Chapter 27: Circuits

Electric circuits are basic parts of all electronic devices.

Here we are mostly interested in circuits operating at their **steady state**

Electric circuit needs battery or generator to produce current – these are called sources of **emf** (electromotive force).

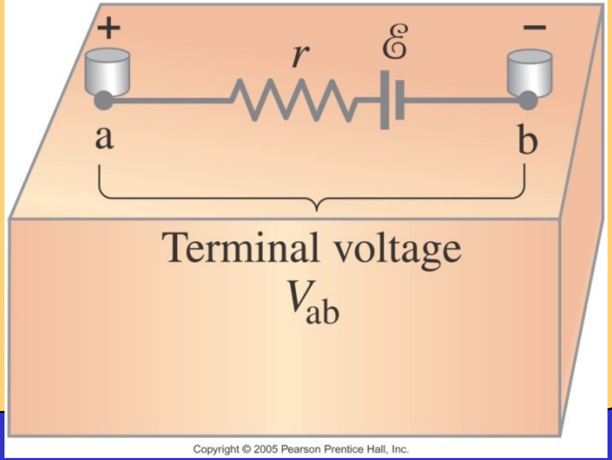
Battery is a nearly constant voltage source, but does have a small **internal** resistance r, which reduces the actual voltage from the ideal emf:

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

$\mathcal{E}$ is the potential difference in the absence of current

V_{ab} is the **terminal voltage** = potential difference

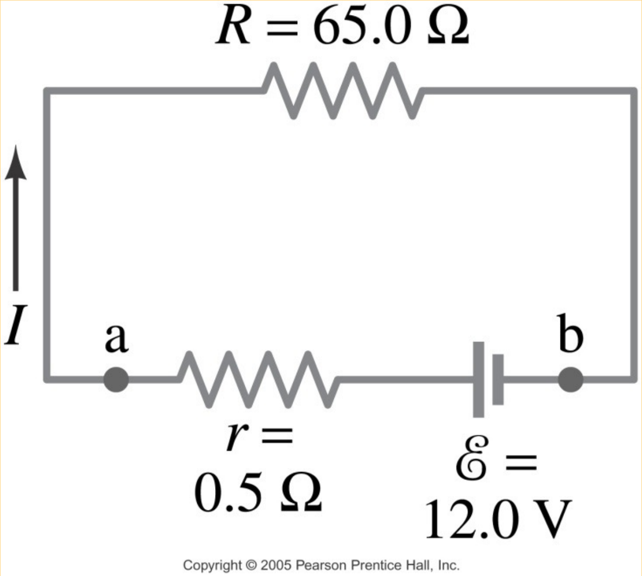
This resistance behaves as though it were in series with the emf.



DC Circuits

Ex. A 65.0Ω resistor is connected to the terminal of a battery whose emf is 12.0 V and whose internal resistance is 0.5 Ω . Calculate (a) the current in the circuit, (b) the terminal voltage of the battery Vab, and (c) the power dissipated in the resistor R and in the battery's internal resistance r.

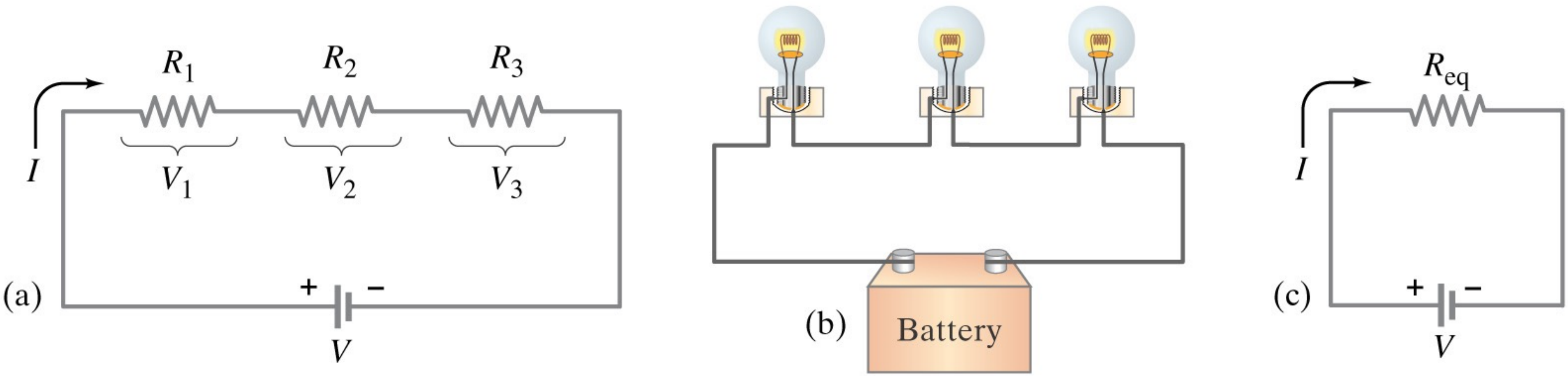
(a) $I=0.183$ A (b) $V_{ab}=11.9$ V
(c) $P_R=2.18$ W, $P_r=0.02$ W



From now on we work with V - voltage

Resistors in Series

One single path – **series** – charge that passes through R1 also passes through R2 and R3:



The current through each resistor is the same; the voltage depends on the resistance. The sum of the voltage drops across the resistors equals the battery voltage.

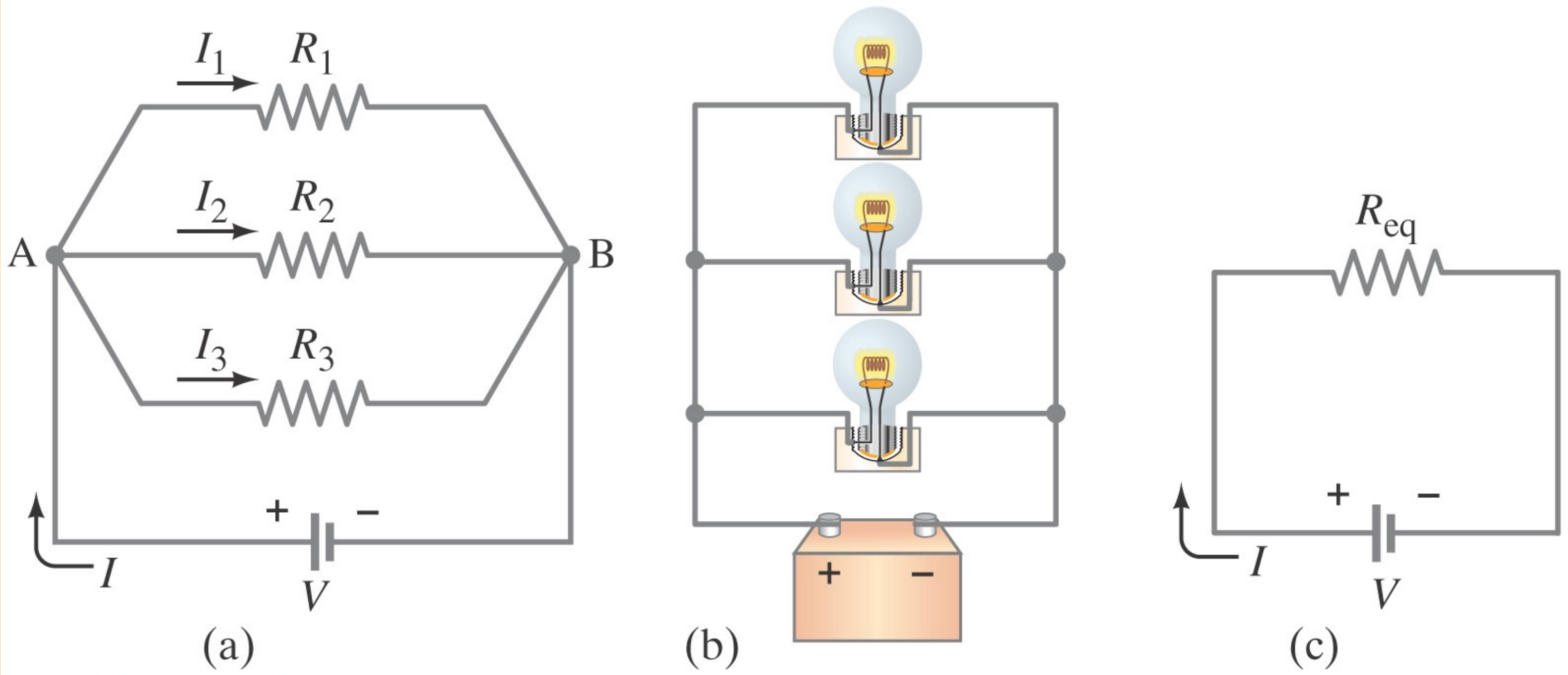
$$V = V_1 + V_2 + V_3 = IR_1 + IR_2 + IR_3$$

$$V = IR_{eq} \Rightarrow$$

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

Resistors in Parallel

A parallel connection splits the current; the voltage across each resistor is the same (this is the wiring in houses and buildings – if you disconnect one device, the current to the others is not interrupted



$$I = I_1 + I_2 + I_3$$

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

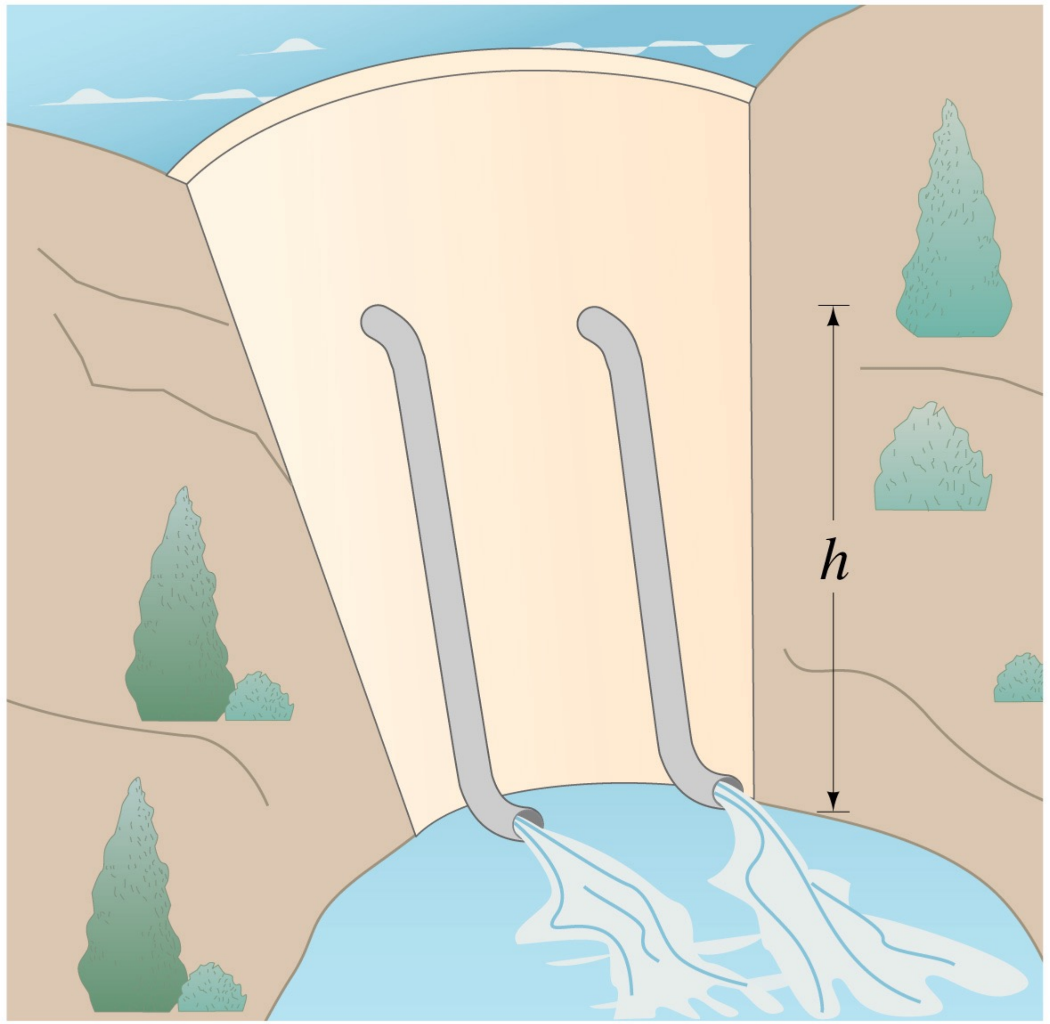
$$\frac{1}{R_{eq}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

Resistors in Parallel - analogy

An analogy using water may be helpful in visualizing parallel circuits:

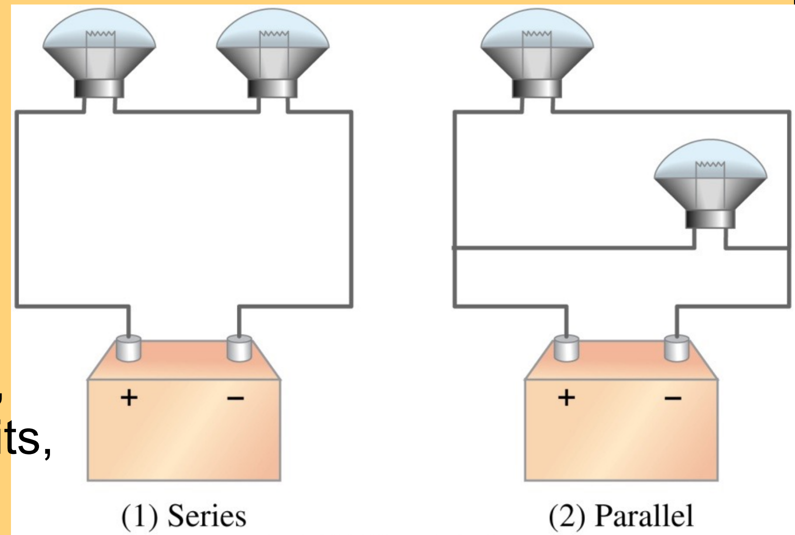
Gravitational potential difference is the same for both pipes and proportional to h, just like voltage is the same for both resistors.

Both pipes open – twice as much water will flow, that is the net resistance is reduced by half, just as for electrical resistors in parallel



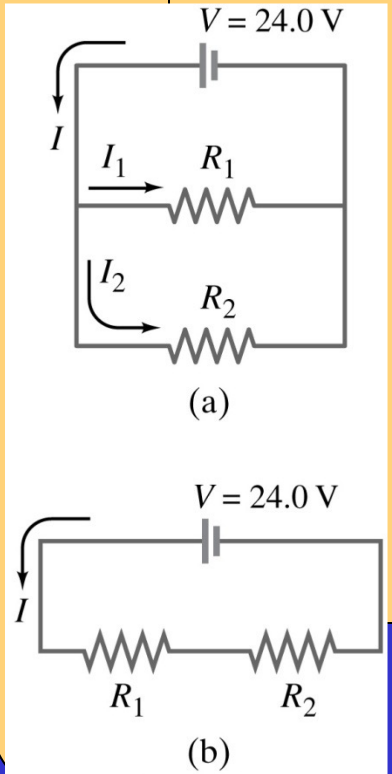
Exercises

Ex. (a) The lightbulbs in the figures are identical and have identical resistance R. Which configuration produces more light? (b) Which way do you think the headlights of a car are wired?



(a) For (1) Req=2R, for (2) Req=R/2, since V is the same for both circuits, there is more I for (2). The power transformed is related to the light produced, P=I.V, so more light is produced in (2)

(b) They are wired in parallel, so if one bulb goes out the other can stay lit.

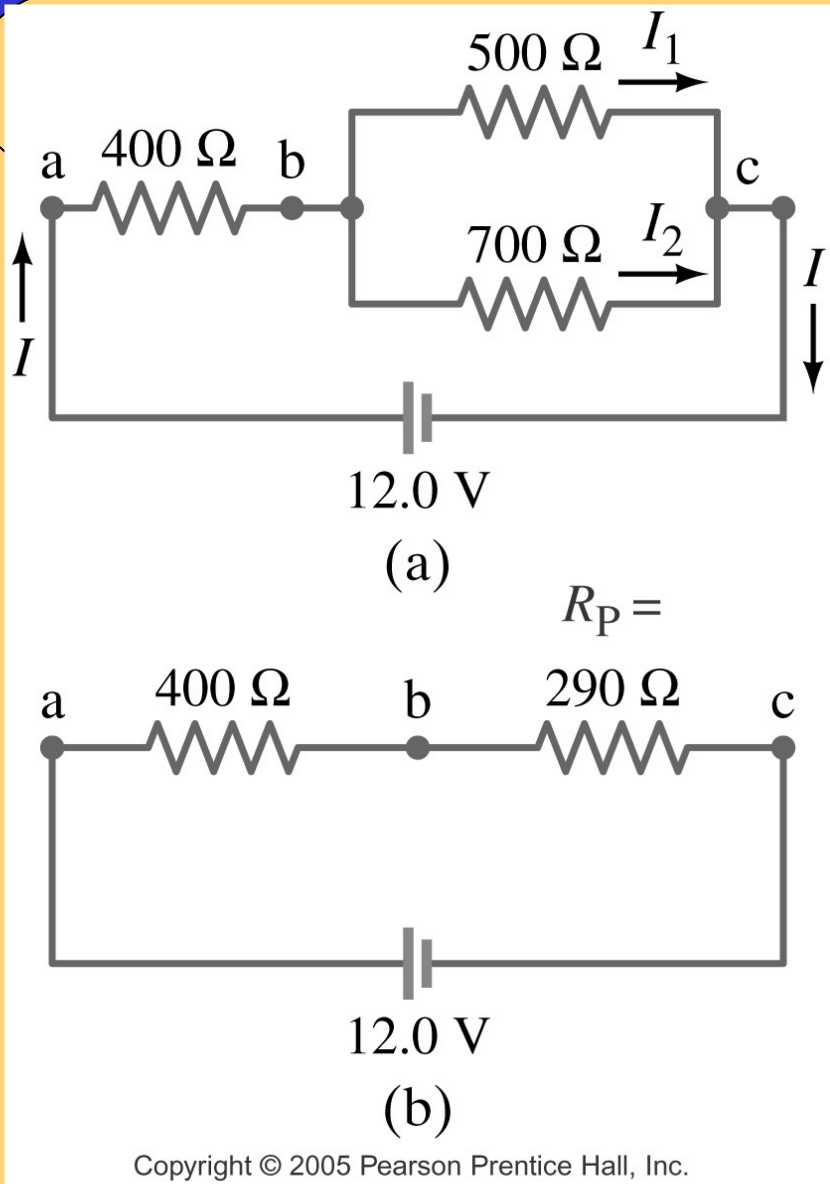


Ex. Two 100-Ω resistors are connected (a) in parallel and (b) in series to a 24.0-V battery. What is the current through each resistor and what is the equivalent resistance of each circuit?

(a) I=0.48 A Req=50Ω (b) I=0.120 A Req=200 Ω

Each I=0.24 A

Exercises



Ex. How much current is drawn from the battery in the figure (a) ?

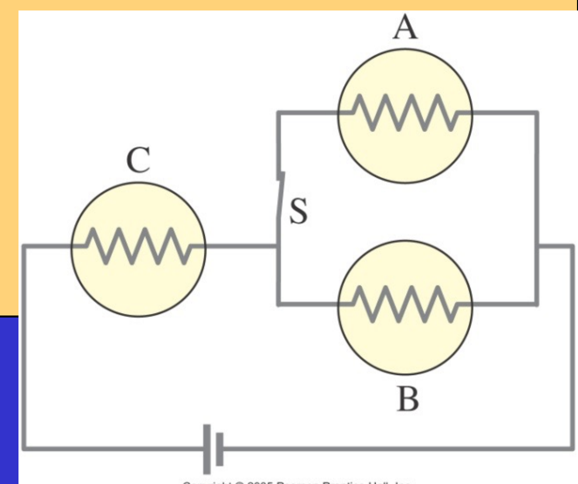
17 mA

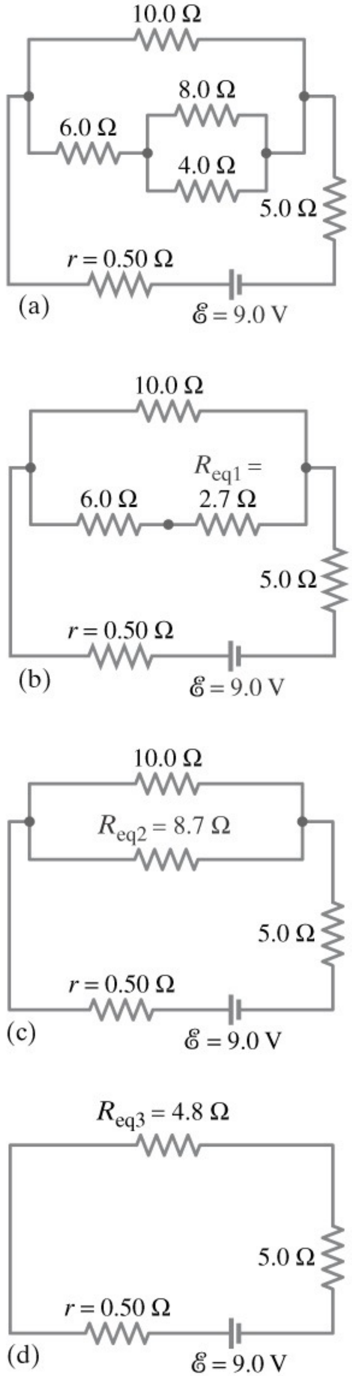
Ex. What is the current through the 500Ω resistor?

10 mA

Ex. The three lightbulbs are identical with resistance R. When the switch S is closed how does the brightness of A and B compare with C?

A and B are equally bright but less bright than C
because the current splits





Exercises

Ex. A 9.0-V battery whose internal resistance r is 0.50Ω is connected in the circuit shown in (a)

(a) How much current is drawn from the battery?

(b) What is the terminal voltage of the battery?

(c) What is the current in the 6.0 Ω-resistor?

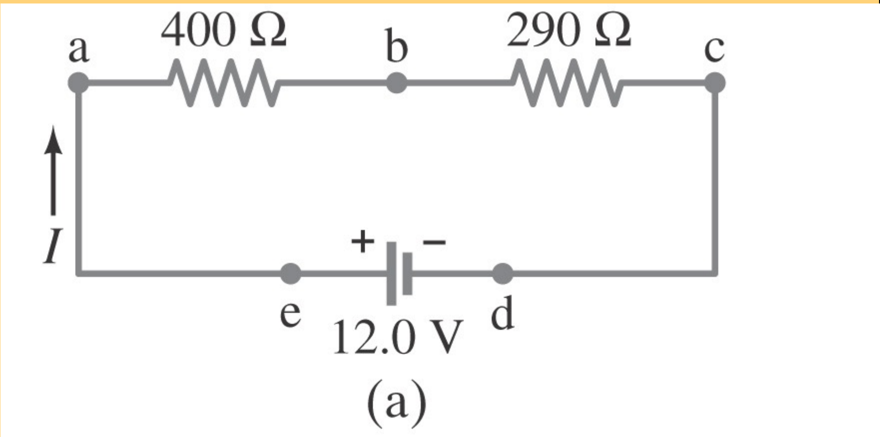
(a) I=0.87 A (b) Vab=8.6 V (c) I=0.48A

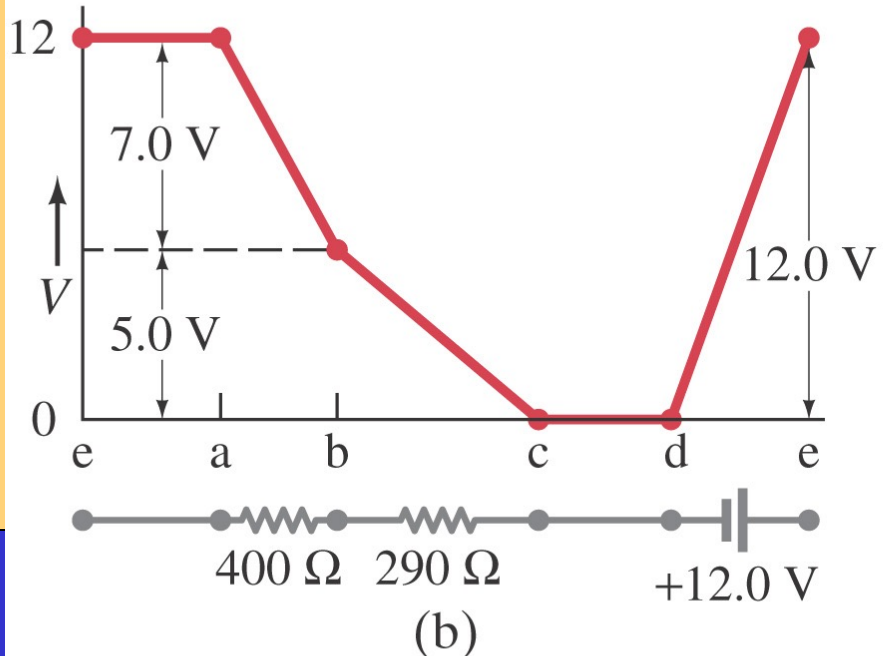
Kirchhoff's Rules

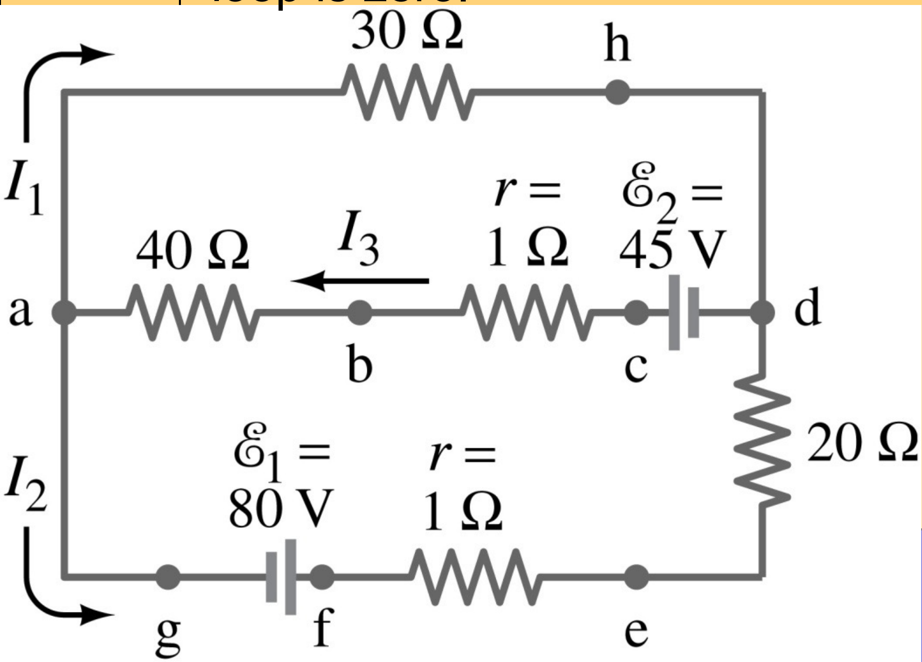
Some circuits are too complicated to be broken down into series and parallel connections - use Kirchhoff's rules.

1st rule or junction rule: The sum of currents entering a junction equals the sum of the currents leaving it.

2nd rule of loop rule: The sum of the changes in potential around a closed loop is zero.

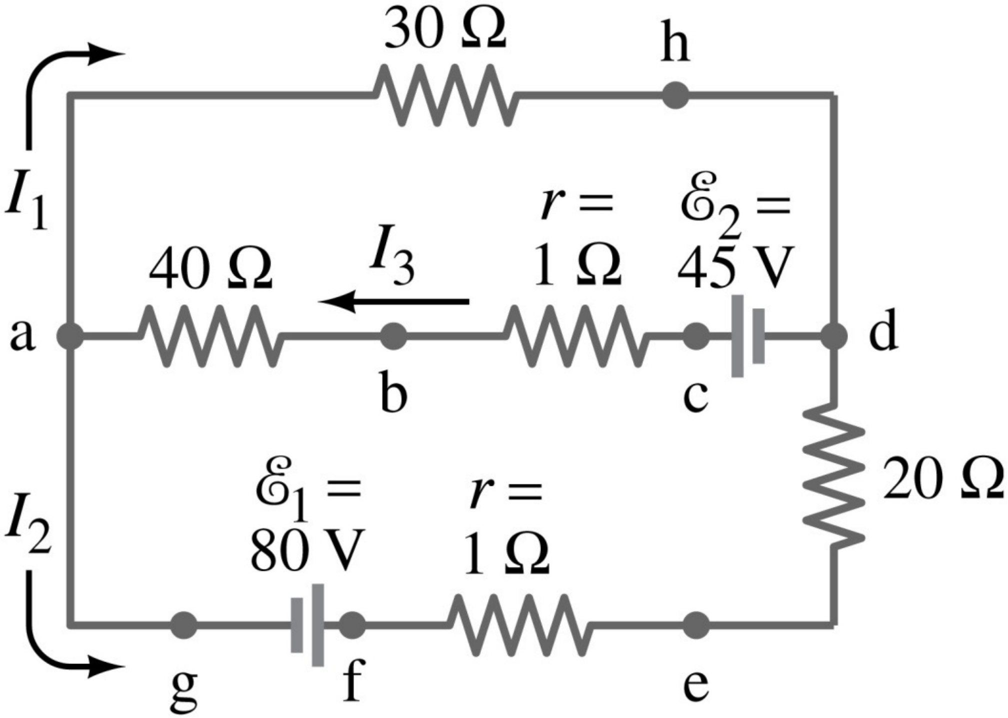






Exercises

Ex. Calculate the currents I_1, I_2, and I_3 in the three branches of the circuit in the figure.



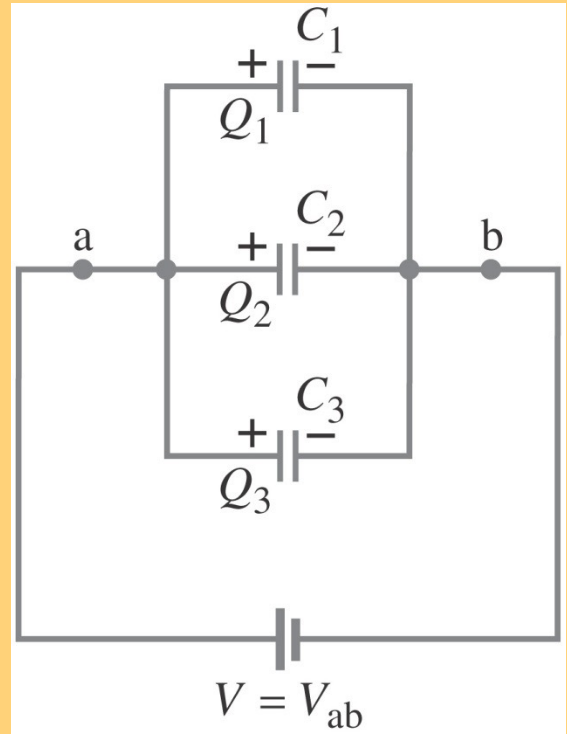
I_1 = -0.87 A, I_2=2.6 A, I_3 =1.7 A

Circuits with Capacitors - Parallel

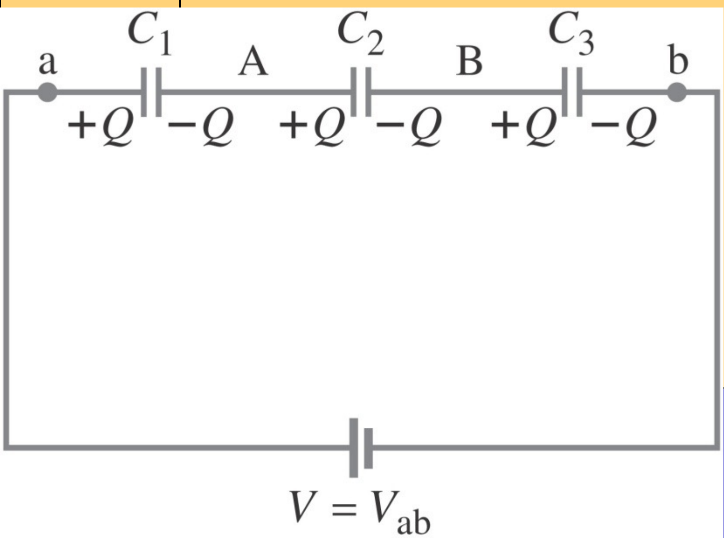
Capacitors in **parallel** have the same voltage across each one:

$$C_{eq}V = C_1V + C_2V + C_3V = (C_1 + C_2 + C_3)V$$

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



Capacitors in **series** have the same charge:

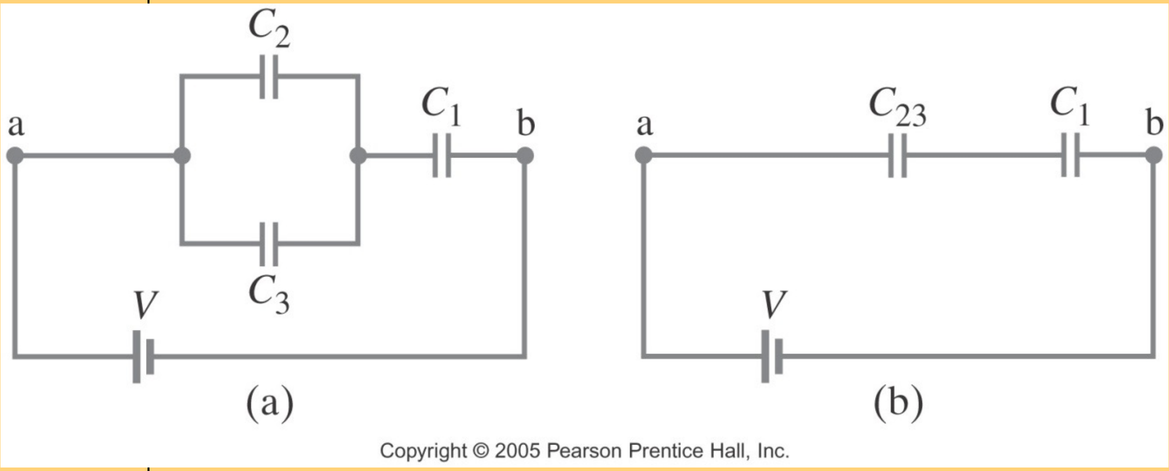


$$\frac{Q}{C_{eq}} = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3} = Q\left(\frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}\right)$$

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

Exercises

Ex. Determine the capacitance of a single capacitor that will have the same effect as the combination shown in the figure (a). Take C1=C2=C3=C.



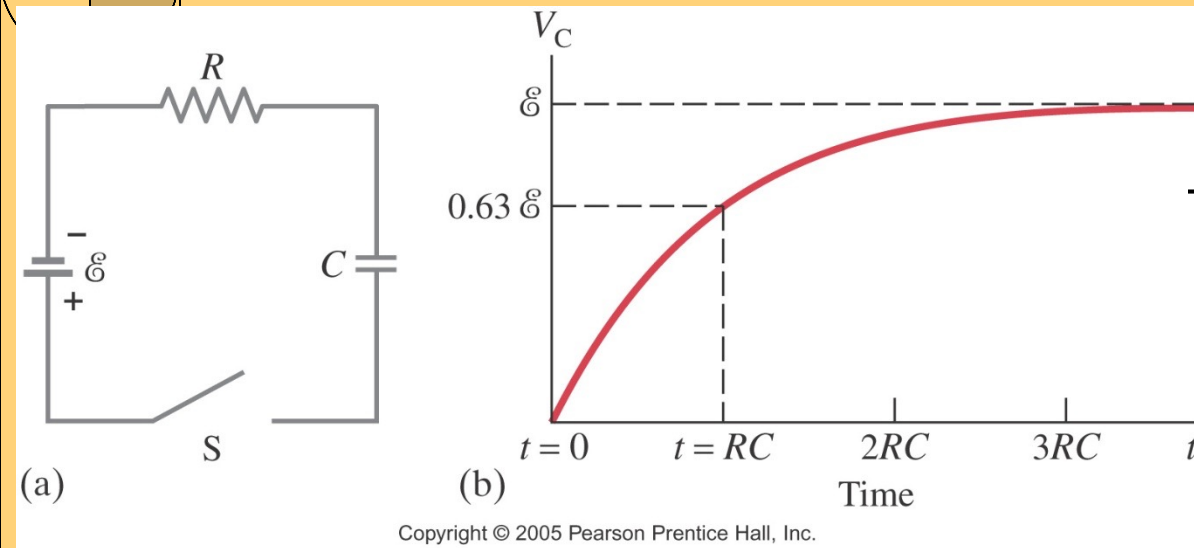
$C_{eq}=2C/3$

Ex. Determine the charge on each capacitor in the figure and the voltage across each assuming C=3.0 μF and the battery voltage is V=4.0 V

Q=8.0μ C V1=2.7 V V2=1.3 V V3=1.3 V

RC Circuits

Now we are **not** interested in the final steady state, but how V and Q change in time. When the switch is closed, the capacitor will begin to charge.



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

The charge follows a similar curve:

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

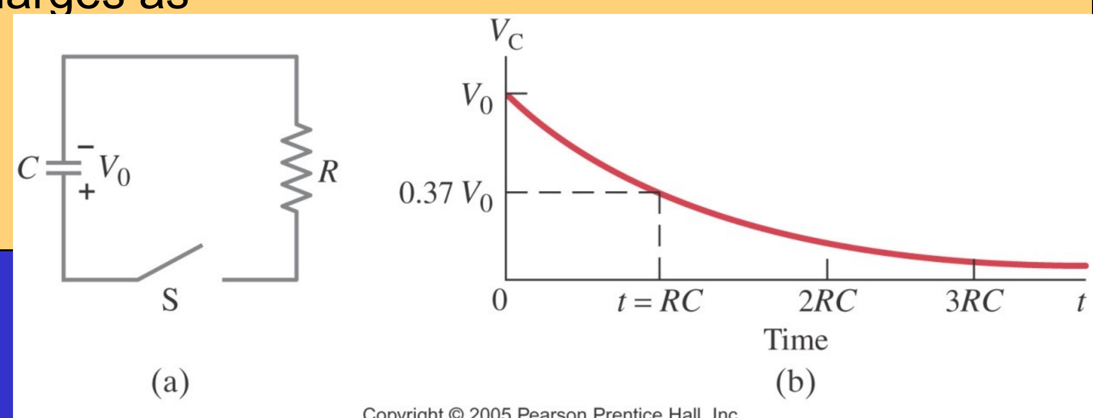
These curves have a characteristic time constant:

$$\tau = RC$$

Now suppose the capacitor is already charged with voltage V0 and charge Q0
If the circuit is closed, it discharges as

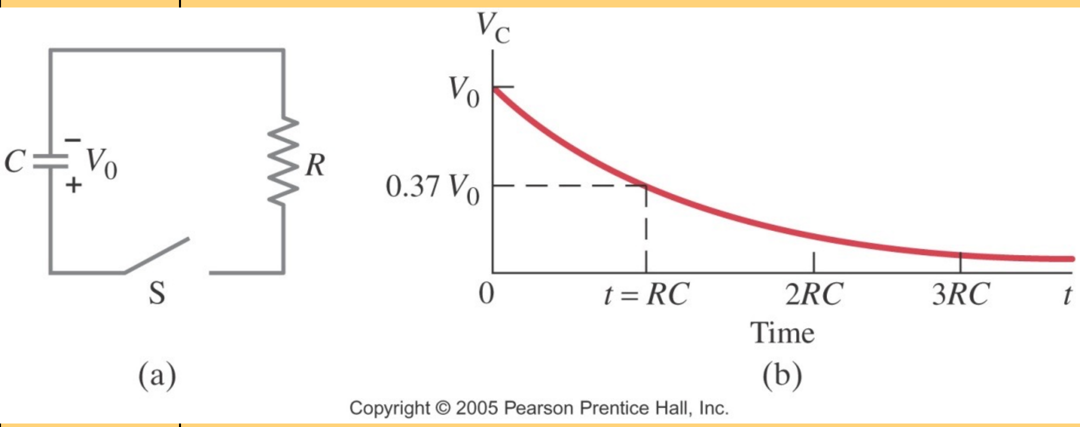
$$V = V_0 e^{-t/RC}$$

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



RC Circuits

Ex. If a charged capacitor, C=35 μF is connected to a resistance R=120Ω as in the figure, how much time will elapse until the voltage falls to 10% of its original maximum value?



$$V = V_0 e^{-t/RC}$$

$$\tau = RC = 4.2\times10^{-3}\, s$$

$$0.10 V_0 = V_0 e^{-t/RC} \Rightarrow e^{-t/RC} = 0.10$$

$$\ln(e^{-t/RC}) = \ln(0.10) \Rightarrow t = 9.7\times10^{-3}\, s$$