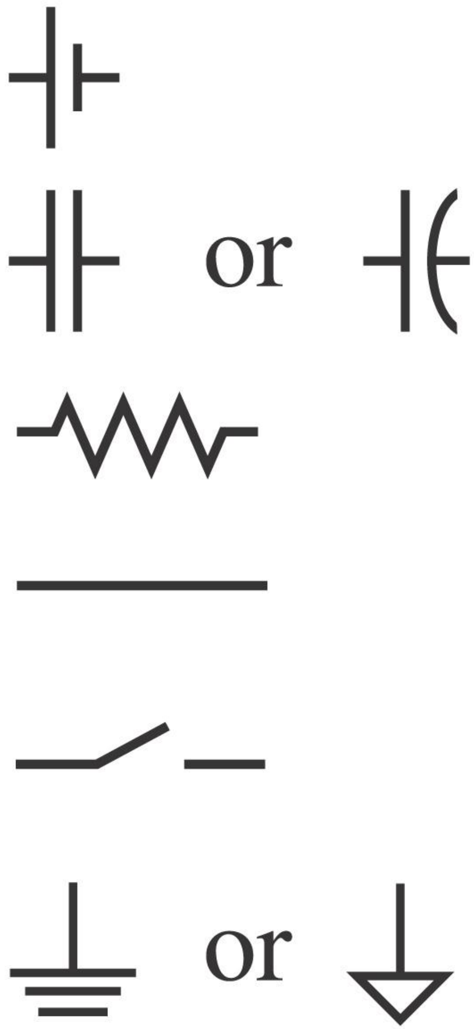
CIRCUITS

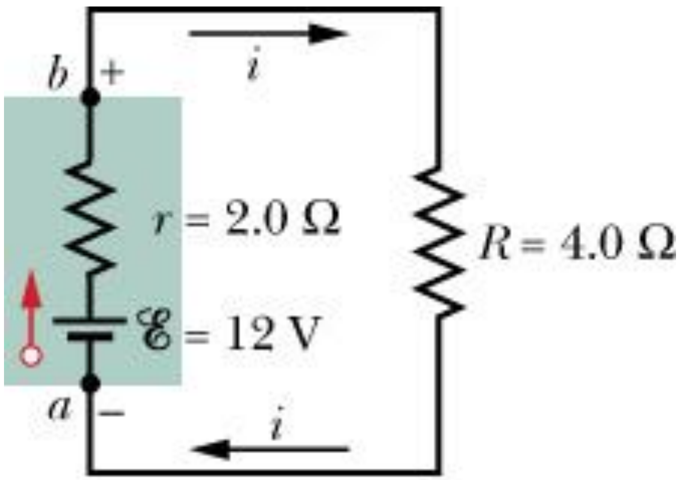
Chapter 19

Don’t do dumb stuff with electricity!!

Learn circuit symbols and how to draw circuits

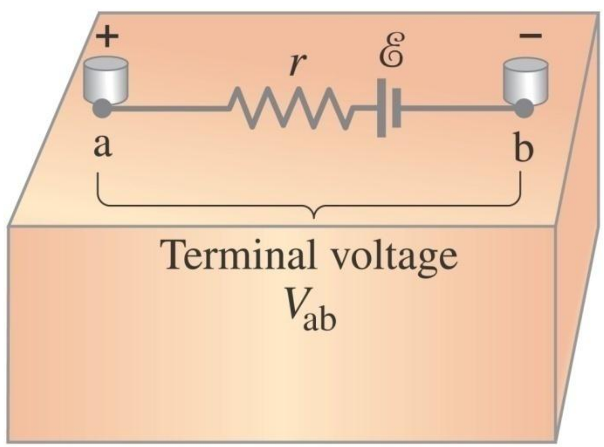


Real batteries have internal resistance

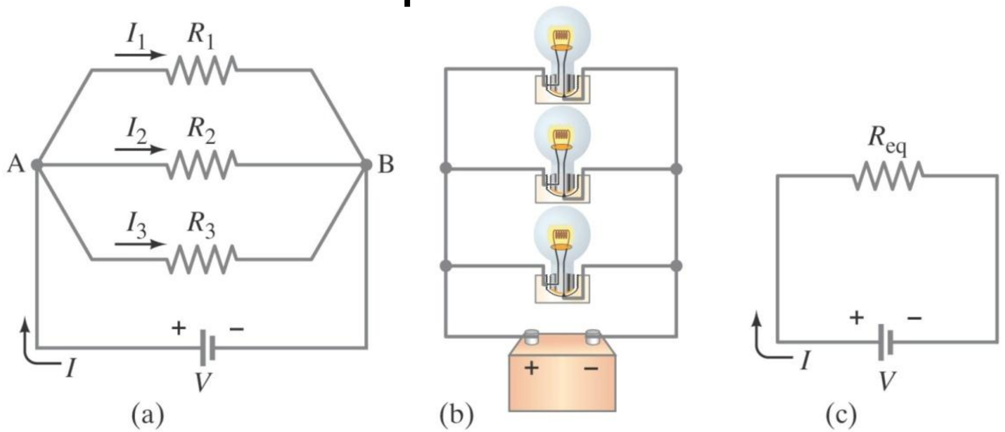


Internal resistance (r) due to current passing through metal

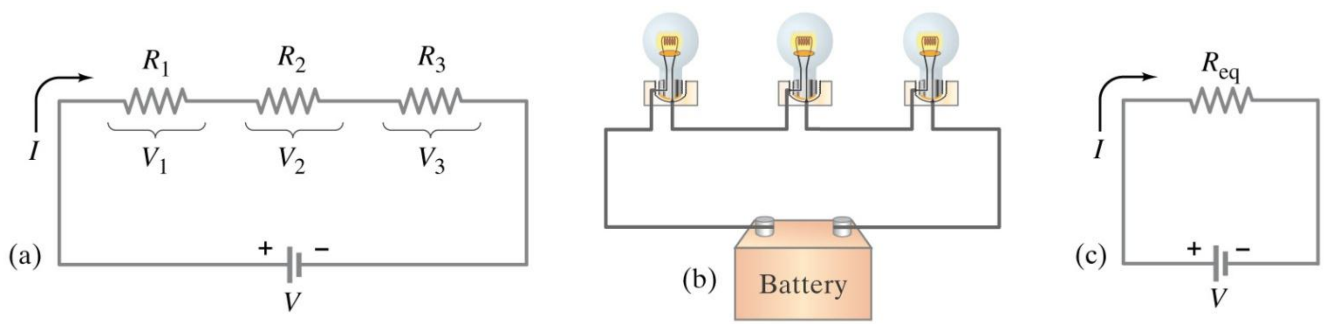
reduces the actual “terminal voltage” that battery operates at (later)



Resistors wired in parallel



Resistors wired in series



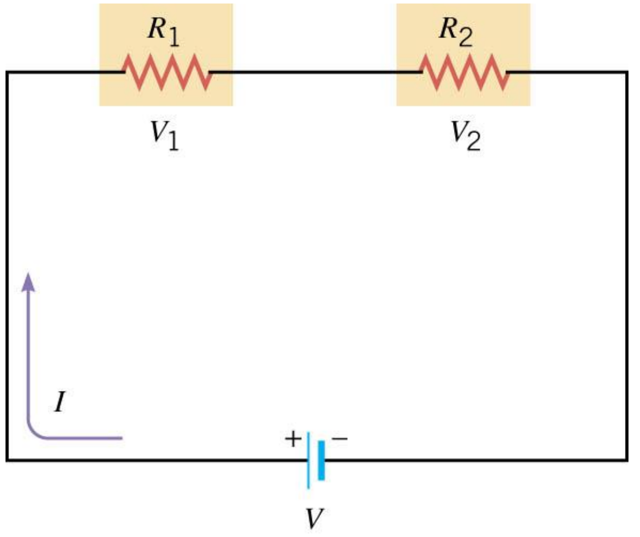
Key to analyzing circuits is determining the equivalent resistance of all resistors in the circuit

Equivalent Resistance of a Circuit

- The one resistor that can replace all the resistors in the circuit and have the voltage source supply the same amount of current
- For series $R_{eq} = R_s$
- For parallel $R_{eq}=R_p$

Series Circuit Wiring

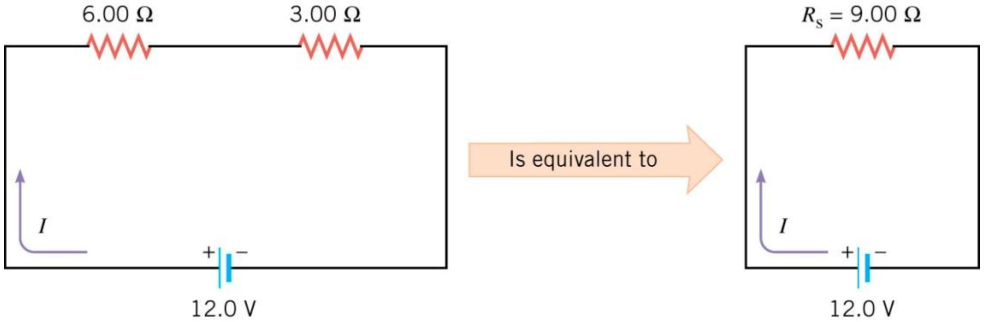
- Resistors (devices) are wired in series when there is the same electric current passing through each device.
- Only one path for current to flow



As more resistors are added in series the length of resistor is getting longer thus equivalent resistance increases

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

R_{eq} for series circuit



Current is equal in all resistors

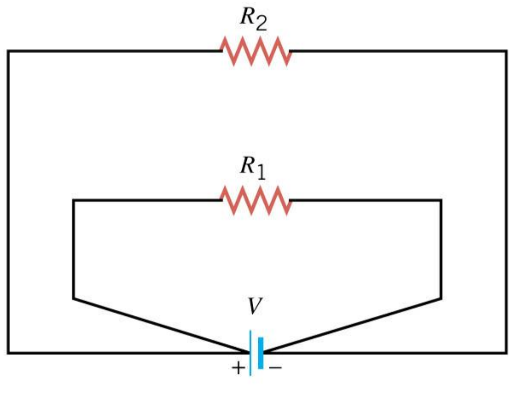
$$I_B = I_1 = I_2$$

Voltage drops sum up

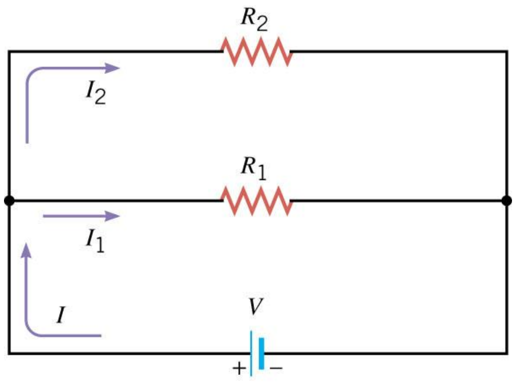
$$V_B = V_1 + V_2$$

$$I_B R_s = I_1 R_1 + I_2 R_2 \quad \Rightarrow \quad R_s = R_1 + R_2$$

Parallel Wiring of Circuits



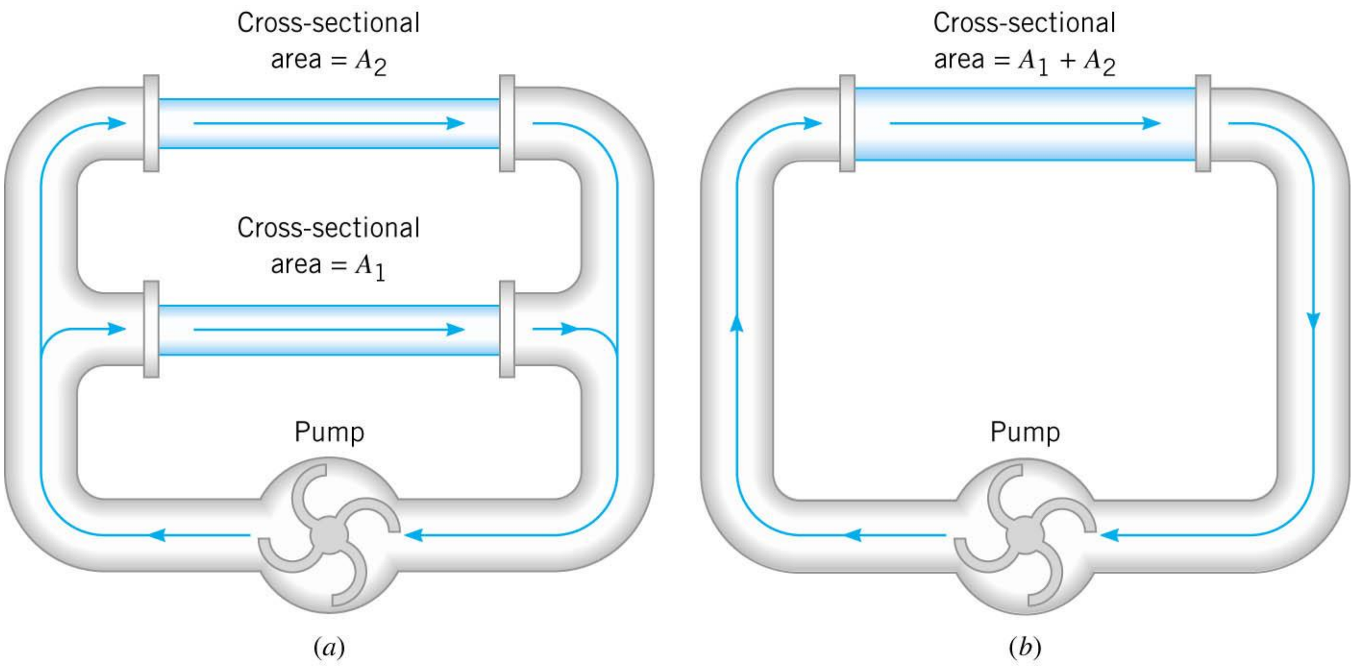
(a)



(b)

- Parallel wiring means devices are connected so that the same voltage is applied across each resistor
- Just as if each resistor is connected independently to source
- Current into each path depends on resistance in that path

Parallel Circuits

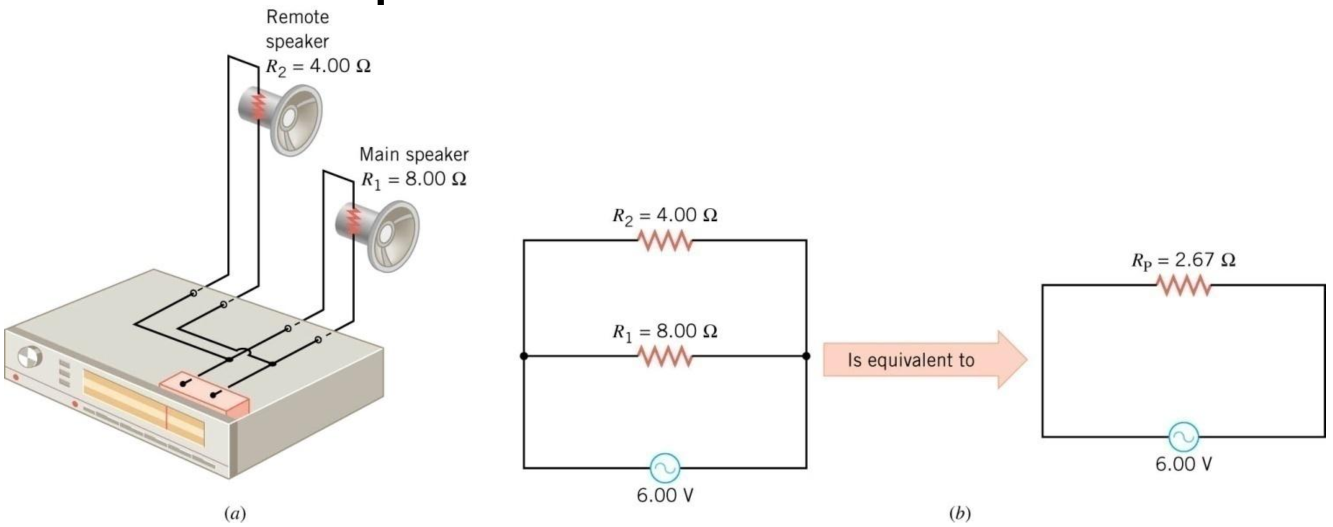


$$R = \rho \frac{L}{A}$$

Pipes in parallel provide more paths for water to flow

Equivalent to having a wider diameter pipe = lower resistance to flow = more water flow

R_{eq} for parallel circuits



currents sum up

$$I_B = I_1 + I_2$$

voltage drop is equal for all resistors

$$V_B = V_1 = V_2$$

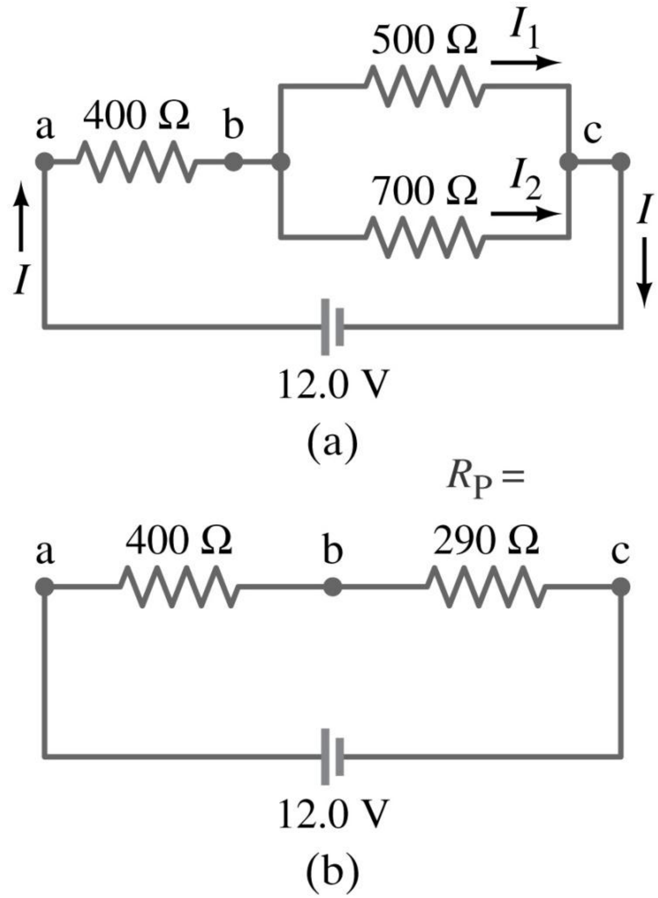
$$\frac{V_B}{R_P} = \frac{V_1}{R_1} + \frac{V_2}{R_2} \quad \Rightarrow \quad \frac{1}{R_P} = \frac{1}{R_1} + \frac{1}{R_2}$$

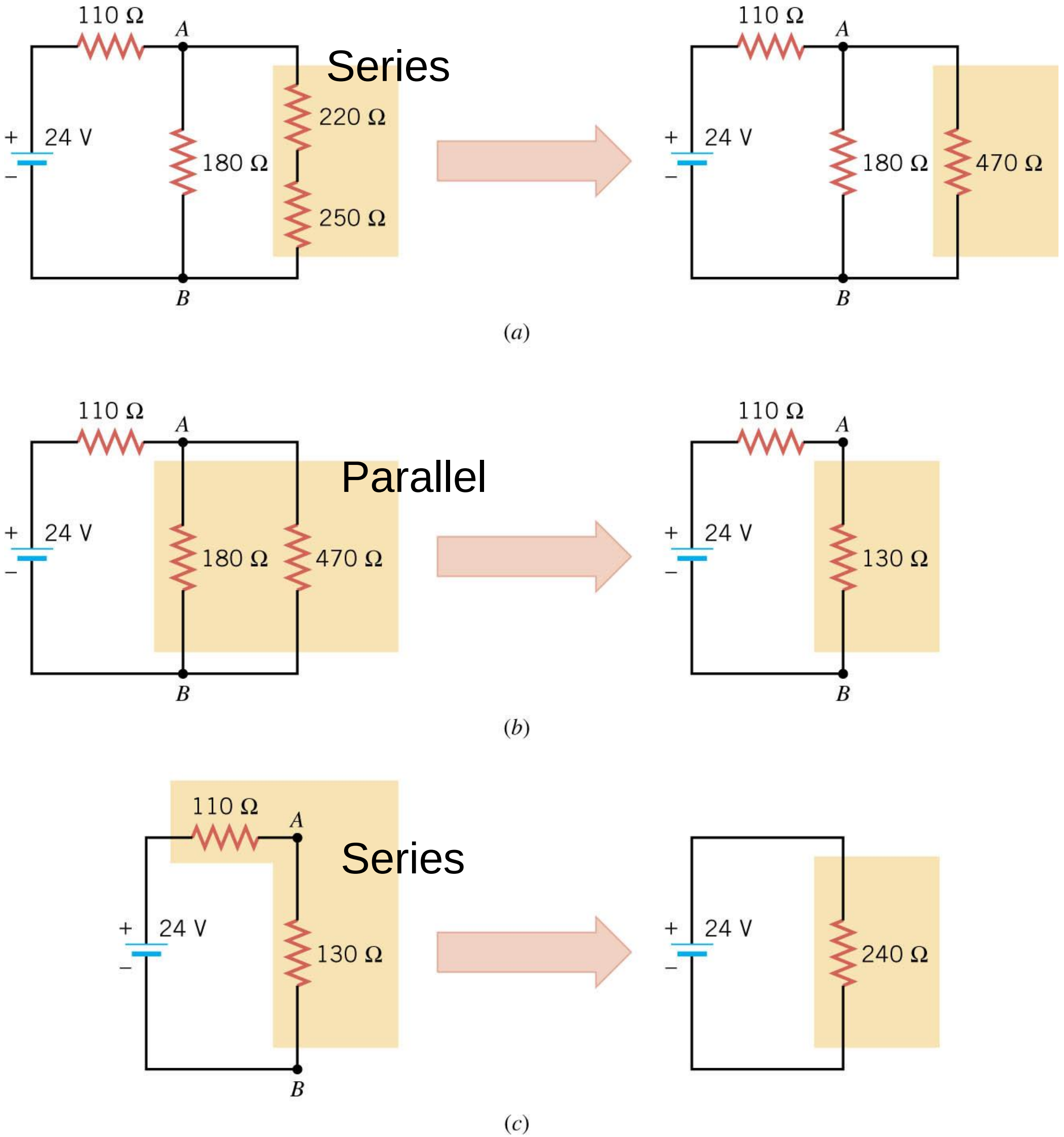
Series/Parallel Comparisons

	Series	Parallel
Adding more resistors	R_{eq} increases I_B decreases	R_{eq} decreases I_B increases
Equivalent resistance	greater than for any single resistor	less than for any single resistor
Interrupt circuit at any point	current flow stops for entire circuit	current remains in the other branches AT THE SAME RATE

3 bulb strip in series/parallel

Analyze combination circuits – series and parallel wiring





1) start with branch that is farthest from the battery and find its R_{eq}

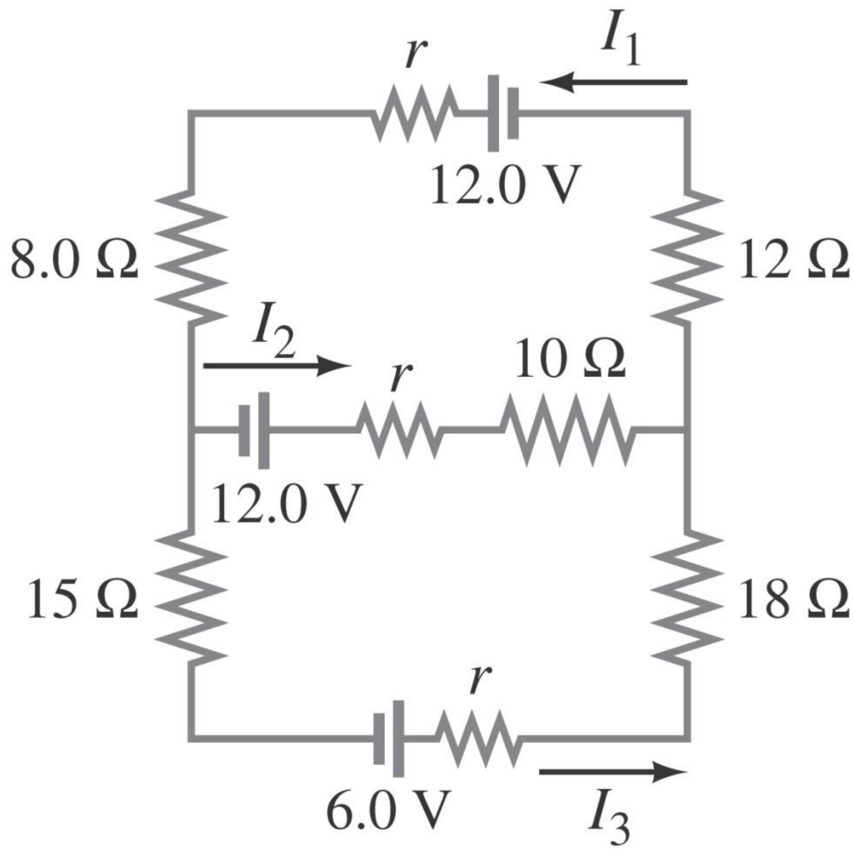
2) redraw circuit

3) continue with next branch

4) work backwards toward battery until only one resistor remains; that is the R_{eq} of circuit

19.3 Kirchhoff's Rules

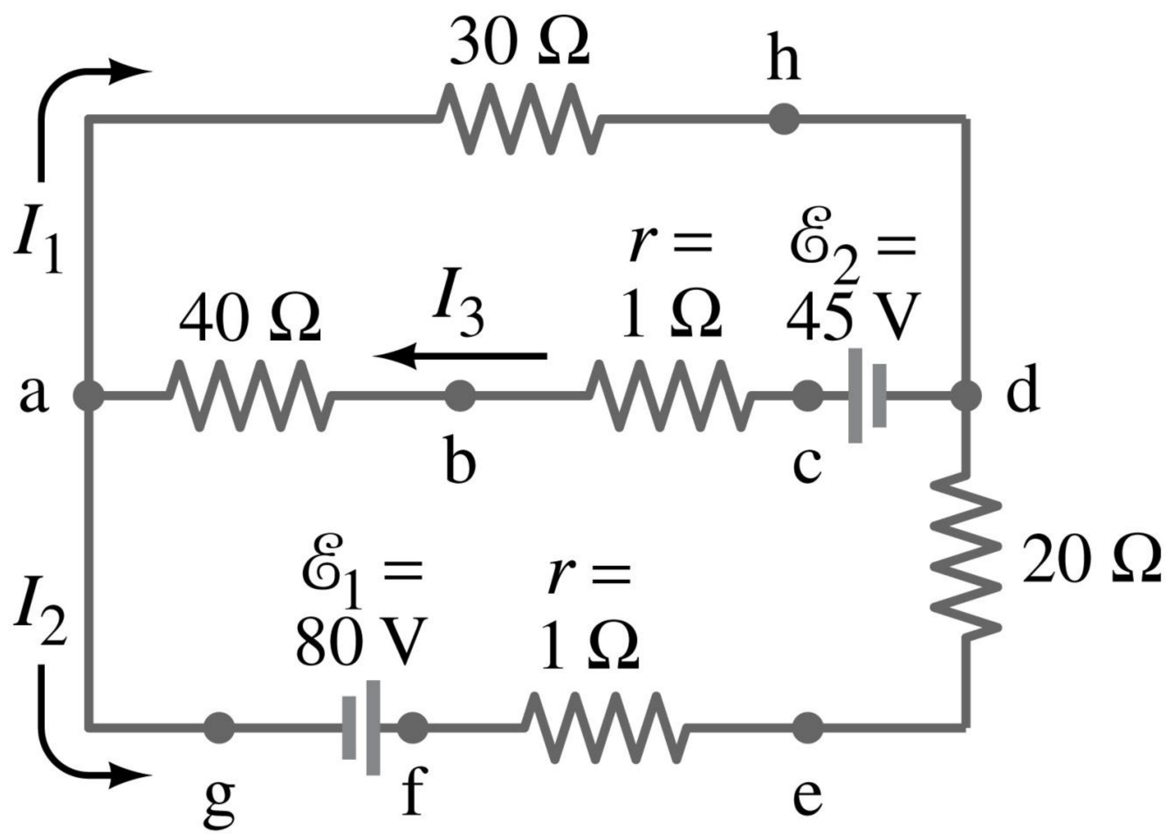
Some circuits cannot be broken down into series and parallel connections.



19.3 Kirchhoff's Rules

For these circuits we use Kirchhoff's rules.

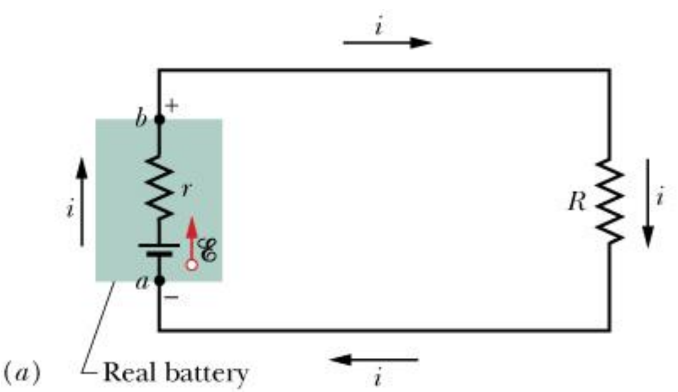
Junction rule: The sum of currents entering a junction equals the sum of the currents leaving it.

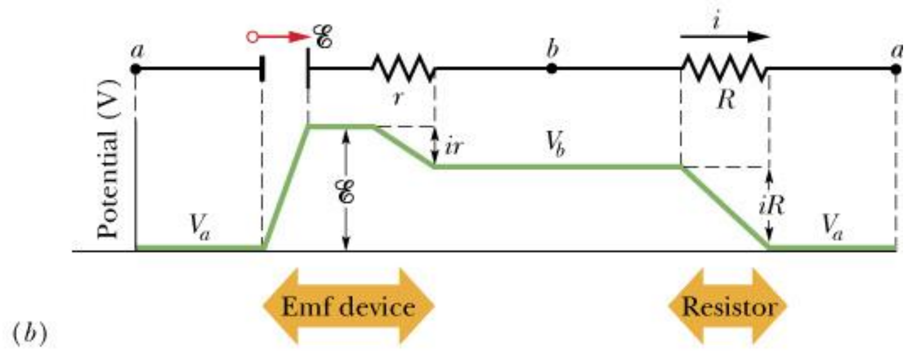


Kirchoff's Loop Rule

The sum of the changes in potential around a closed loop is zero.

all increases in potential have to be accompanied by a decrease in potential for $\Sigma\Delta V$'s = 0





Application of Loop Rule: + and – ΔV's

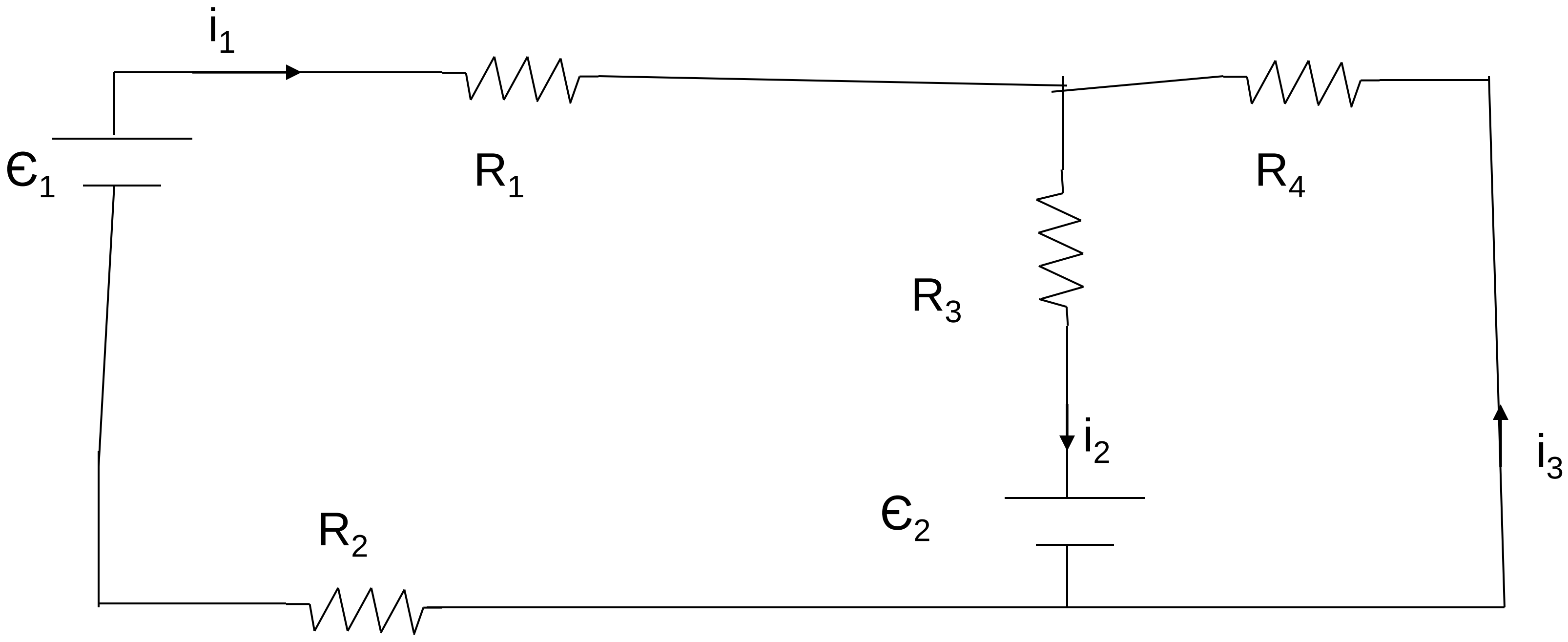
Moving through resistor with your loop

- same direction as current $\Delta V = -iR$ voltage drop (downhill)
- opposite the current $\Delta V = +iR$ voltage increase (uphill)

Moving through battery with your loop

- from – to + $\Delta V = +\mathcal{E}$
- from + to - $\Delta V = -\mathcal{E}$

** You choose current direction and loop direction based on emf directions: arbitrary!



Left loop:

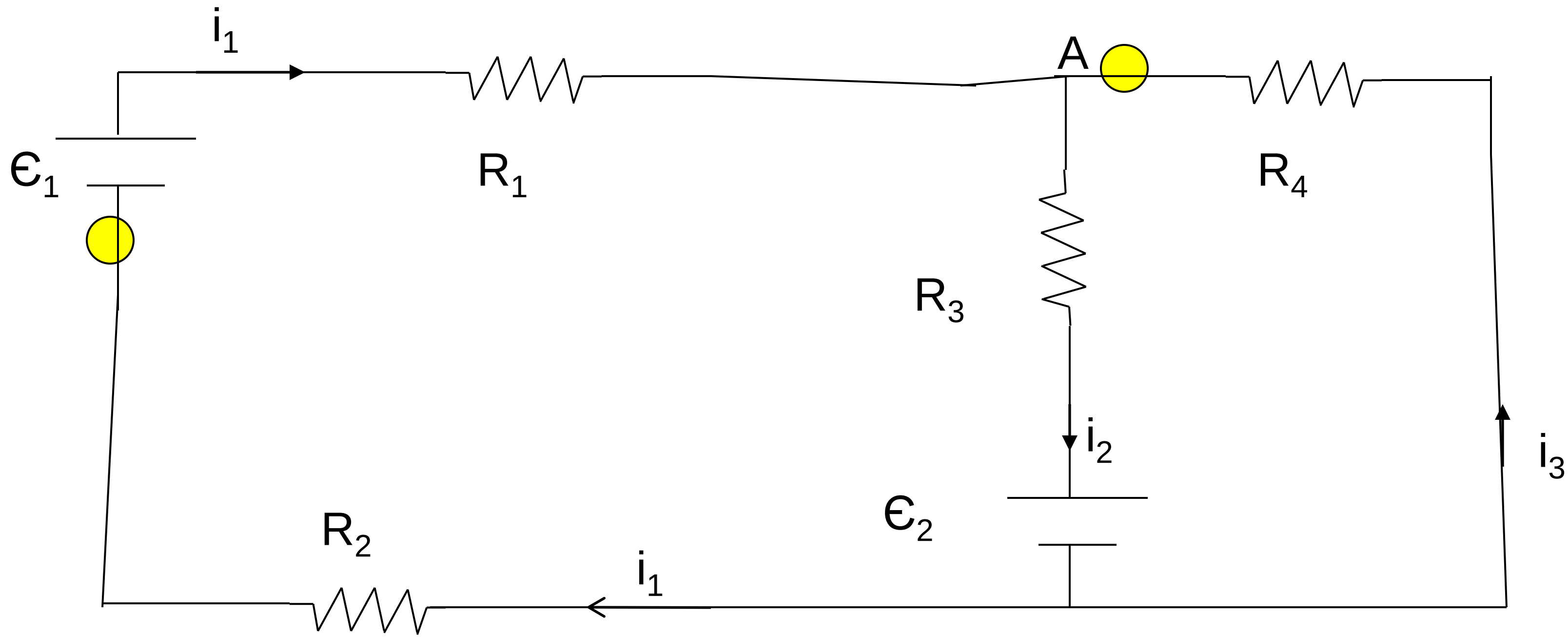
$$\varepsilon_1 - i_1R_1 - i_2R_3 - \varepsilon_2 - i_1R_2 = 0$$

Right loop:

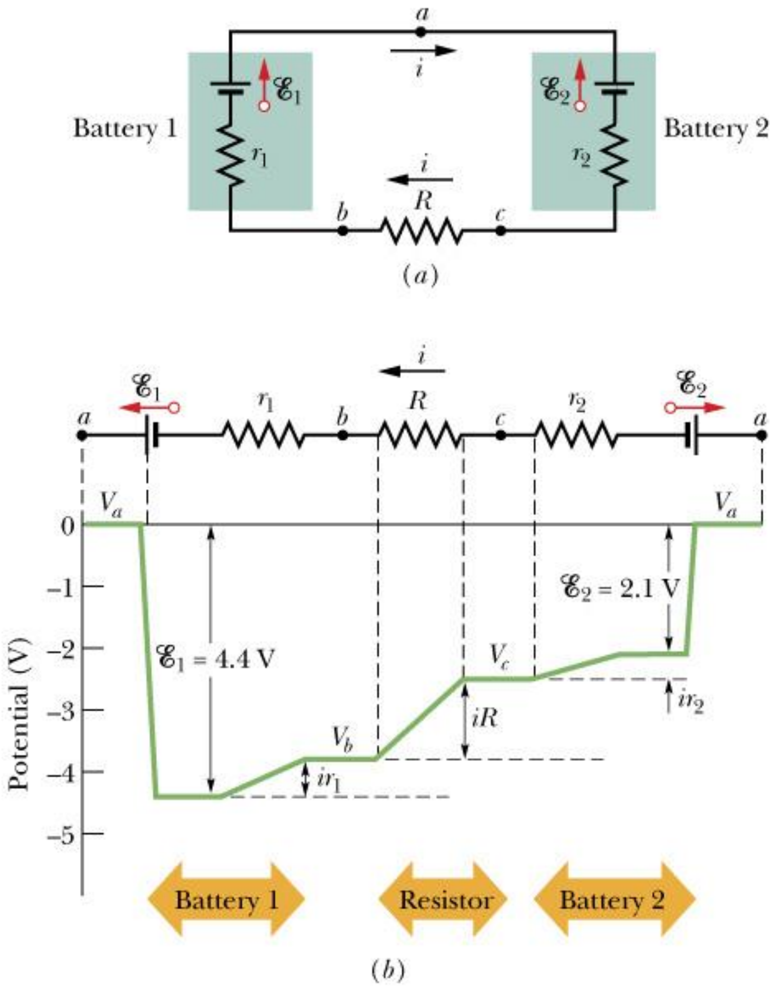
$$+i_3R_4 + \varepsilon_2 + i_2R_3 = 0$$

Junction A:

$$i_1 + i_3 = i_2$$



3 ways to use loop rule



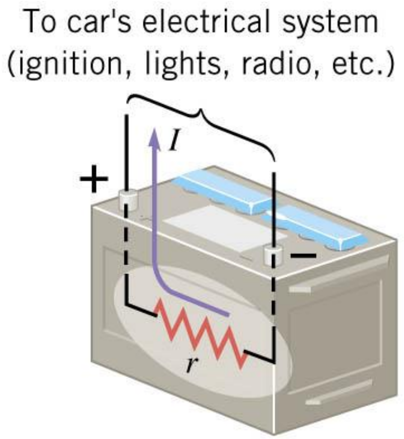
1) use $\Sigma\Delta V$'s = 0 for entire loop to solve for current or one of the resistor values

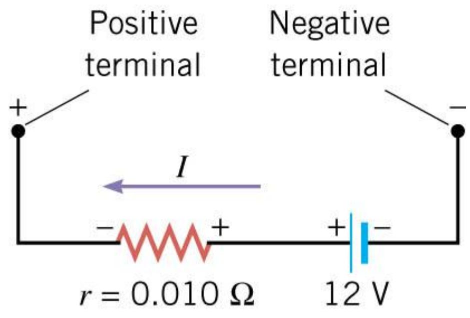
2) use part of the loop - go point a to point b to solve for V_a or V_b or ΔV between them

3) solve for terminal voltage of real battery

Internal Resistance of emf source

- Real batteries have an $\mathcal{E}$ source and an small amount of resistance to current flow
- Two voltages
  - terminal voltage = what is measured between external + and – terminals
  - the potential difference provided by the $\mathcal{E}$ source inside the battery
- Terminal voltage depends on
  - direction of current
  - amount of external resistance in the circuit



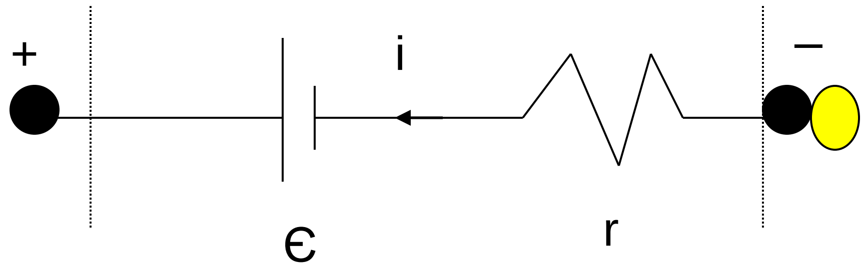


Terminal Voltage

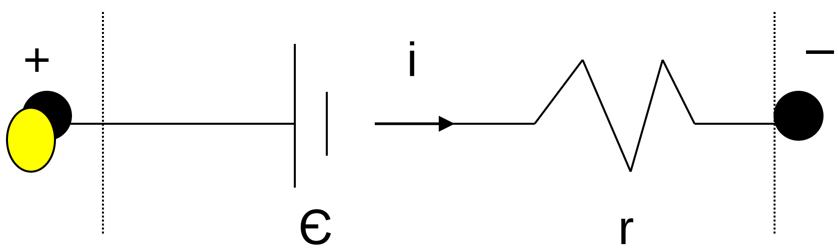
Normal operation: terminal voltage < ε

$$V_{-} - ir + \varepsilon = V_{+}$$

$$V_{+} - V_{-} = V_{T} = \varepsilon - ir$$



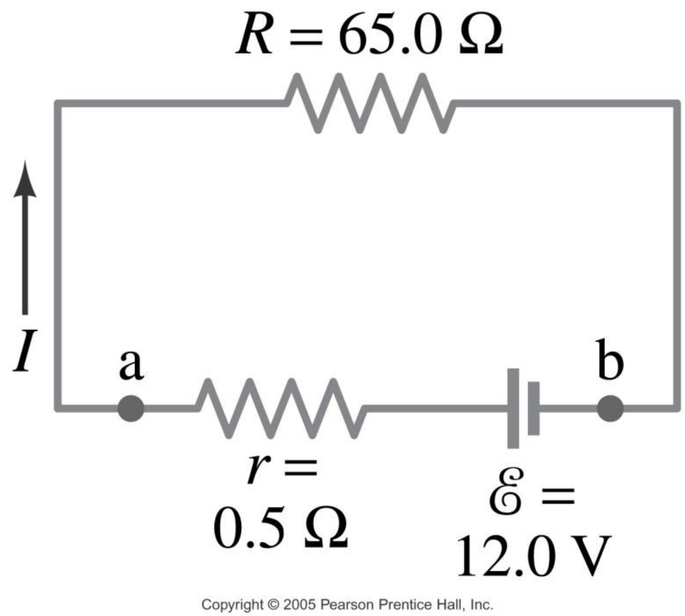
Recharging battery: terminal voltage > ε



$$V_{+} - \varepsilon - ir = V_{-}$$

$$V_{+} - V_{-} = V_{T} = \varepsilon + ir$$

Determine terminal voltage of real battery



Sum up the ΔV's as you go from b to a to find ΔV between them

$$V_b + 12 - Ir = V_a$$

$$I = \frac{V_B}{R_{eq}} = \frac{12\,V}{65.5\,\Omega} = .18\ A$$

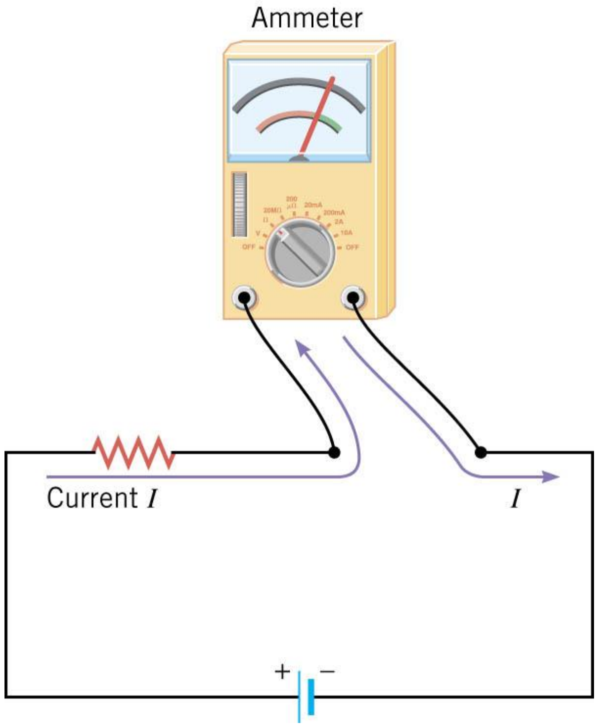
$R_{eq} = 65 + 0.5\ \Omega$

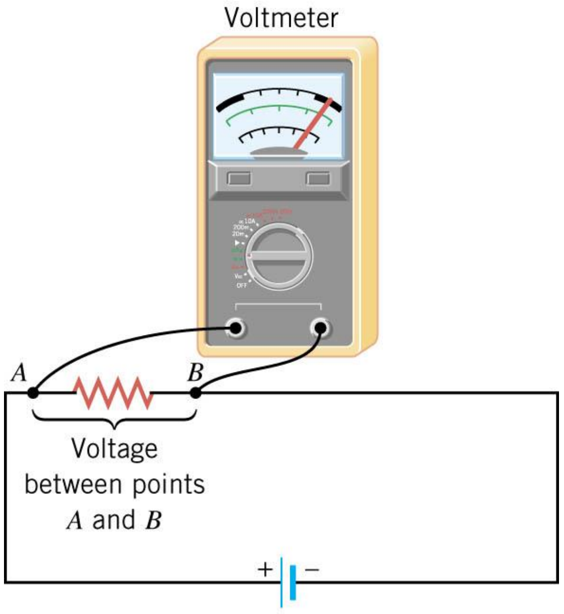
$$V_a - V_b = V_T = 12 - (.18)(.5) = 11.91V$$

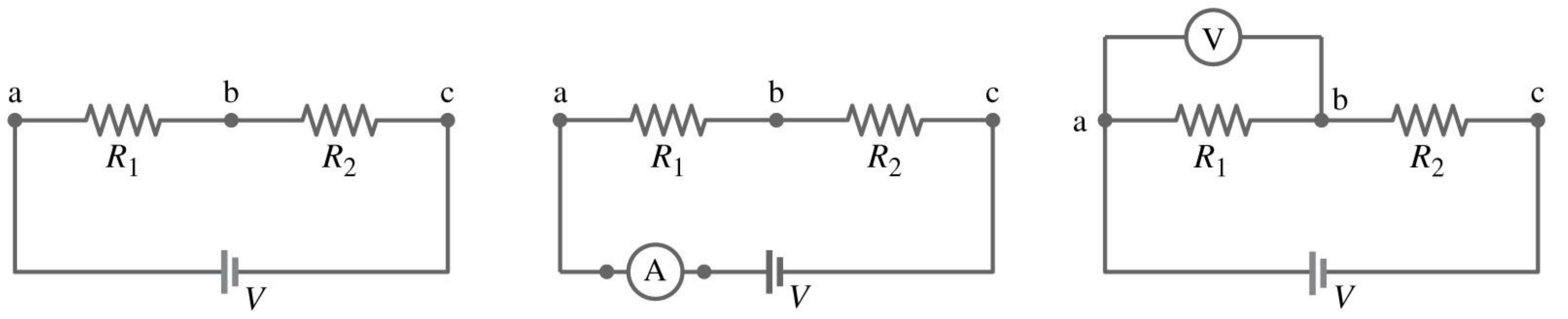
Ammeters & Voltmeters

- ammeters put in series where current is being measured

- voltmeter always placed in parallel when measuring voltage drop "across" a resistor







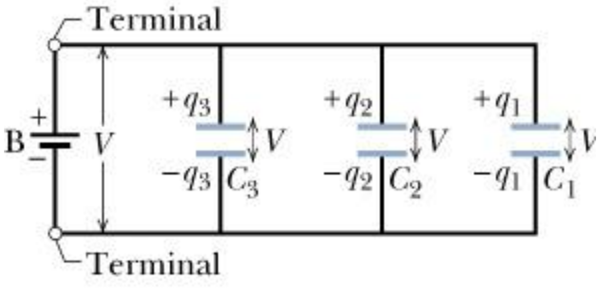
(a) (b) (c)

Capacitors in Circuits

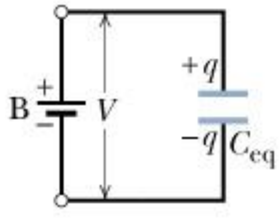
- What is equal? What sums up? Voltage, charge
- Parallel:
  - voltages are all equal
  - charges sum up
- Series:
  - charges are equal
  - voltages sum up
- Equivalent capacitance:
  - value of the one capacitor that can replace all capacitors in the circuit and have the same charge flowing through battery

Parallel Connection

- All devices in parallel have same voltage drop across them
- Equivalent capacitance increases as if there are two very large area plates at +, – potential



(a)



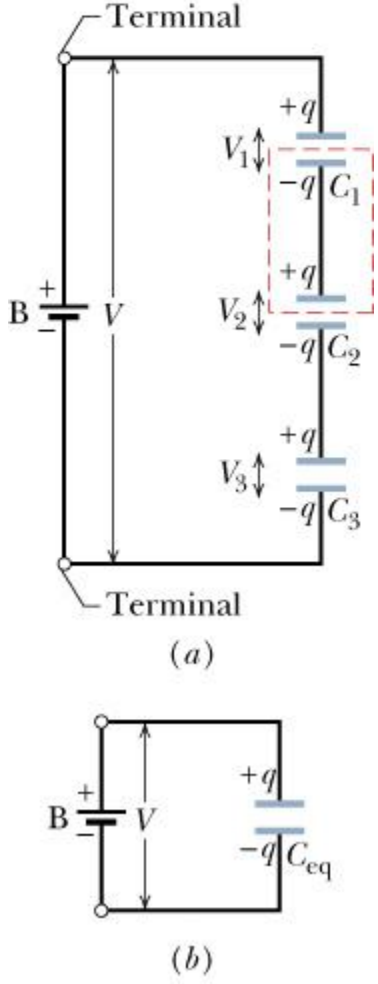
(b)

$$C = \frac{\varepsilon_0 A}{d}$$

Series Connection

- Series connection means only one path for charges to move through
- Equivalent capacitance decreases as if the plate separation distance d has increased
- Charge on each capacitor is equal

$$C = \frac{\varepsilon_0 A}{d}$$

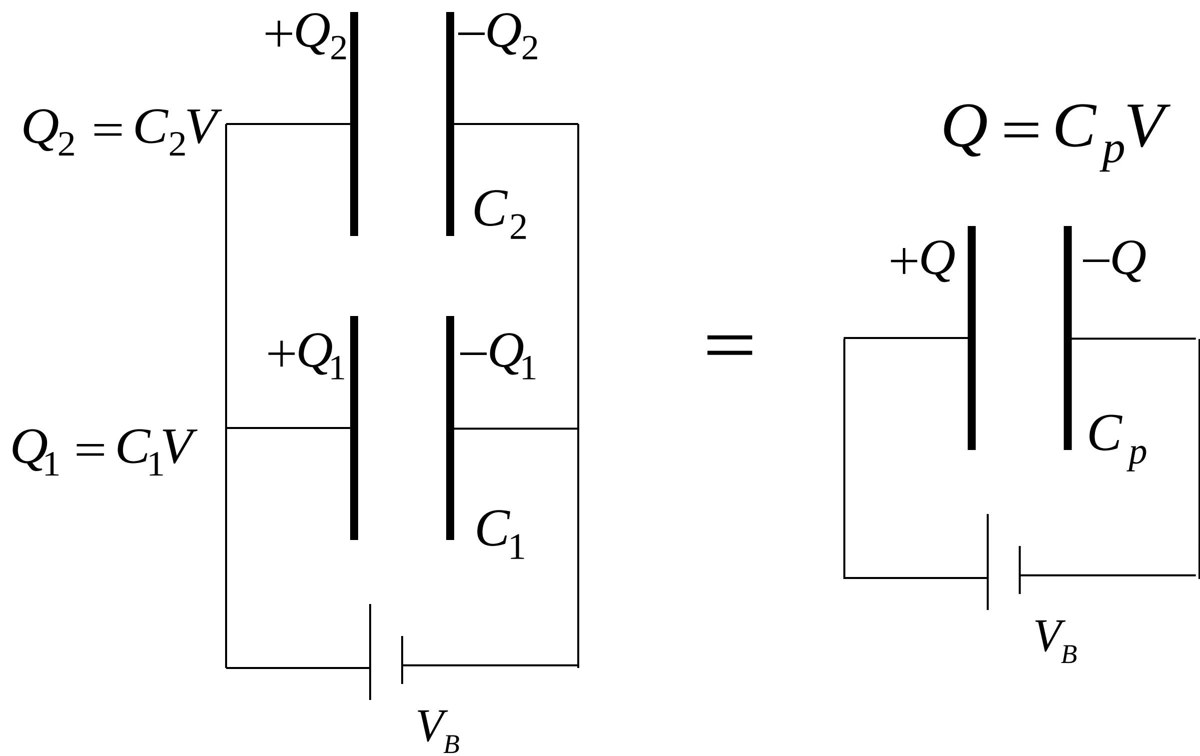


Equivalent capacitance for capacitors in parallel

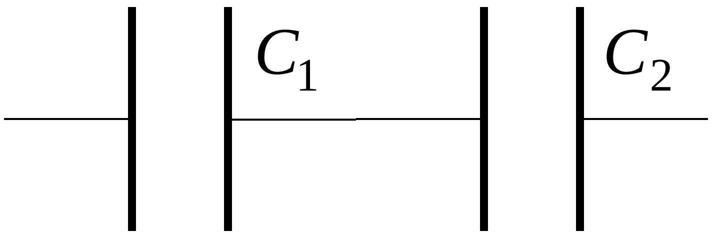
$$Q_B = Q_1 + Q_2 \quad \Rightarrow \quad C_P V_B = C_1 V_1 + C_2 V_2 \quad \Rightarrow$$

$$V_B = V_1 = V_2$$

$$C_p = C_1 + C_2$$



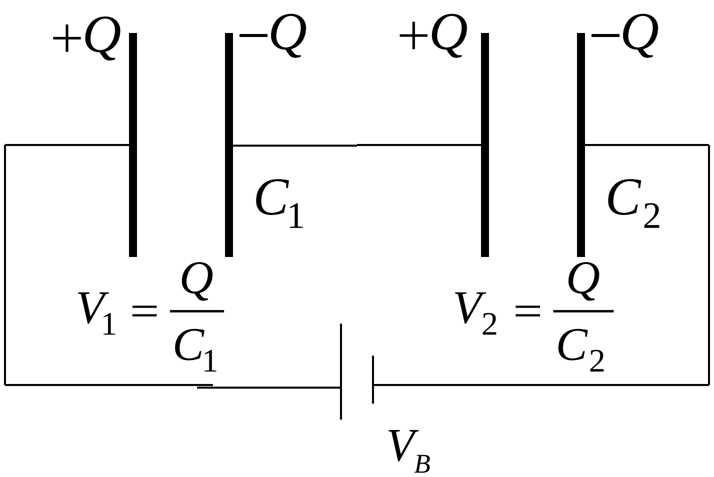
Equivalent Capacitance for Capacitors in Series



$$\left.\begin{aligned} Q_B &= Q_1 = Q_2 \\ V_B &= V_1 + V_2 \end{aligned}\right\}$$

$$\frac{Q_B}{C_s} = \frac{Q}{C_1} + \frac{Q}{C_2}$$

$$\frac{1}{C_s} = \frac{1}{C_1} + \frac{1}{C_2}$$



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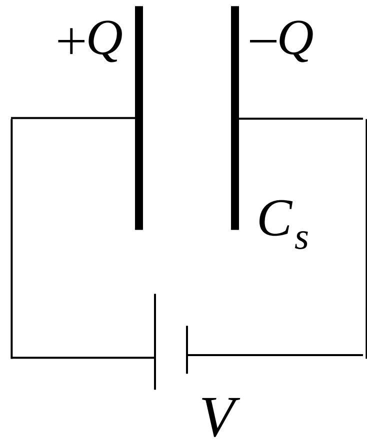
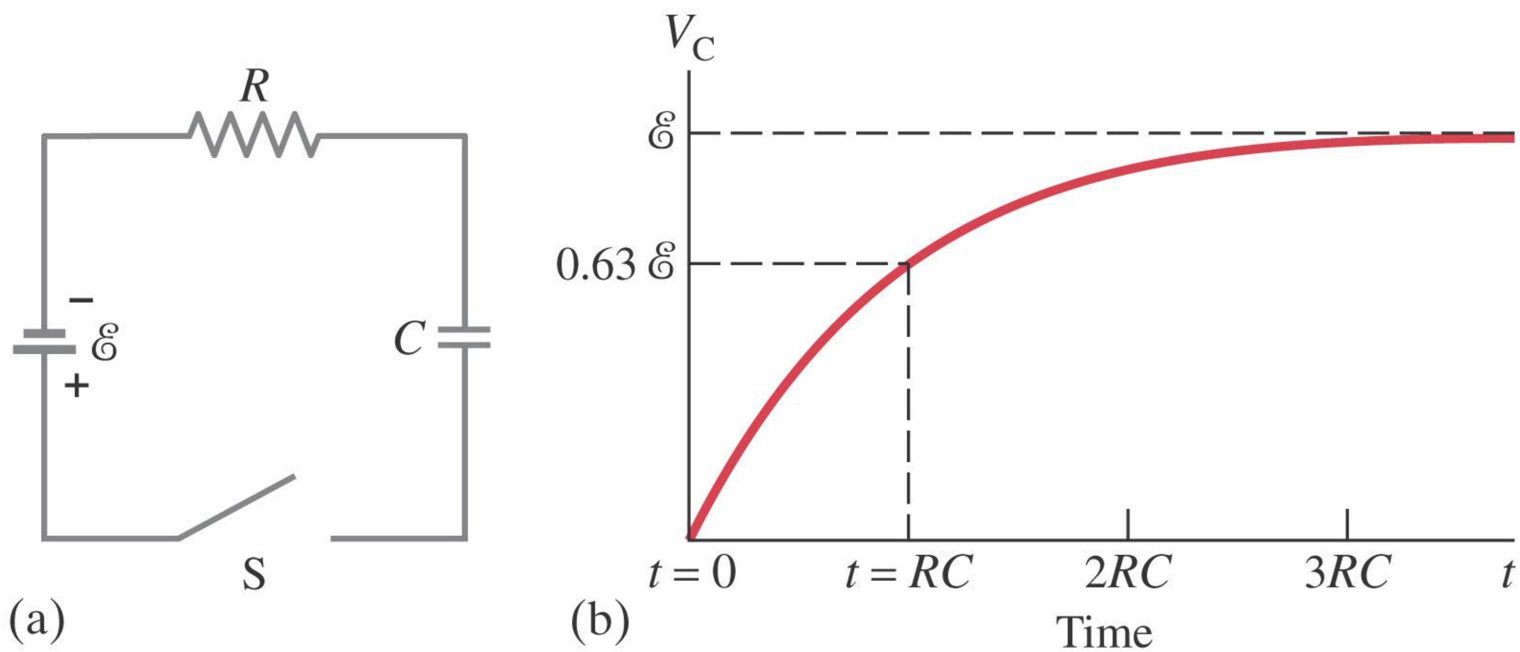


$$V_B = \frac{Q_B}{C_s}$$

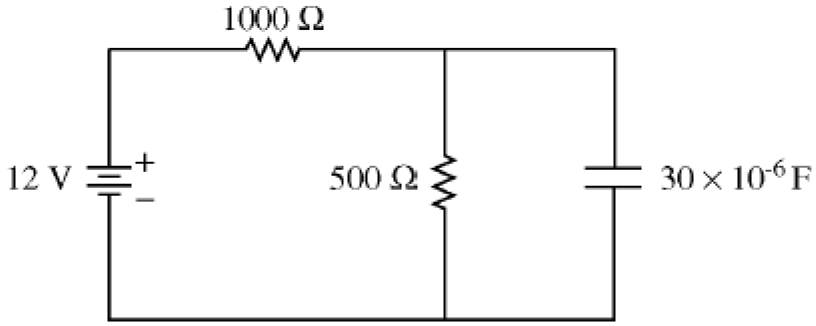
caps in series

19.6 RC Circuits – Resistor and Capacitor in Series

- when the switch is closed, the capacitor will begin to charge.
- current will drop off because it cannot flow through a capacitor
- final voltage reached is that of battery



RC circuit analysis



- Initially current flows to the capacitor to provide charge to the plates.
- After the capacitor has been connected for a long time no current can flow through it, only through the two resistors.
- The voltage drop across the capacitor will be the same as through the 500 Ω resistor since it is in parallel with it.