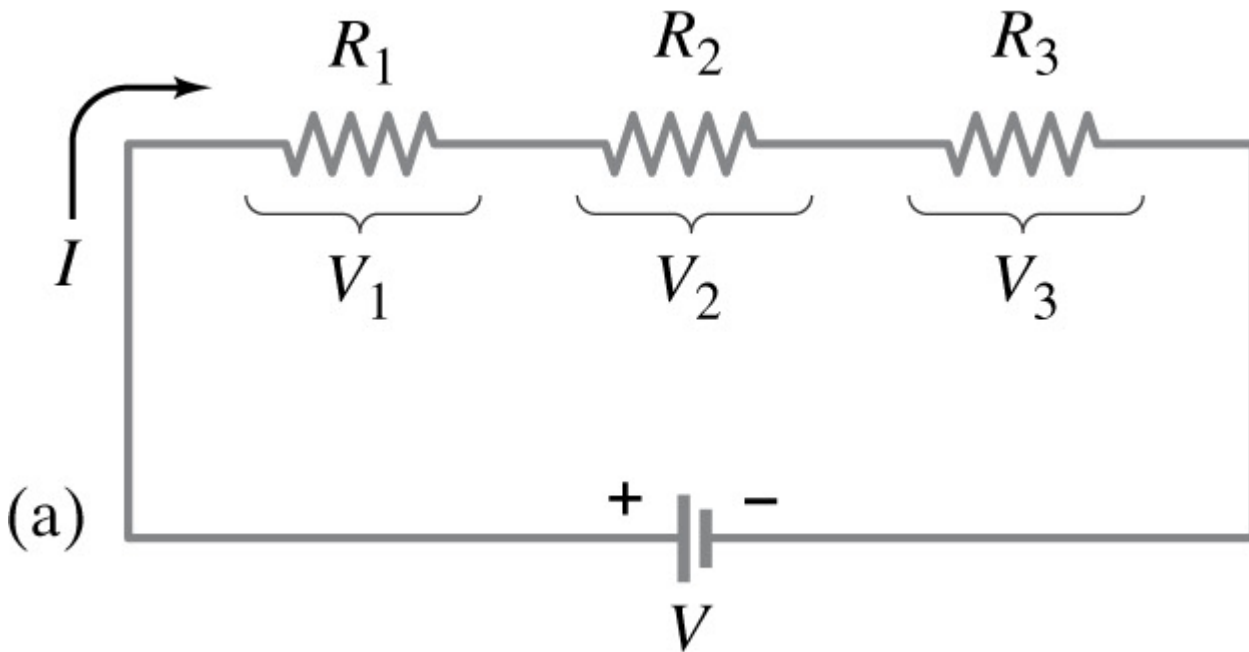| Battery	Amp.hr rating
AAA	0.5-1
AA	1-2
C	4-8
D	8-12
Car	50-100

Resistors (or devices) in Series

A series connection has a single path from the battery, through each circuit element in turn, then back to the battery.
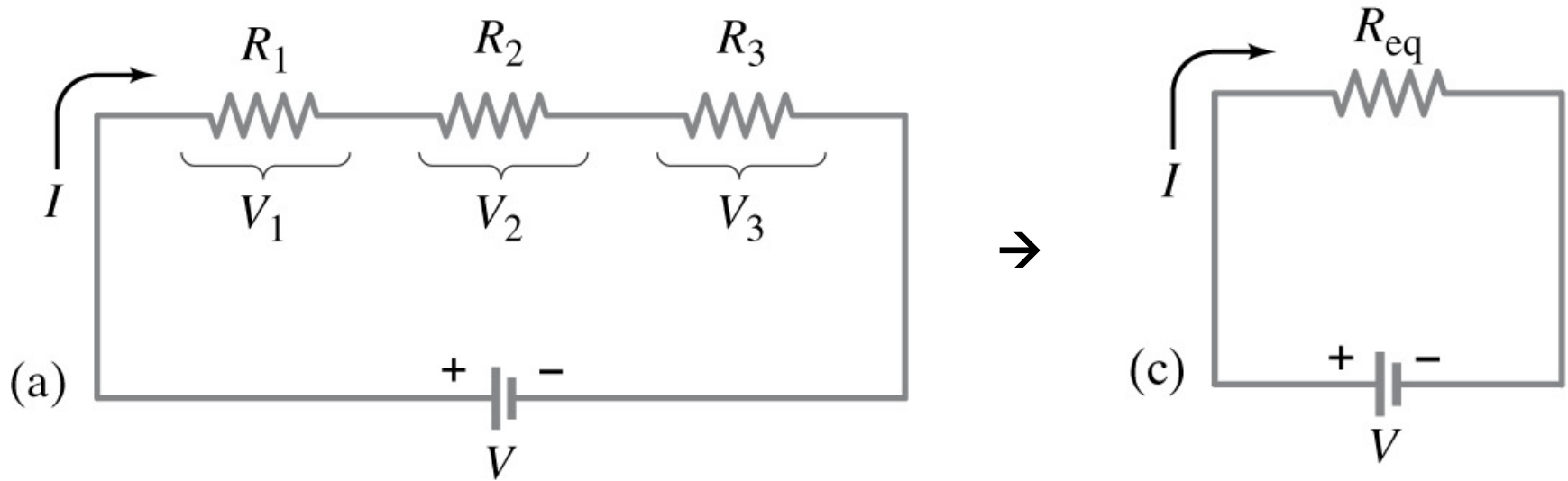

(a)

$$V = V_1 + V_2 + V_3 = IR_1 + IR_2 + IR_3$$

19.2 Resistors in Series

-The current through each resistor is the same.

-T he voltage depends on the resistance.

-The sum of the voltage drops across the resistors equals the battery voltage.

$$V = V_1 + V_2 + V_3 = IR_1 + IR_2 + IR_3 \quad \textbf{(19-2)}$$

19.2 Resistors in Series

**From this we get the equivalent resistance - single resistance that gives the same current in the circuit.**

$$R_{eq} = R_1 + R_2 + R_3 \qquad \textbf{(19-3)}$$

But is there another way to connect appliances together, so that they can all draw as much <u>current</u> as they need?

19.2 Resistors in Parallel

A parallel connection splits the current; the voltage across each resistor is the same:

(a)   (b)   (c)

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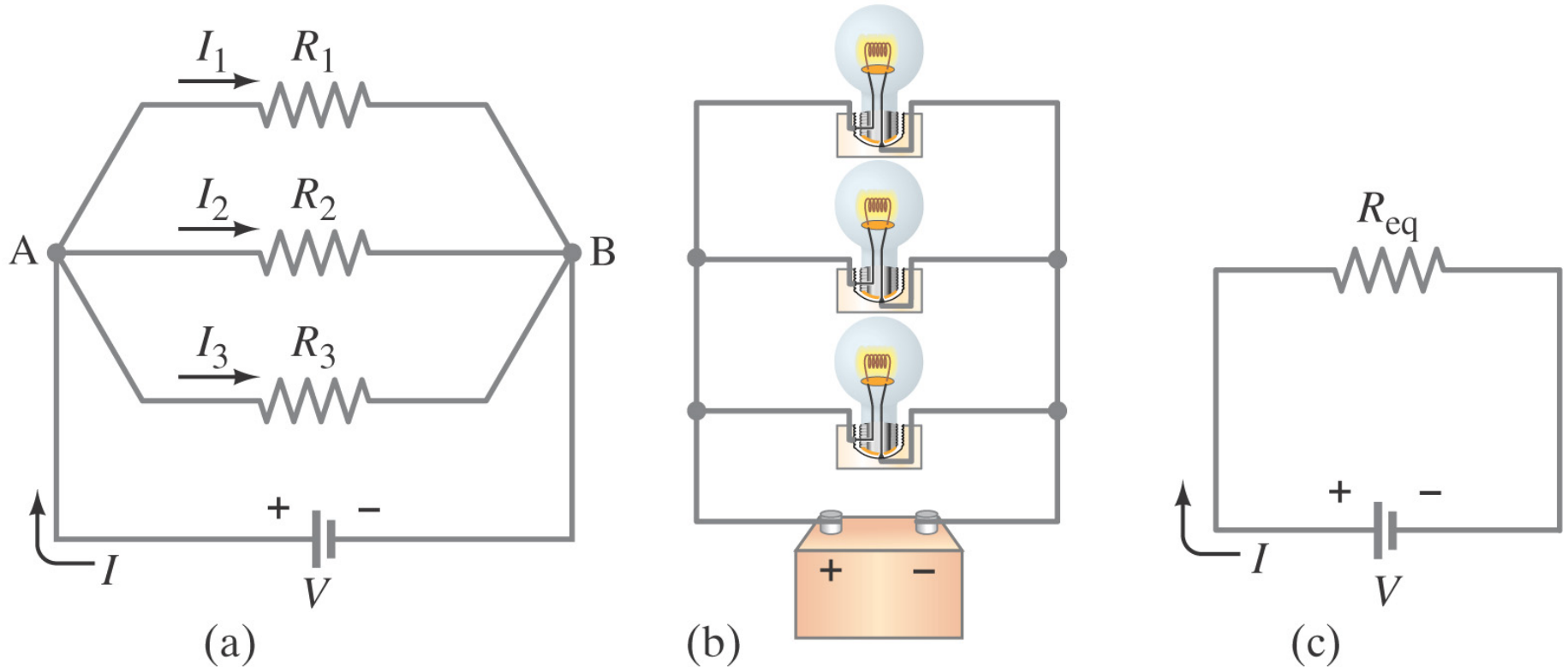
19.2 Resistors in Parallel

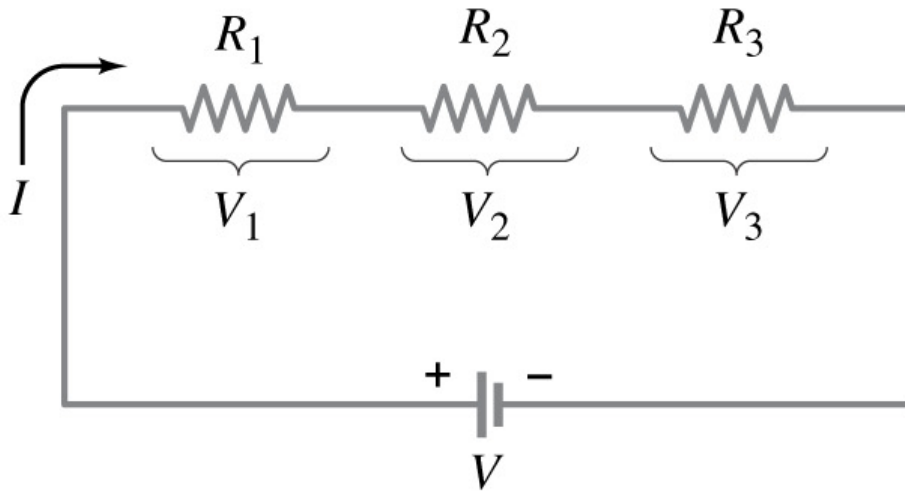**The total current is the sum of the currents across each resistor:**

$$I = I_1 + I_2 + I_3$$

$$\frac{V}{R_{eq}} = \frac{V}{R_1} + \frac{V}{R_2} + \frac{V}{R_3}$$

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

(19-4)

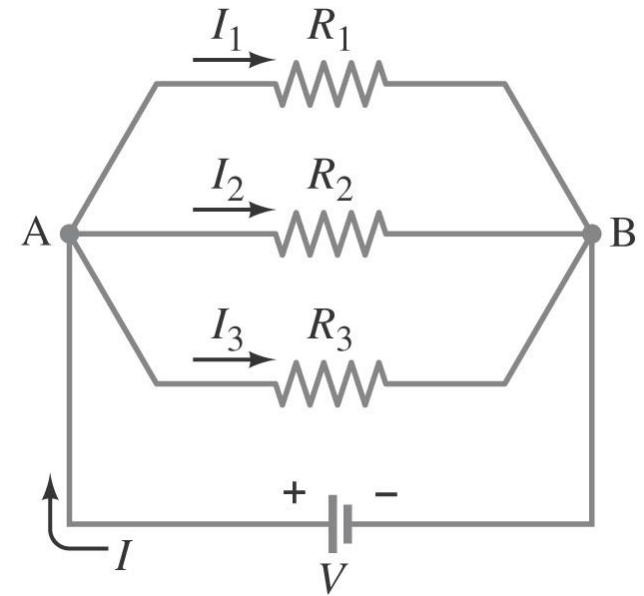# Circuit 1

Circuit 2

These circuit diagrams show two different ways of connecting the same battery and 3 resistors, R_1, R_2 & R_3.
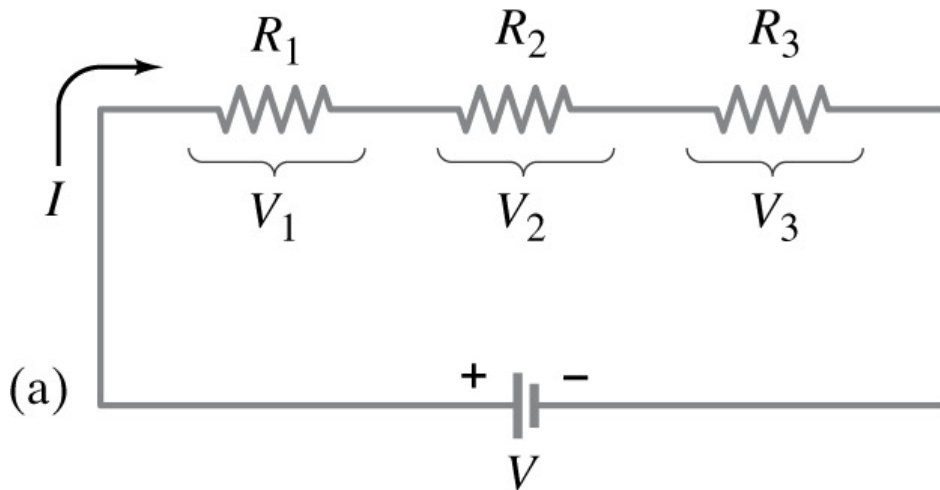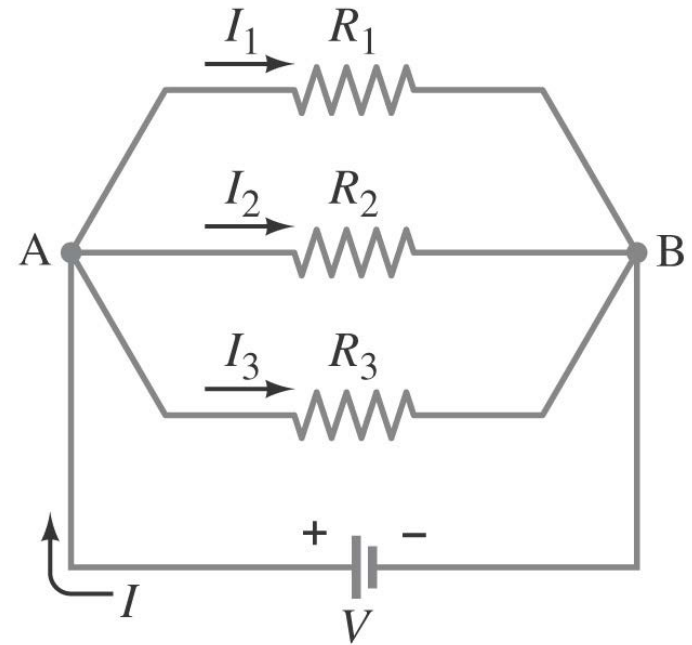
<u>**Which has the lower total resistance?**</u>

A. Circuit 1
B. Circuit 2
C. Same

Circuit 1

Circuit 2

These circuit diagrams show two different ways of connecting the same battery and 3 resistors, R_1, R_2 & R_3.

<u>**Which draws more Current from the battery?**</u>

A. Circuit 1
B. Circuit 2
C. Neither

19.3 Kirchhoff's Rules

**Complicated circuits cannot be simply broken down into series and parallel connections.**

1. **Junction Rule: Sum of currents entering a junction equals the sum of currents leaving it. (Conservation of Charge)**

2. **Loop Rule: Sum of voltage drops around a closed path equals zero. (Conservation of Energy)**

r
I_1
12.0 V
8.0 Ω
12 Ω
I_2
r
10 Ω
12.0 V
15 Ω
18 Ω
r
6.0 V
I_3
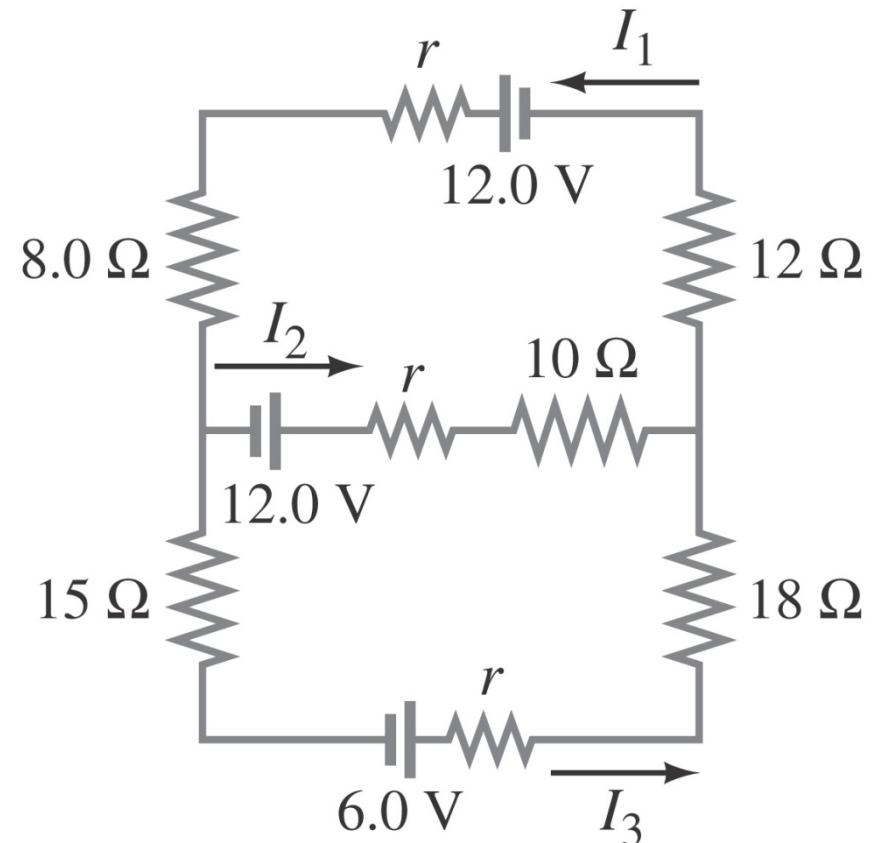
Kirchhoff's Junction Rule

Example: 19-8:

The sum of currents entering a junction equals the sum of the currents leaving it.

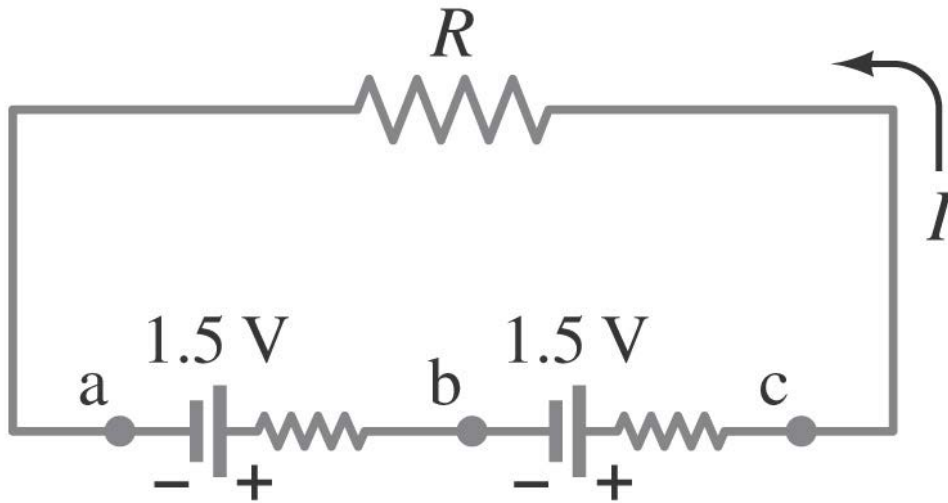Copyright © 2005 Pearson Prentice Hall, Inc.
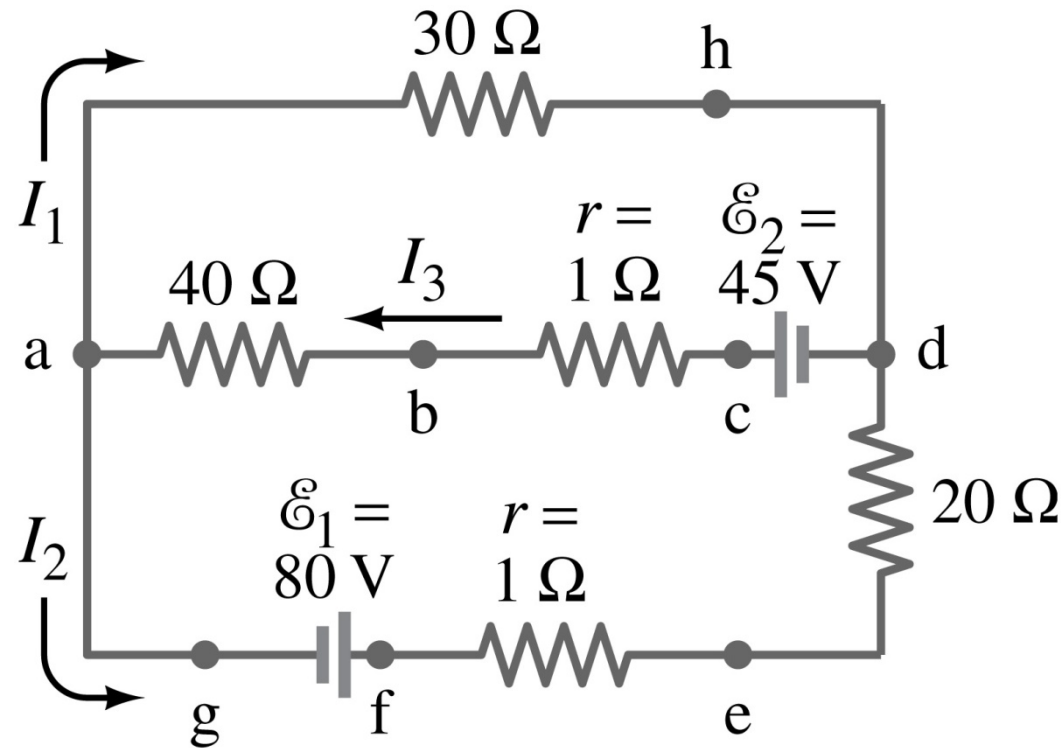
Using Kirchhoff's Rules

Problem Solving: Kirchhoff's Rules

1. Label each current.

2. Identify unknowns.

3. Apply junction and loop rules; you will need as many independent equations as there are unknowns.

4. Solve the equations, being careful with signs.

19.4 EMFs in Series

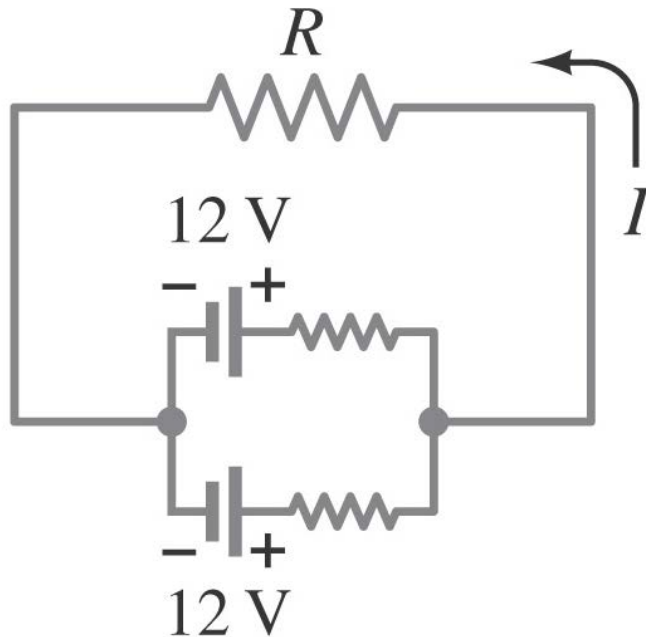**EMFs in series in the same direction: total voltage is the sum of the separate voltages**

Connect batteries in series to get a higher voltage.

Common example: Flashlights

19.4 EMFs in Parallel

- EMFs in parallel only make sense if the voltages are the same;

- This arrangement produces more current than a single emf.

- Large batteries contain several cells (or even smaller batteries) connected in parallel.

Charging a Battery

- **EMFs in series, opposite direction: total voltage is the difference, but the lower-voltage battery is charged.**

- **Rechargable batteries contain electrodes and chemicals whose redox reactions are <u>reversible.</u>**
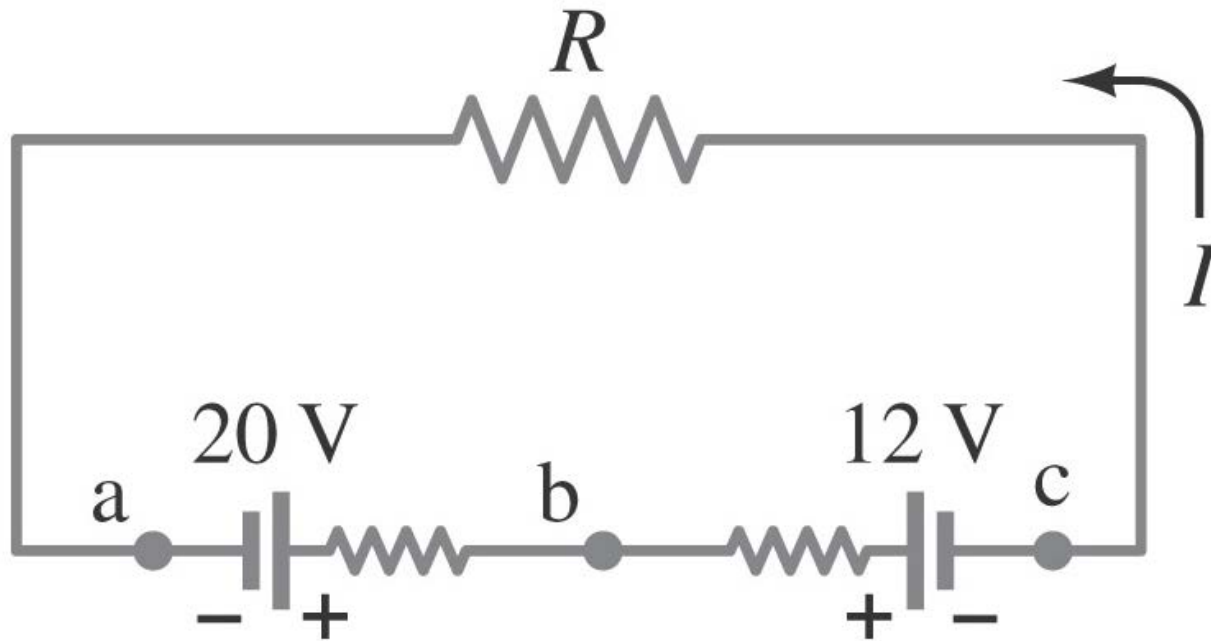
19.5 Circuits Containing Capacitors

Connecting Capacitors in parallel

- **Remember capacitors store energy by holding opposite charges on their plates.**

- **Capacitors in parallel have the same voltage across each one.**

- **Each capacitor stores the same amount of charge as if it were the only capacitor in the circuit.**

- **A <u>bank</u> of capacitors connected in parallel is the best way to store a large amount of energy.**

$$C_{eq} = C_1 + C_2 + C_3$$

C_1

Q_1

C_2

a   b

Q_2

C_3

Q_3

$V = V_{ab}$
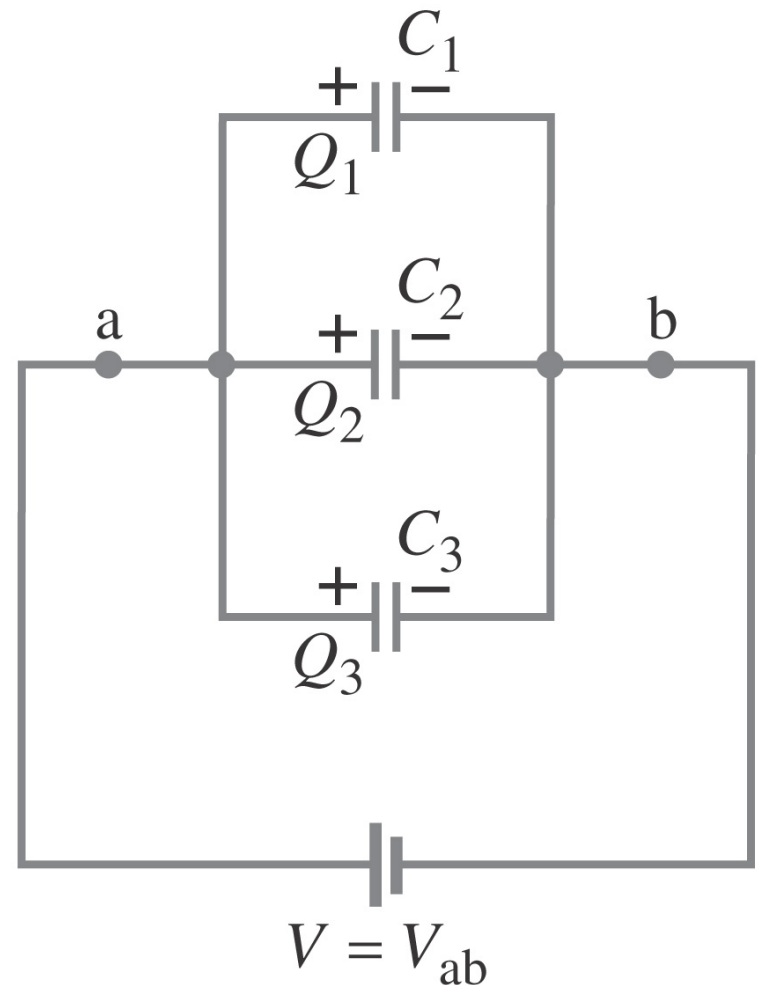
Connecting Capacitors in Series
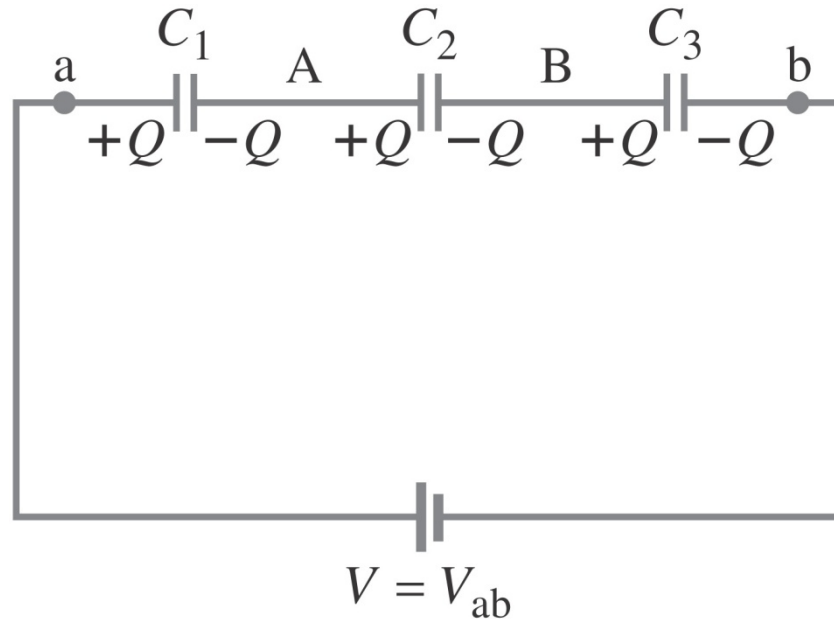
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- **In a DC circuit, current cannot flow "through" a capacitor.**

- **Hence series capacitors are connected only by their electric fields!**

- **Adding more units doesn't increase the total energy stored by much.**

- **Capacitors in series are not very useful.**

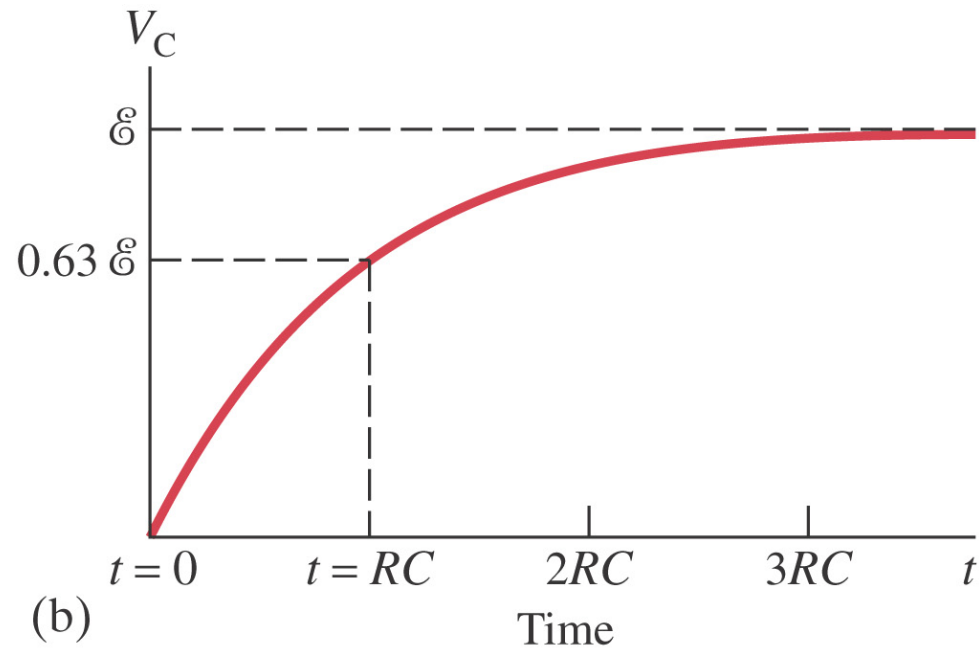$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

19.6 RC Circuits – Resistor and Capacitor in Series - Very useful

• **When the switch is closed, the capacitor will begin to charge.**

• **As you might expect, it takes a while.**

• **How long is "a while" ?**

• **We can control precisely how long it takes by a setting the voltage across the capacitor**

(a)

(b)
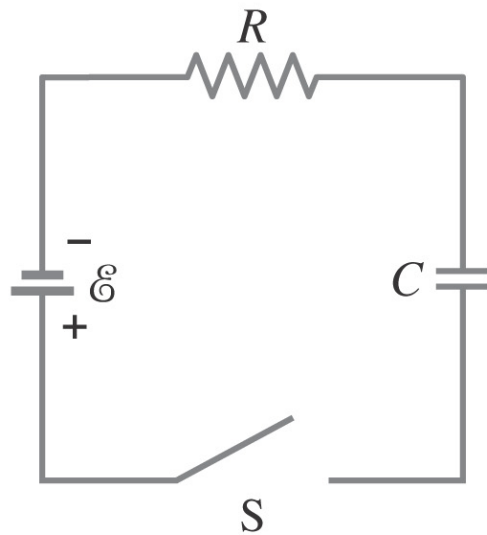
Time

RC Time Constant - The(?) fundamental principle of Electronics

• **Charge flows onto a capacitor rapidly at first, slowing down as it fills.**

• **Why? -The charges flowing into plate A are attracted by plate B, but are at the same time repelled by the other charges already in plate A.**

• **The rate at which the capacitor fills with charge is described by a math function called an Exponential (y=e^x)**

$$\Delta Q = Q_0 e^{-t/\tau}$$

**Euler's number**
e = 2.71828………

RC Circuits –
Just what is the Time Constant ?

• **The time constant τ is the amount of time it would take for the charge on the capacitor to change by a certain factor.**

• **In electronics we can construct a physical property of the circuit that happens to have the dimension of time.**

• **The product of resistance and capacitance, RC has the units of seconds**

$$\tau = RC$$

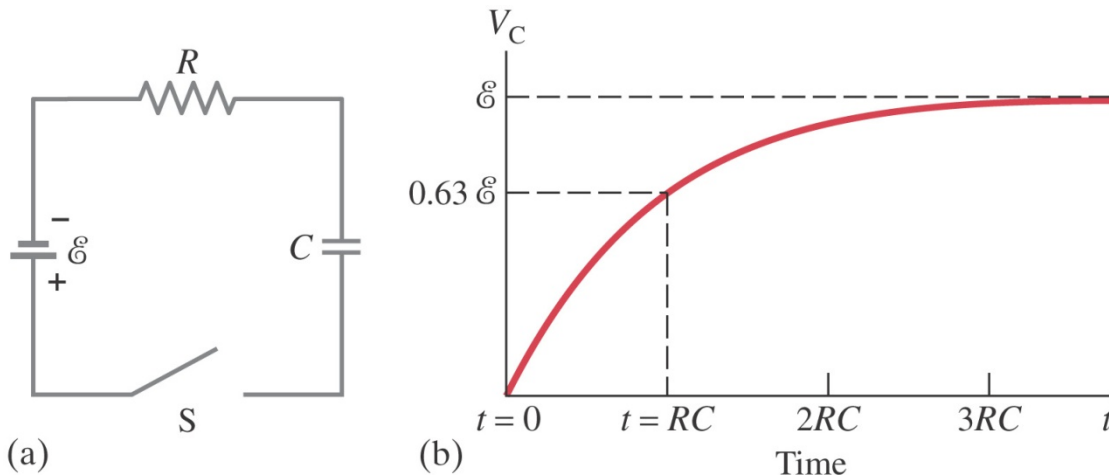$$Q = Q_0\left(1 - e^{-t/RC}\right)$$

(a)

(b)
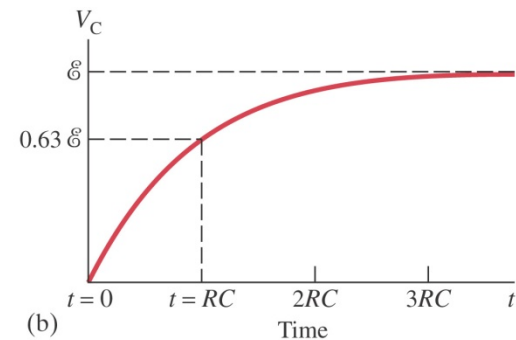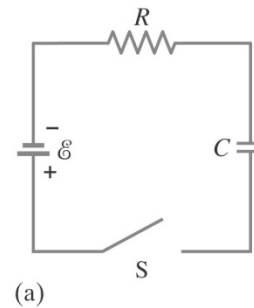
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Handy Fact: It turns out that the charge stored in the capacitor changes by 63% in the time RC.

The voltage across the terminals of the capacitor follows a similar curve to the charge

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

(a)

(b)

V_C

$\mathcal{E}$

$0.63\,\mathcal{E}$

$t = 0$ $t = RC$ $2RC$ $3RC$ t

Time

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- **EMF ($\mathcal{E}$)here is the voltage being supplied (usually by a battery) to the circuit.**

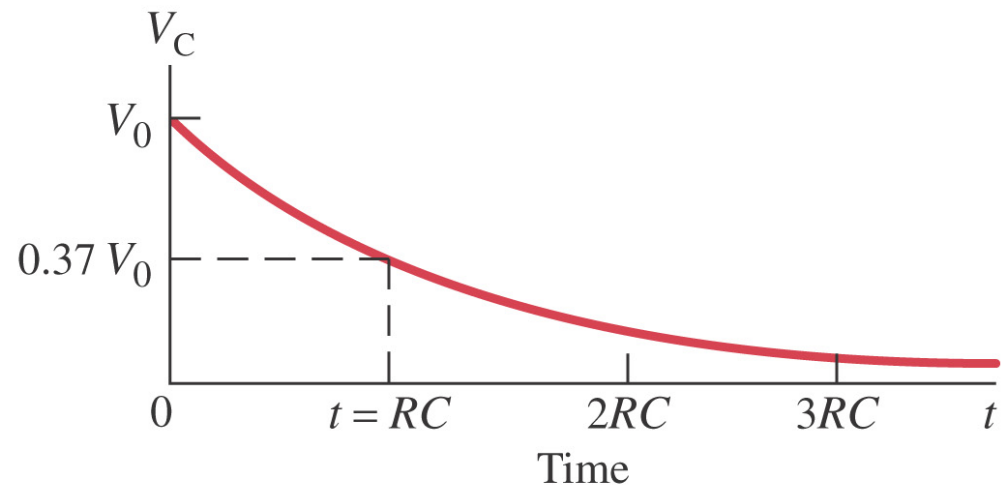- **V_c is the capacitor's voltage after charging for a time "t" in seconds.**

Discharging a Capacitor

If an isolated charged capacitor is connected across a resistor (or a load, like a flash-bulb) it discharges exponentially.

$$Q = Q_0 e^{-t/RC}$$

(a)

(b)
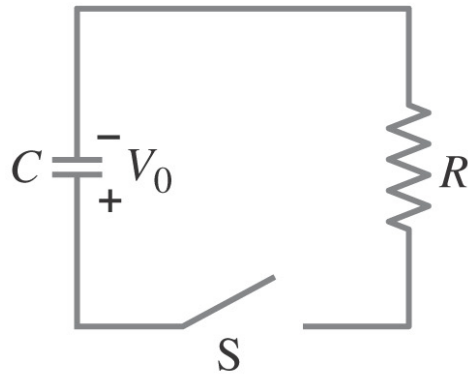
A flashbulb has a very small resistance (it draws a large current), so the capacitor will discharge very fast, which is what you need!

19.7 Electric Hazards

Even very small currents – 10 to 100 mA can be dangerous, disrupting the nervous system. Larger currents may also cause burns.

Household voltage can be lethal if you are wet and in good contact with the ground. Be careful!

- Your electrical resistance is about 10^4-10^6 Ohms

- When wet: 10^3 Ohms or less

19.7 Electric Hazards

Faulty wiring and improper grounding can be hazardous. Make sure electrical work is done by a professional.

Current   120 V   (a)

I   I   120 V   I   (b)

I   I   Current   120 V   (c)
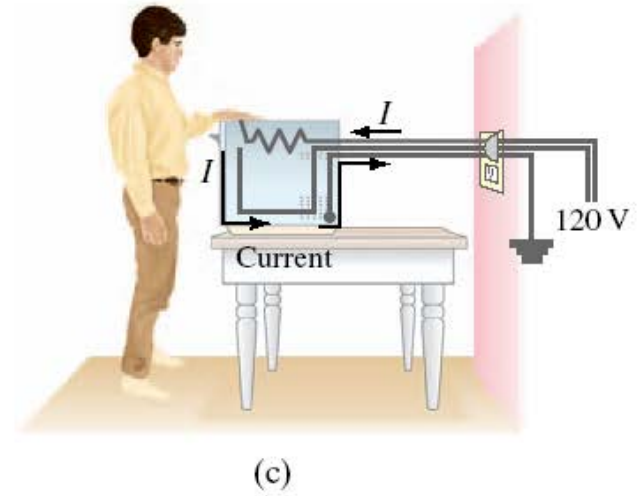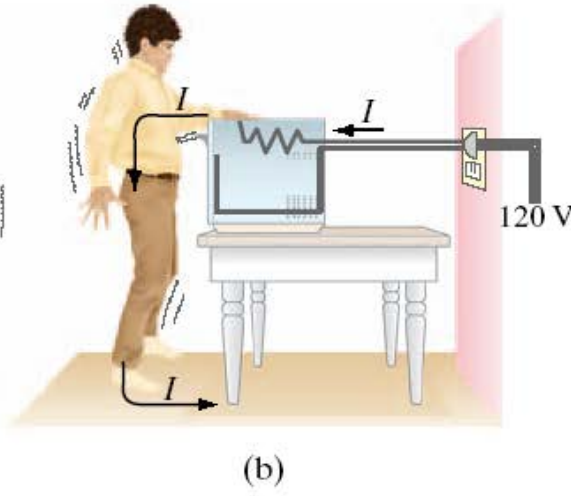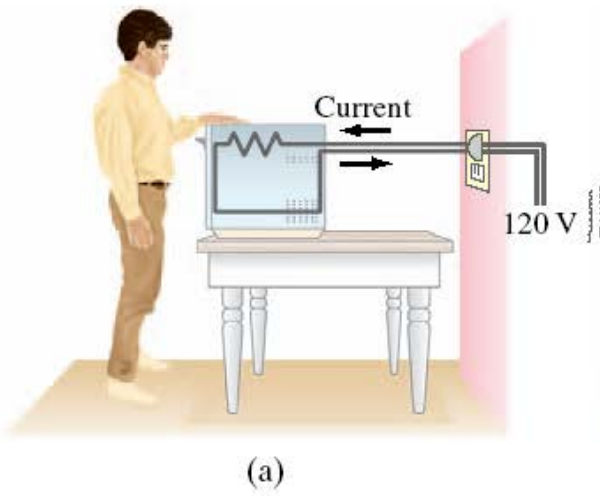
19.8 Measuring Current, Voltage, and Resistance.

An **Ammeter** measures current. **(needs low R)**

A **Voltmeter** measures voltage. **(needs high R)**

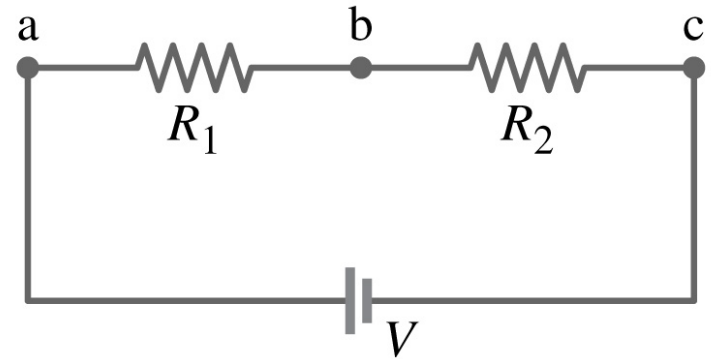An **Ohmmeter** measures resistance. **(needs a battery)**

Today all 3 functions are typically performed by a single instrument called a **Multimeter**

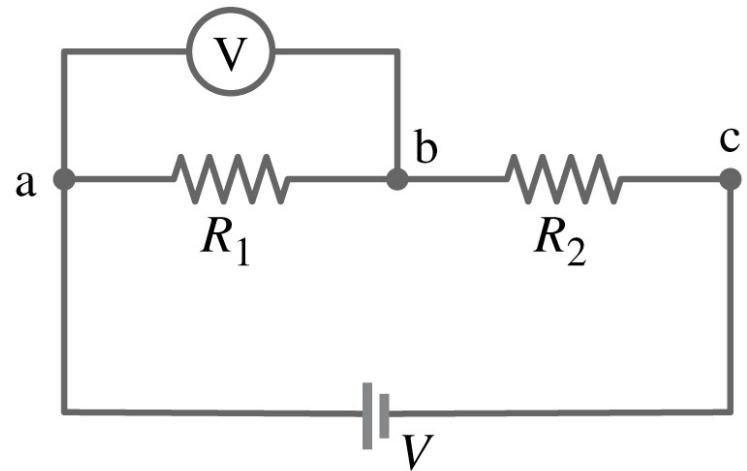**Multimeters** have a separate mode for AC, remember to use it!

Ammeters and Voltmeters

The current in a circuit passes through the ammeter; the ammeter should have low resistance so as not to affect the current.

(a)

A voltmeter should not affect the voltage across the circuit element it is measuring; therefore its resistance should be very large.

(b)

Summary of Chapter 19

- **A source of emf transforms energy from some other form to electrical energy**

- **A battery is a source of emf in parallel with an internal resistance**

- **Resistors in series:**

$$R_{eq} = R_1 + R_2 + R_3$$

- **Resistors in parallel:**

$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Summary of Chapter 19

- **Kirchhoff's rules:**

  - sum of currents entering a junction equals sum of currents leaving it

  - total potential difference around closed loop is zero.

- Capacitors in parallel:

$$C_{eq} = C_1 + C_2 + C_3$$

- Capacitors in series:

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Summary of Chapter 19

- RC circuit has a characteristic time constant:

$$\tau = RC$$

- To avoid shocks, don't allow your body to become part of a complete circuit

- Ammeter: measures current

- Voltmeter: measures voltage