Basic Laws of Electric Circuits

Fundamentals

Lesson 1

Basic Electric Circuit Concepts

System of Units:

We use the SI (System International) units. The system uses meters (m), kilograms (kg), seconds (s), ampere (A), degree kelvin (^{O}K) and candela (cd) as the fundamental units.

We use the following prefixes:

pica (p): 10^{-12}

tera (T): 10^{12}

nano (n): 10^{-9}

giga (G) : 10^{9}

micro (μ): 10^{-6}

mega (M): 10^{6}

milli (m): 10^{-3}

kilo (k): 10^{3}

Basic Electric Circuit Concepts

What is electricity?

One might define electricity as the separation of positive and negative electric charge. (see slide note)

When the charges are separated and stationary we call this static electricity. The charging of a capacitor is an example. The separation of charge between clouds and the earth before a lighting discharge is a static electricity.

When the charges are in motion (changing with time relative to one another) we have variable electricity.

Basic Electric Circuit Concepts

Basic Quantities: Current

The unit of current is the ampere (A). We note that

1 ampere = 1 coulomb/second

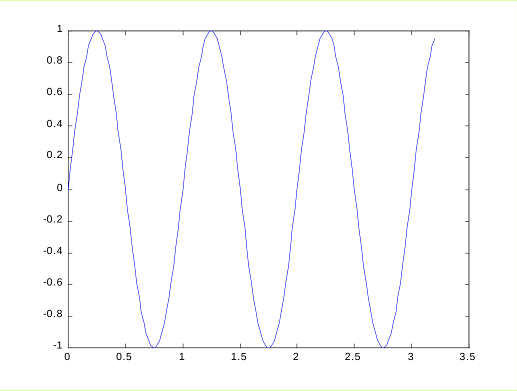
We normally refer to current as being either direct (dc) or alternating (ac).

i(t)

t

dc current

i(t)

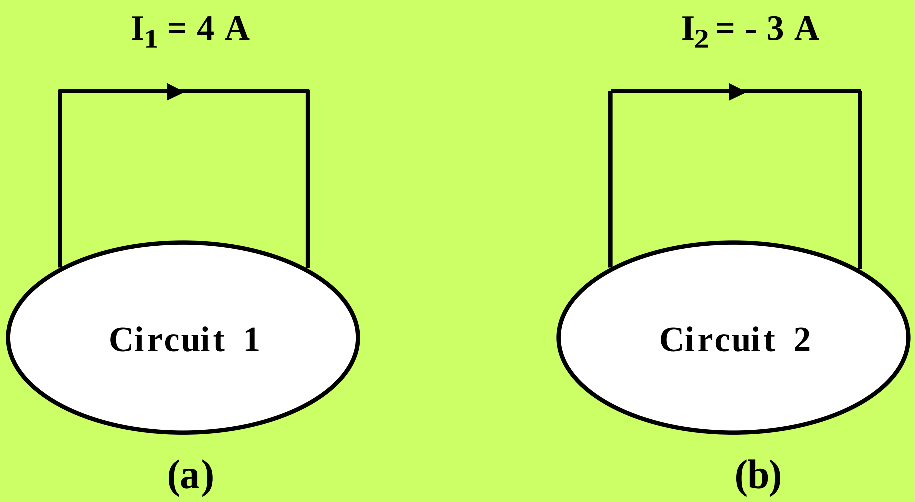


ac current

Basic Electric Circuit Concepts

Basic Quantities: Current

In solving for current in a circuit, we must assume a direction, solve for the current, then reconcile our answer. This is illustrated below.



In the diagram above, current I_1 is actually 4 A as assumed. The actual positive direction of current I_2 (equal to -3 A) in the opposite direction of the arrow for I_2.

Basic Electric Circuit Concepts

Basic Quantities: Voltage

The next quantity of interest is voltage. Voltage is also called an electromotive force (emf). It is also called potential (coming from the expression, "potential energy." However, voltage is not energy.)

Suppose one coulomb of charge is located at point b and one joule of energy is required to move the charge to point a. Then we say that V_{ab} = 1 volt = 1 joule/coulomb = 1 newton.meter/coulomb.

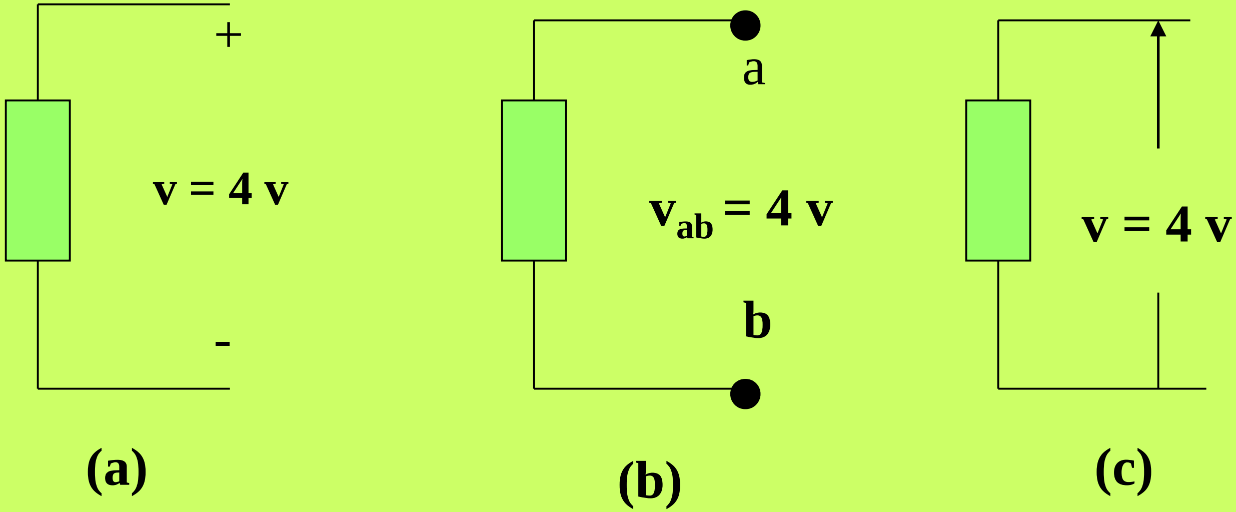
V_{ab} = 1 volt states that the potential of point a (voltage at point a) is l volt (positive) with respect to point b.

The sign associated with a voltage is also called its polarity.

Basic Electric Circuit Concepts

Basic Quantities: Voltage

As in the case for current, we must assume a positive direction (polarity) for the voltage. Consider the three diagrams below.

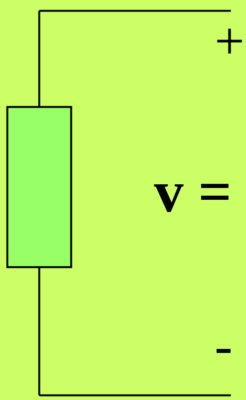


Each of the above gives the same information.

Basic Electric Circuit Concepts

Basic Quantities: Voltage

We need to keep in mind that we assume a polarity for the voltage. When we solve the circuit for the voltage, we may find that the actual polarity is not the polarity we assumed.



v = -6 v

The negative sign for 6 v indicates that if the red lead of a voltmeter is placed on + terminal and the black lead on the – terminal the meter will read downscale or –6v. A digital meter would read –6 v. What would an analog meter do?

Basic Electric Circuit Concepts

Basic Quantities: Voltage

In summary, we should remember that,

$$v = \frac{\Delta w}{\Delta q} \qquad \textbf{(2)}$$

This can be expressed in differential form as,

$$v = \frac{dw}{dq} \qquad \textbf{(3)}$$

***w*: energy in joules** ***q*: charge in coulombs**

Basic Electric Circuit Concepts

Basic Quantities: Power

Power is defined as the time rate of change of doing work. We express this as,

$$p = \frac{dw}{dt} \qquad \textbf{(3)}$$

We can write equation (3) as follows:

$$\boxed{p = \frac{dw}{dq}\frac{dq}{dt} = vi} \qquad \textbf{(4)}$$

Power has units of watts.

Basic Electric Circuit Concepts

Basic Quantities: Power

In any closed electric circuit, power is both supplied and absorbed. The amount that is supplied must be equal to the amount that is absorbed.

Stated another way, we can say that the law of conversation of energy must hold. Therefore, in any electric circuit the algebraic sum of the power must be zero.

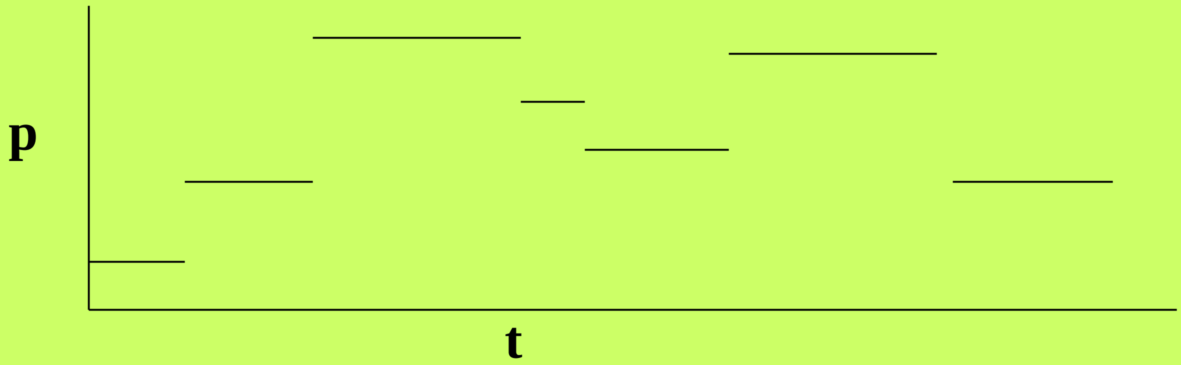
$$\sum p = 0 \qquad (5)$$

Basic Electric Circuit Concepts

<u>Basic Quantities:</u> Power and Energy

When we pay our electric bills we pay for (watt)(hours) but because this is such as large number we usually think KWH.

A profile of the power you use during a day may be as shown below.



The energy we pay for is the area under the power-time curve.

$$w = \int_{t_o}^{t} p\,dt = \int_{t_o}^{t} vi\,dt \qquad \textbf{(6)}$$

Direct Current Circuits

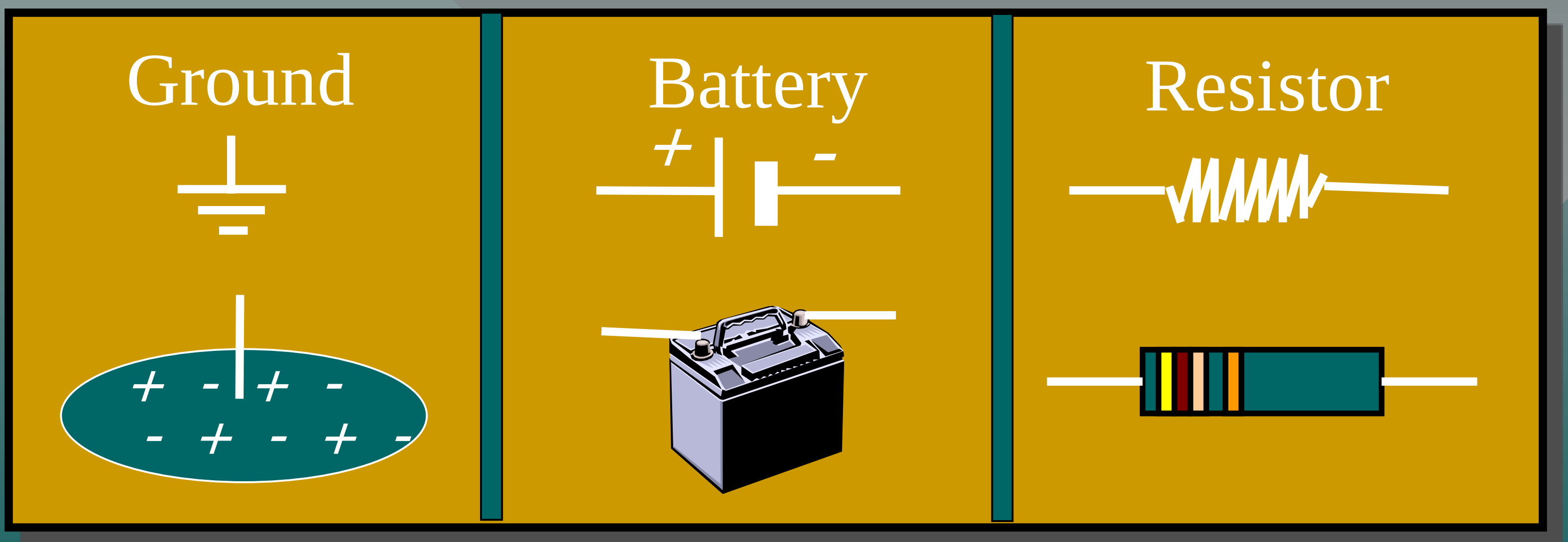
Objectives: After completing this module, you should be able to:

- Determine the effective resistance for a number of resistors connected in series and in parallel.
- For simple and complex circuits, determine the voltage and current for each resistor.
- Apply Kirchoff' s laws to find currents and voltages in complex circuits.

Electrical Circuit Symbols

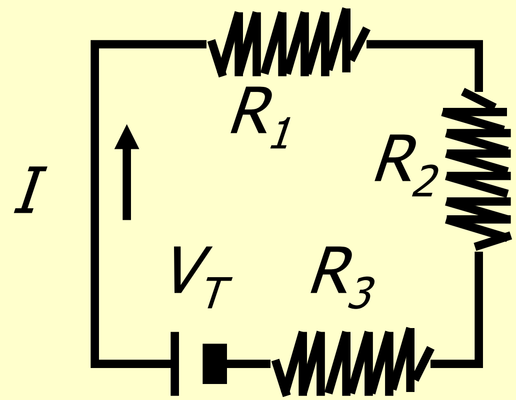
Electrical circuits often contain one or more resistors grouped together and attached to an energy source, such as a battery.

The following symbols are often used:



Resistances in Series

Resistors are said to be connected in series when there is a single path for the current.



Only one current

The current I is the same for each resistor R_1, R_2 and R_3.

The energy gained through $\mathcal{E}$ is lost through R_1, R_2 and R_3.

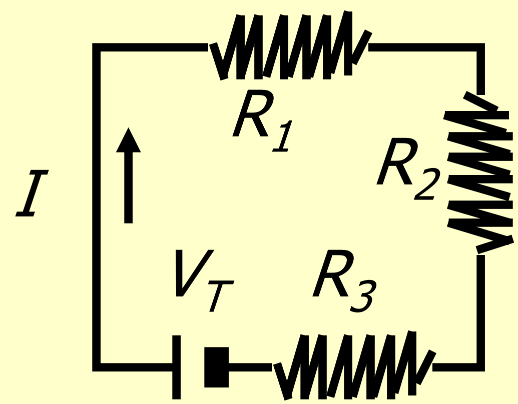
The same is true for voltages:

For series connections:

$$I = I_1 = I_2 = I_3$$
$$V_T = V_1 + V_2 + V_3$$

Equivalent Resistance: Series

The equivalent resistance R_e of a number of resistors connected in series is equal to the sum of the individual resistances.



Equivalent Resistance

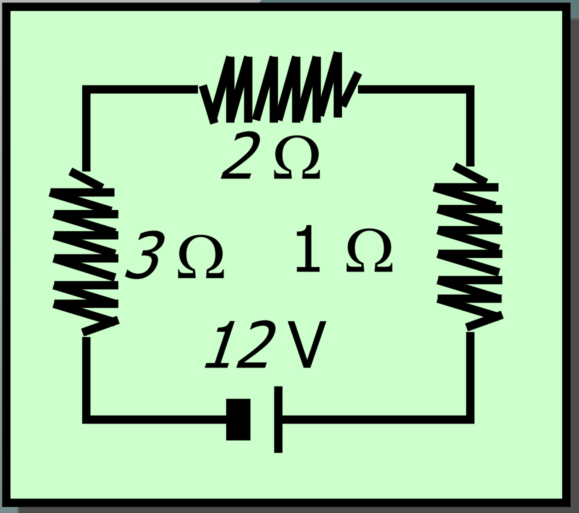
$$V_T = V_1 + V_2 + V_3\,; \quad (V = IR)$$

$$\cancel{I_T}R_e = \cancel{I_1}R_1 + \cancel{I_2}R_2 + \cancel{I_3}R_3$$

$$But\ .\ .\ .\ I_T = I_1 = I_2 = I_3$$

$$\boxed{R_e = R_1 + R_2 + R_3}$$

Example 1: Find the equivalent resistance R_e. What is the current I in the circuit?



$$R_e = R_1 + R_2 + R_3$$

$$R_e = 3\ \Omega + 2\ \Omega + 1\ \Omega = 6\ \Omega$$

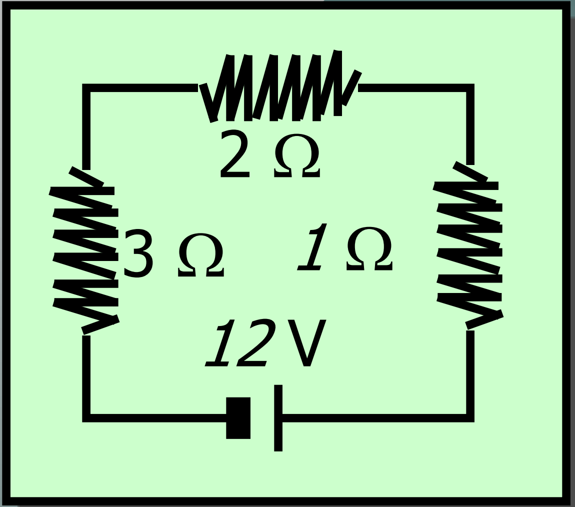
$$\boxed{\text{Equivalent } R_e = 6\ \Omega}$$

The current is found from Ohm's law: $V = IR_e$

$$I = \frac{V}{R_e} = \frac{12\text{ V}}{6\ \Omega}$$

$$\boxed{I = 2\text{ A}}$$

Example 1 (Cont.): Show that the voltage drops across the three resistors totals the 12-V emf.



$R_e = 6\ \Omega$

I = 2 A

Current I = 2 A same in each R.

$V_1 = IR_1;\ \ V_2 = IR_2;\ V_3 = IR_3$

$V_1 = (2\text{ A})(1\ \Omega) = 2\text{ V}$

$V_1 = (2\text{ A})(2\ \Omega) = 4\text{ V}$

$V_1 = (2\text{ A})(3\ \Omega) = 6\text{ V}$

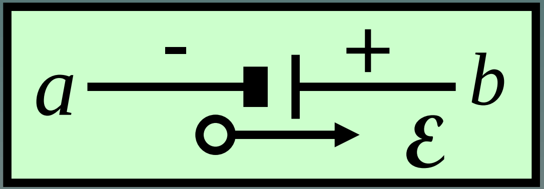
$V_1 + V_2 + V_3 = V_T$

2 V + 4 V + 6 V = 12 V

Check !

Sources of EMF in Series

The output direction from a source of emf is from + side:



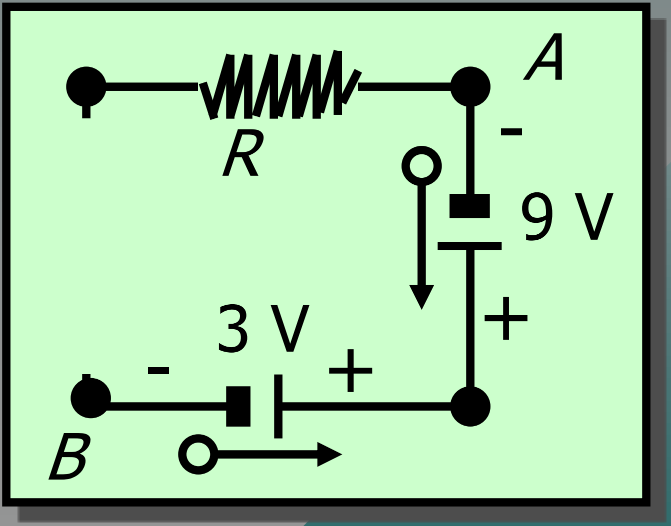
Thus, from ***a*** to *b* the potential increases by $\mathcal{E}$;

From *b* to ***a***, the potential decreases by $\mathcal{E}$.

Example: Find ΔV for path AB and then for path BA.

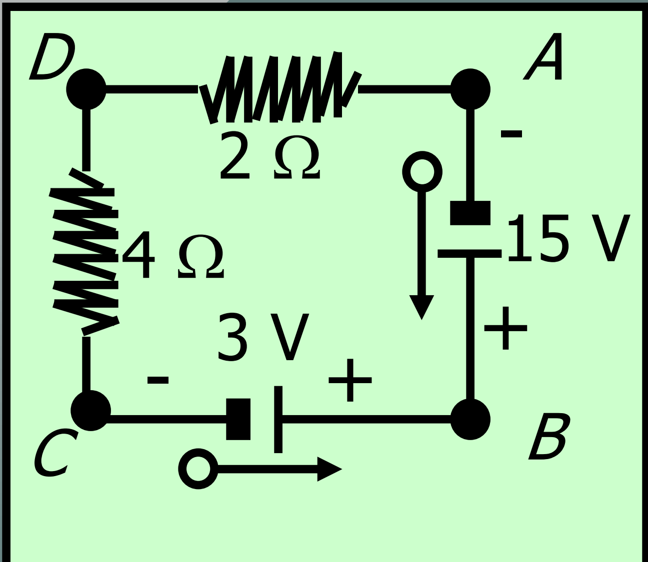
AB: ΔV = +9 V – 3 V = +6 V

BA: ΔV = +3 V - 9 V = -6 V



A Single Complete Circuit

Consider the simple series circuit drawn below:



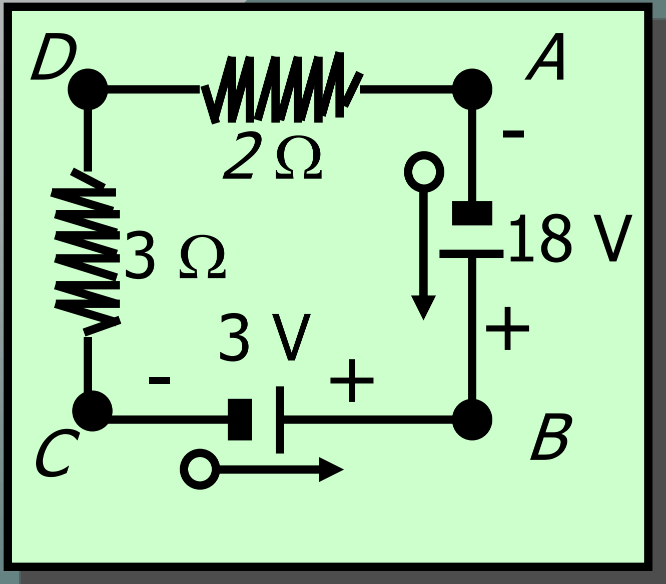
Path ABCD: Energy and V increase through the 15-V source and decrease through the 3-V source.

$$\Sigma\mathcal{E} = 15\text{ V} - 3\text{ V} = 12\text{ V}$$

The net gain in potential is lost through the two resistors: these voltage drops are IR_2 and IR_4, so that the sum is zero for the entire loop.

Finding I in a Simple Circuit.

Example 2: Find the current I in the circuit below:



$$\Sigma\mathcal{E} = 18\text{ V} - 3\text{ V} = 15\text{ V}$$

$$\Sigma R = 3\ \Omega + 2\ \Omega = 5\ \Omega$$

Applying Ohm's law:

$$I = \frac{\Sigma\mathcal{E}}{\Sigma R} = \frac{15\text{ V}}{5\ \Omega}$$

$$\boxed{I = 3\text{ A}}$$

In general for a single loop circuit:

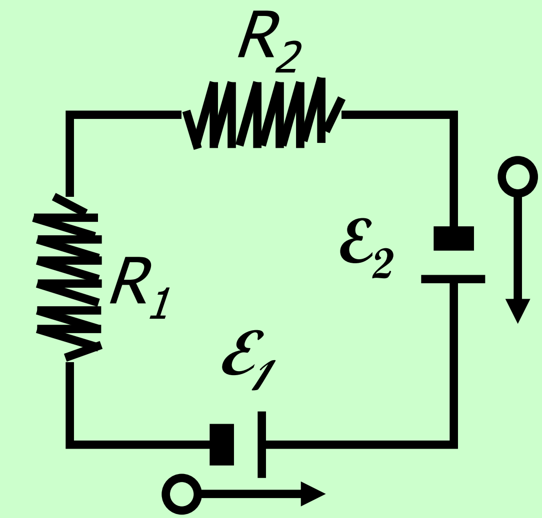
$$\boxed{I = \frac{\Sigma\mathcal{E}}{\Sigma R}}$$

Summary: Single Loop Circuits:

Resistance Rule: $R_e = \Sigma R$

Current: $I = \dfrac{\Sigma \mathcal{E}}{\Sigma R}$

Voltage Rule: $\Sigma \mathcal{E} = \Sigma IR$



Complex Circuits

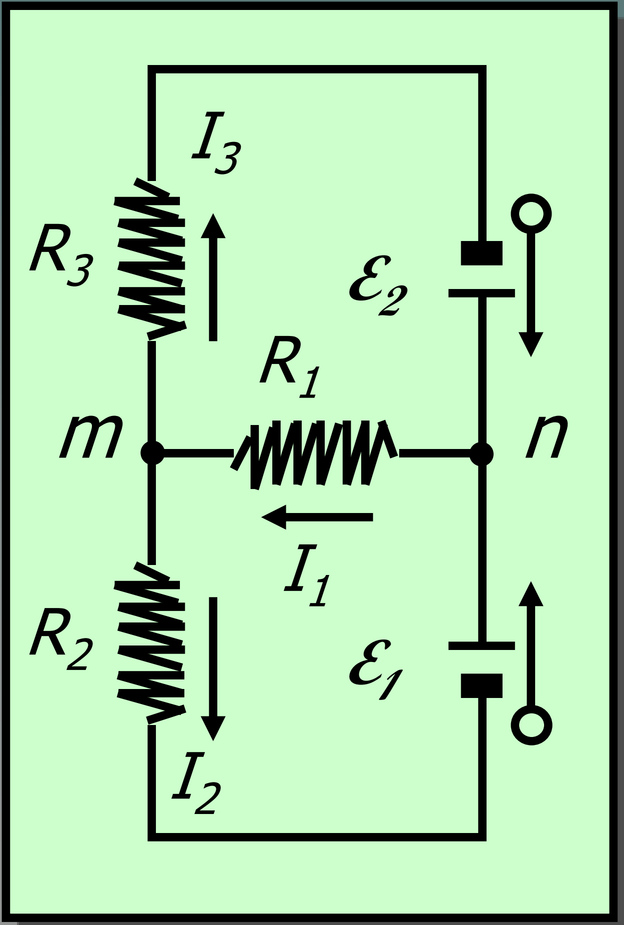
A complex circuit is one containing more than a single loop and different current paths.

At junctions m and n:

$I_1 = I_2 + I_3$ or $I_2 + I_3 = I_1$

Junction Rule:

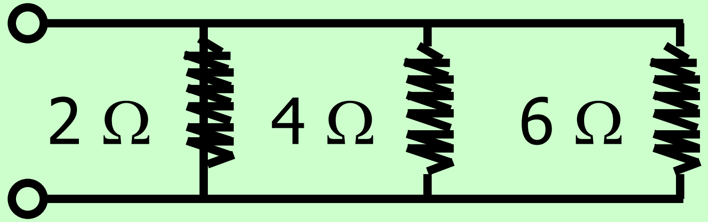
ΣI (enter) = ΣI (leaving)



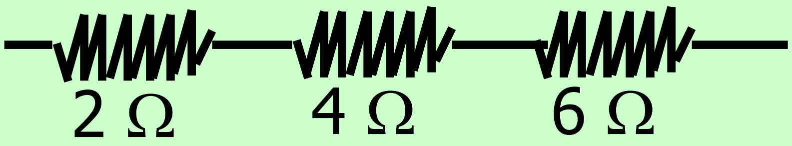
Parallel Connections

Resistors are said to be connected in parallel when there is more than one path for current.

Parallel Connection:



Series Connection:



For Parallel Resistors:

$$V_2 = V_4 = V_6 = V_T$$

$$I_2 + I_4 + I_6 = I_T$$

For Series Resistors:

$$I_2 = I_4 = I_6 = I_T$$

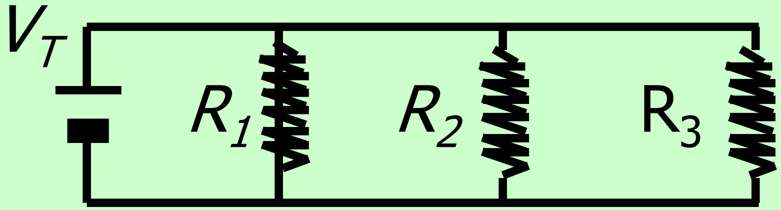
$$V_2 + V_4 + V_6 = V_T$$

Equivalent Resistance: Parallel

$$V_T = V_1 = V_2 = V_3$$

$$I_T = I_1 + I_2 + I_3$$

Parallel Connection:



Ohm's law: $I = \frac{V}{R}$

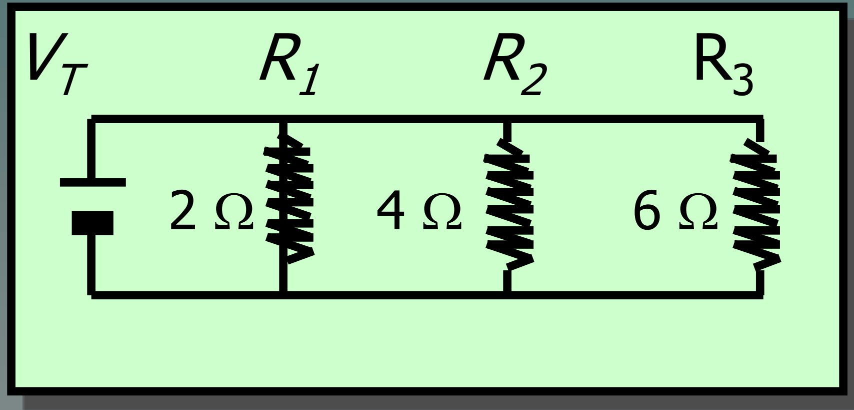
$$\frac{\cancel{V_T}}{R_e} = \frac{\cancel{V_1}}{R_1} + \frac{\cancel{V_2}}{R_2} + \frac{\cancel{V_3}}{R_3} \Rightarrow \frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

The equivalent resistance for Parallel resistors:

$$\boxed{\frac{1}{R_e} = \sum_{i=1}^{N} \frac{1}{R_i}}$$

Example 3. Find the equivalent resistance R_e for the three resistors below.

$$\boxed{\frac{1}{R_e} = \sum_{i=1}^{N} \frac{1}{R_i}}$$



$$\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3}$$

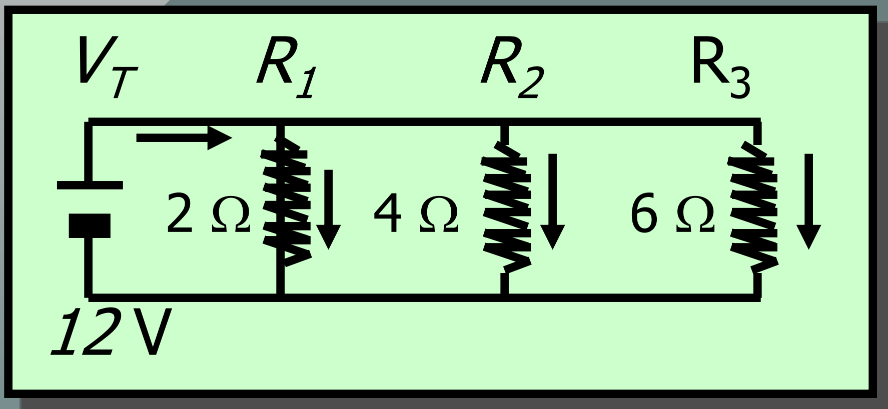
$$\frac{1}{R_e} = \frac{1}{2\Omega} + \frac{1}{4\Omega} + \frac{1}{6\Omega} = 0.500 + 0.250 + 0.167$$

$$\frac{1}{R_e} = 0.917; \quad R_e = \frac{1}{0.917} = 1.09\,\Omega$$

$$\boxed{R_e = 1.09\ \Omega}$$

For parallel resistors, R_e is less than the least R_i.

Example 3 (Cont.): Assume a 12-V emf is connected to the circuit as shown. What is the total current leaving the source of emf?



$V_T = 12$ V; $R_e = 1.09\ \Omega$

$V_1 = V_2 = V_3 = 12$ V

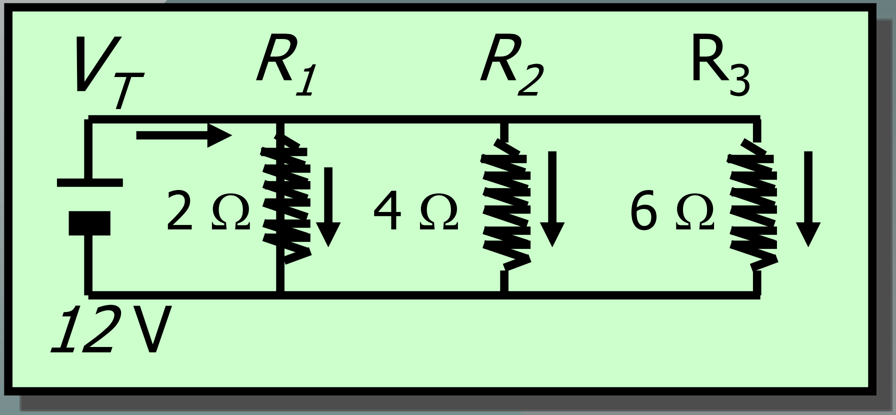
$I_T = I_1 + I_2 + I_3$

Ohm's Law: $I = \dfrac{V}{R}$

$$I_e = \frac{V_T}{R_e} = \frac{12\text{ V}}{1.09\ \Omega}$$

Total current: $I_T = 11.0$ A

Example 3 (Cont.): Show that the current leaving the source I_T is the sum of the currents through the resistors R_1, R_2, and R_3.



$I_T = 11\text{ A}$; $R_e = 1.09\ \Omega$

$V_1 = V_2 = V_3 = 12\text{ V}$

$I_T = I_1 + I_2 + I_3$

$$I_1 = \frac{12\text{ V}}{2\ \Omega} = 6\text{ A} \quad I_2 = \frac{12\text{ V}}{4\ \Omega} = 3\text{ A} \quad I_3 = \frac{12\text{ V}}{6\ \Omega} = 2\text{ A}$$

6 A + 3 A + 2 A = 11 A

Check !

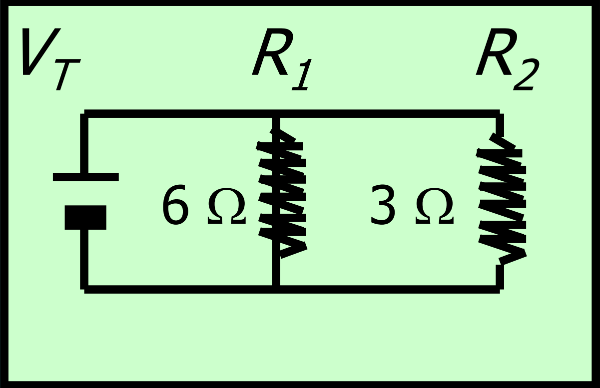
Short Cut: Two Parallel Resistors

The equivalent resistance R_e for two parallel resistors is the product divided by the sum.

$$\frac{1}{R_e} = \frac{1}{R_1} + \frac{1}{R_2};$$

$$\boxed{R_e = \frac{R_1 R_2}{R_1 + R_2}}$$

Example:

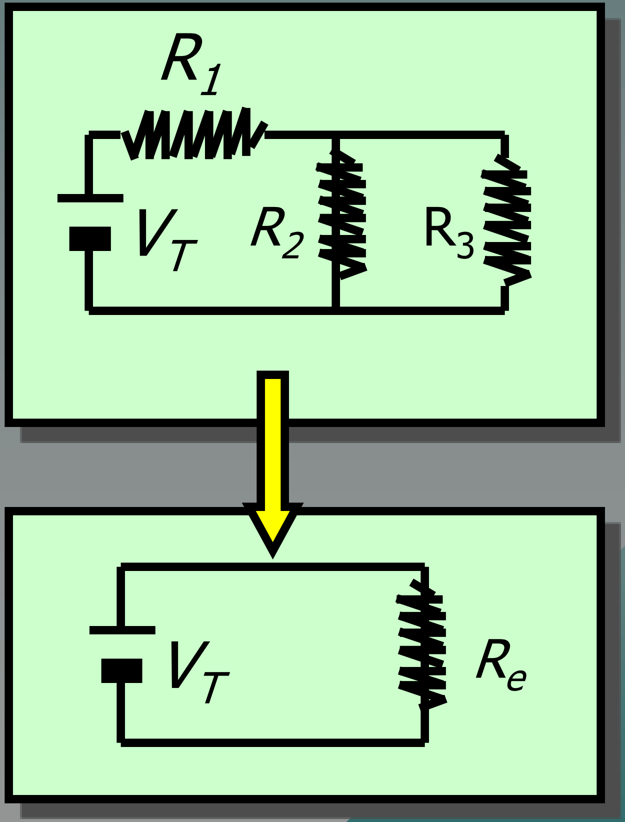


$$R_e = \frac{(3\Omega)(6\Omega)}{3\Omega + 6\Omega}$$

$$\boxed{R_e = 2\ \Omega}$$

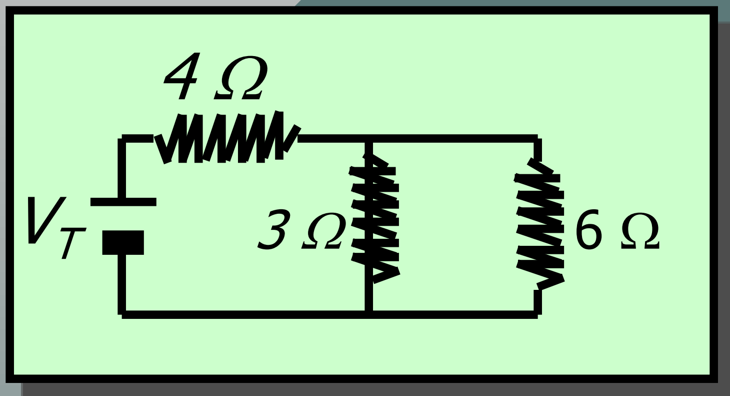
Series and Parallel Combinations

In complex circuits resistors are often connected in both series and parallel.



In such cases, it's best to use rules for series and parallel resistances to reduce the circuit to a simple circuit containing one source of emf and one equivalent resistance.

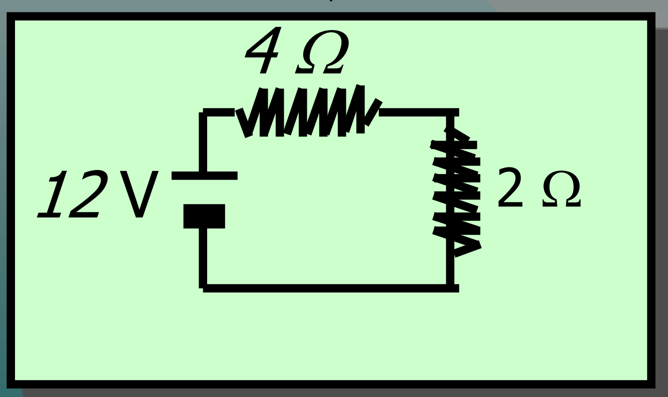
Example 4. Find the equivalent resistance for the circuit drawn below (assume V_T = 12 V).

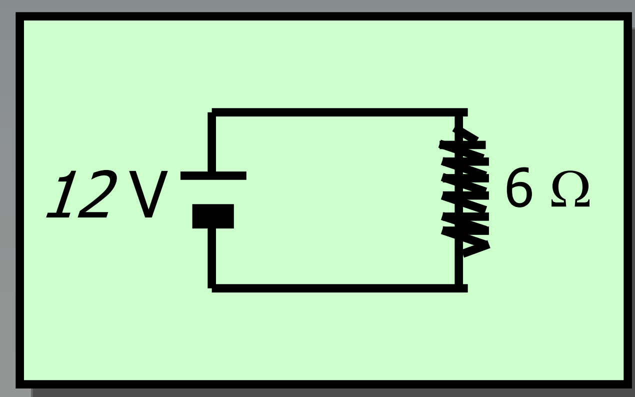


$$R_{3,6} = \frac{(3\Omega)(6\Omega)}{3\Omega + 6\Omega} = 2\Omega$$

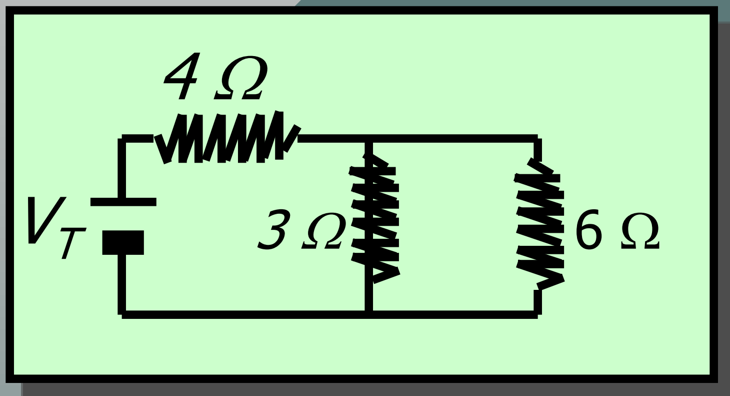
$$R_e = 4\ \Omega + 2\ \Omega$$

$$\boxed{R_e = 6\ \Omega}$$





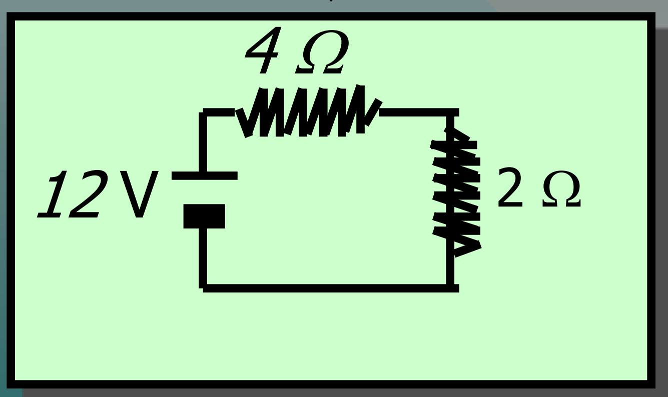
Example 3 (Cont.) Find the total current I_T.

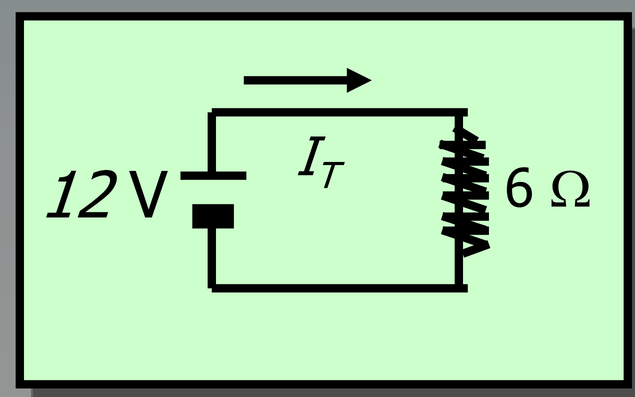


$$R_e = 6\ \Omega$$

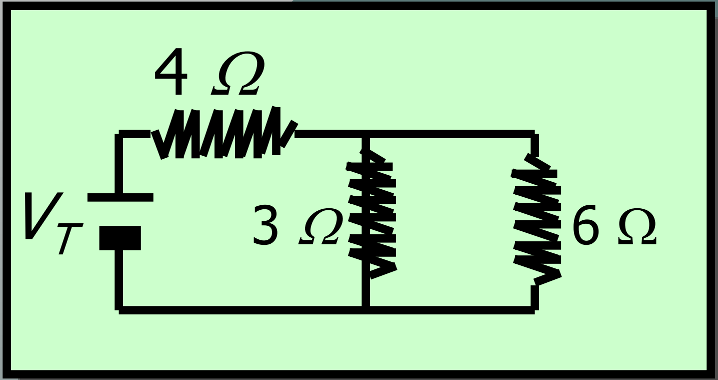
$$I = \frac{V_T}{R_e} = \frac{12\text{ V}}{6\ \Omega}$$

$$I_T = 2.00\text{ A}$$





Example 3 (Cont.) Find the currents and the voltages across each resistor.



$$I_4 = I_T = 2\text{ A}$$

$$V_4 = (2\text{ A})(4\ \Omega) = 8\text{ V}$$

The remainder of the voltage: (12 V – 8 V = 4 V) drops across EACH of the parallel resistors.

$$V_3 = V_6 = 4\text{ V}$$

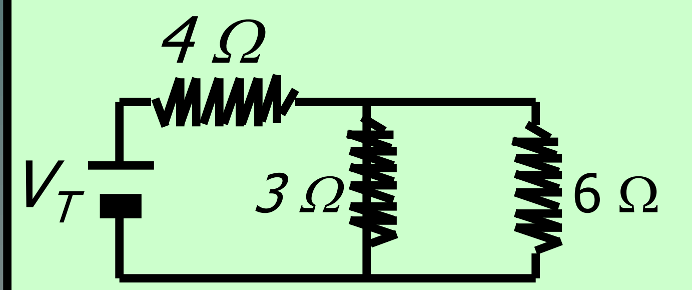
This can also be found from $V_{3,6} = I_{3,6}R_{3,6} = (2\text{ A})(2\ \Omega)$

(Continued . . .)

Example 3 (Cont.) Find the currents and voltages across each resistor.

$V_4 = 8\text{ V}$

$V_6 = V_3 = 4\text{ V}$



$$I_3 = \frac{V_3}{R_3} = \frac{4\text{ V}}{3\Omega}$$

$I_3 = 1.33\text{ A}$

$$I_6 = \frac{V_6}{R_6} = \frac{4\text{ V}}{6\Omega}$$

$I_6 = 0.667\text{ A}$

$I_4 = 2\text{ A}$

Note that the junction rule is satisfied:

$\Sigma I\ (\text{enter}) = \Sigma I\ (\text{leaving})$

$I_T = I_4 = I_3 + I_6$

Kirchoff’ s Laws for DC Circuits

Kirchoff’ s first law: The sum of the currents entering a junction is equal to the sum of the currents leaving that junction.

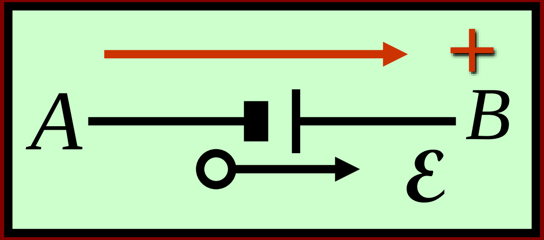
Junction Rule: ΣI *(enter)* = ΣI *(leaving)*

Kirchoff’ s second law: The sum of the emf’ s around any closed loop must equal the sum of the IR drops around that same loop.

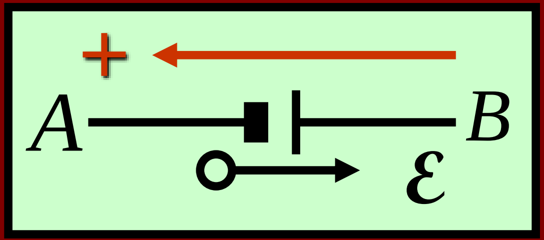
Voltage Rule: $\Sigma \mathcal{E} = \Sigma IR$

Sign Conventions for Emf's

- When applying Kirchoff's laws you must assume a consistent, positive tracing direction.
- When applying the voltage rule, emf's are positive if normal output direction of the emf is with the assumed tracing direction.
- If tracing from A to B, this emf is considered positive.



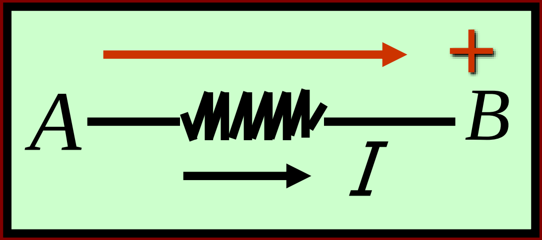
- If tracing from B to A, this emf is considered negative.



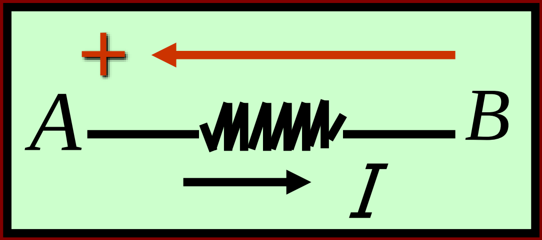
Signs of IR Drops in Circuits

- When applying the voltage rule, IR drops are positive if the assumed current direction is with the assumed tracing direction.

- If tracing from A to B, this IR drop is positive.

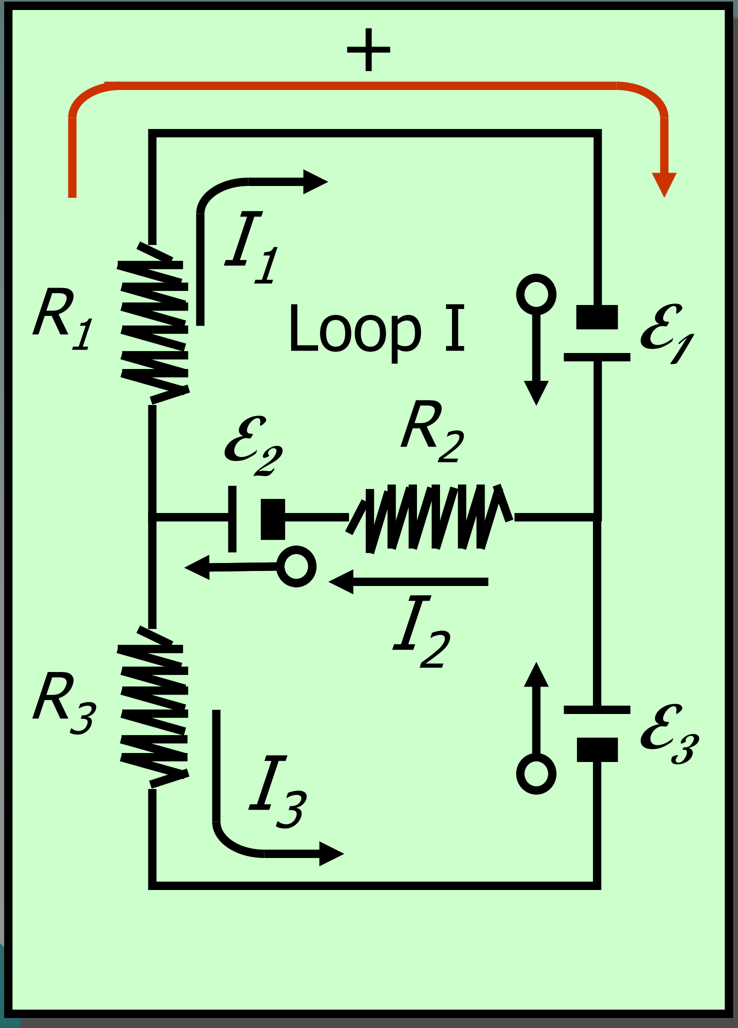


- If tracing from B to A, this IR drop is negative.



Kirchoff's Laws: Loop I

1. Assume possible consistent flow of currents.
2. Indicate positive output directions for emf's.
3. Indicate consistent tracing direction. (clockwise)



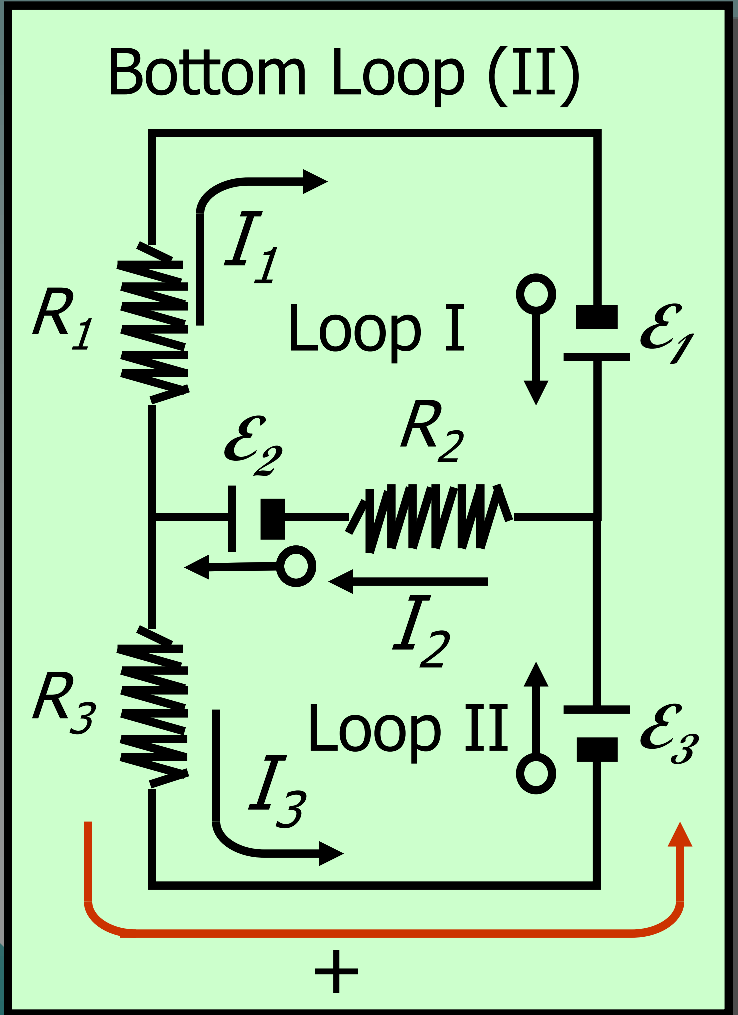
Junction Rule: $I_2 = I_1 + I_3$

Voltage Rule: $\Sigma\mathcal{E} = \Sigma IR$

$$\mathcal{E}_1 + \mathcal{E}_2 = I_1R_1 + I_2R_2$$

Kirchoff' s Laws: Loop II

4. Voltage rule for Loop II: Assume counterclockwise positive tracing direction.



Voltage Rule: $\Sigma\mathcal{E} = \Sigma IR$

$$\mathcal{E}_2 + \mathcal{E}_3 = I_2R_2 + I_3R_3$$

Would the same equation apply if traced clockwise?

Yes! $-\mathcal{E}_2 - \mathcal{E}_3 = -I_2R_2 - I_3R_3$

Kirchoff' s laws: Loop III

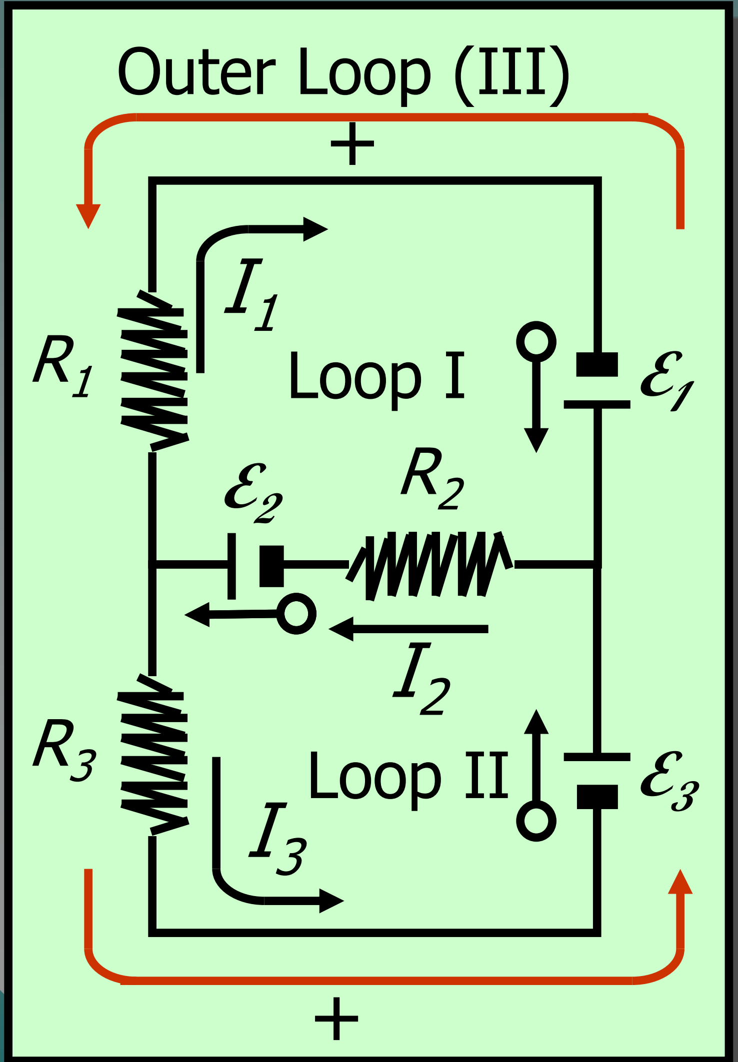
5. Voltage rule for Loop III: Assume counterclockwise positive tracing direction.

Voltage Rule: $\Sigma\mathcal{E} = \Sigma IR$

$$\mathcal{E}_3 - \mathcal{E}_1 = -I_1R_1 + I_3R_3$$

Would the same equation apply if traced clockwise?

Yes! $\mathcal{E}_3 - \mathcal{E}_1 = I_1R_1 - I_3R_3$



Four Independent Equations

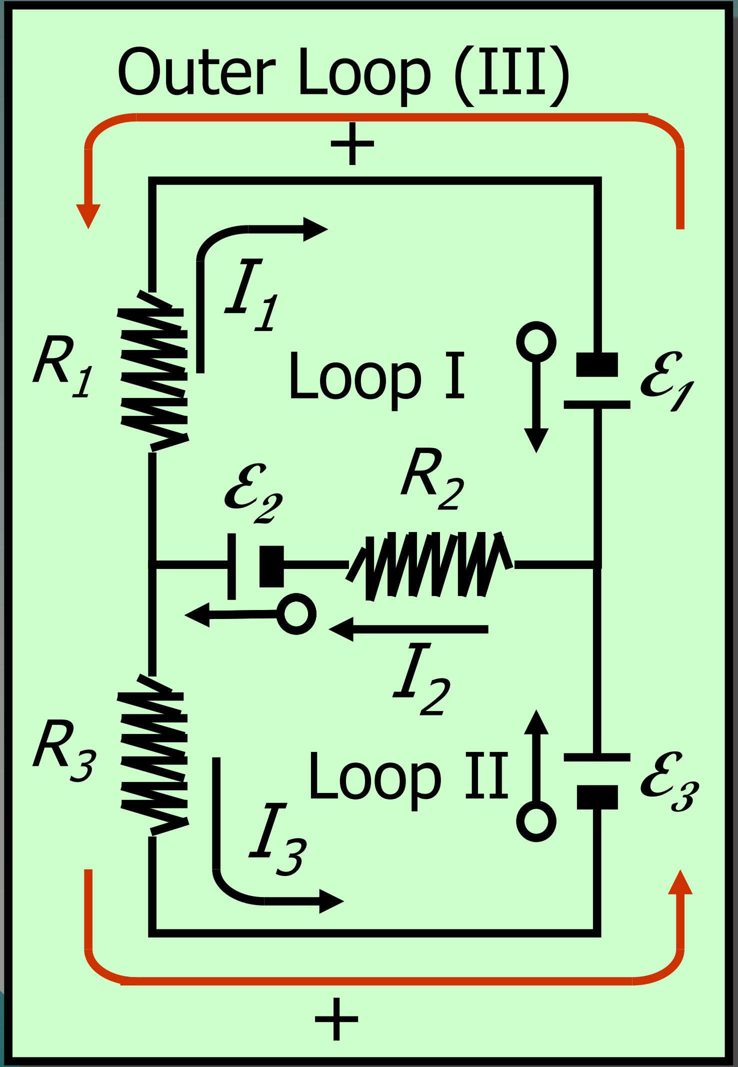
6. Thus, we now have four independent equations from Kirchoff's laws:

$$I_2 = I_1 + I_3$$

$$\mathcal{E}_1 + \mathcal{E}_2 = I_1R_1 + I_2R_2$$

$$\mathcal{E}_2 + \mathcal{E}_3 = I_2R_2 + I_3R_3$$

$$\mathcal{E}_3 - \mathcal{E}_1 = -I_1R_1 + I_3R_3$$



Example 4. Use Kirchoff's laws to find the currents in the circuit drawn to the right.

Junction Rule: $I_2 + I_3 = I_1$

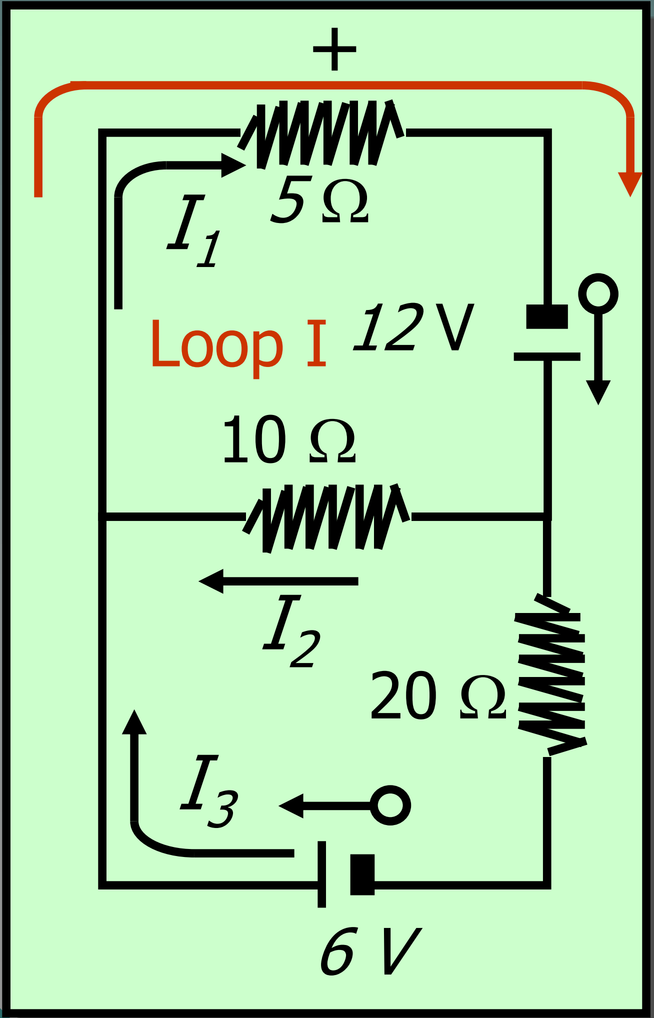
Consider Loop I tracing clockwise to obtain:

Voltage Rule: $\Sigma\mathcal{E} = \Sigma IR$

$$12\text{ V} = (5\ \Omega)I_1 + (10\ \Omega)I_2$$

Recalling that V/Ω = A, gives

$$\boxed{5I_1 + 10I_2 = 12\text{ A}}$$



Example 5 (Cont.) Finding the currents.

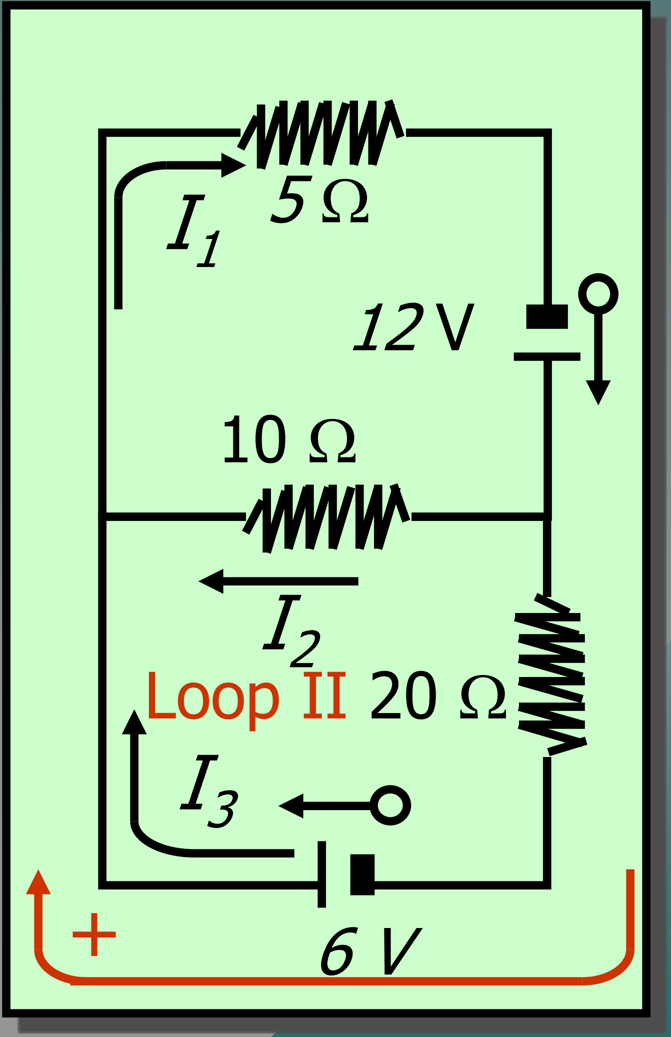
Consider Loop II tracing clockwise to obtain:

Voltage Rule: $\Sigma\mathcal{E} = \Sigma IR$

$$6\text{ V} = (20\ \Omega)I_3 - (10\ \Omega)I_2$$

Simplifying: Divide by 2 and V/Ω = A, gives

$$\boxed{10I_3 - 5I_2 = 3\text{ A}}$$

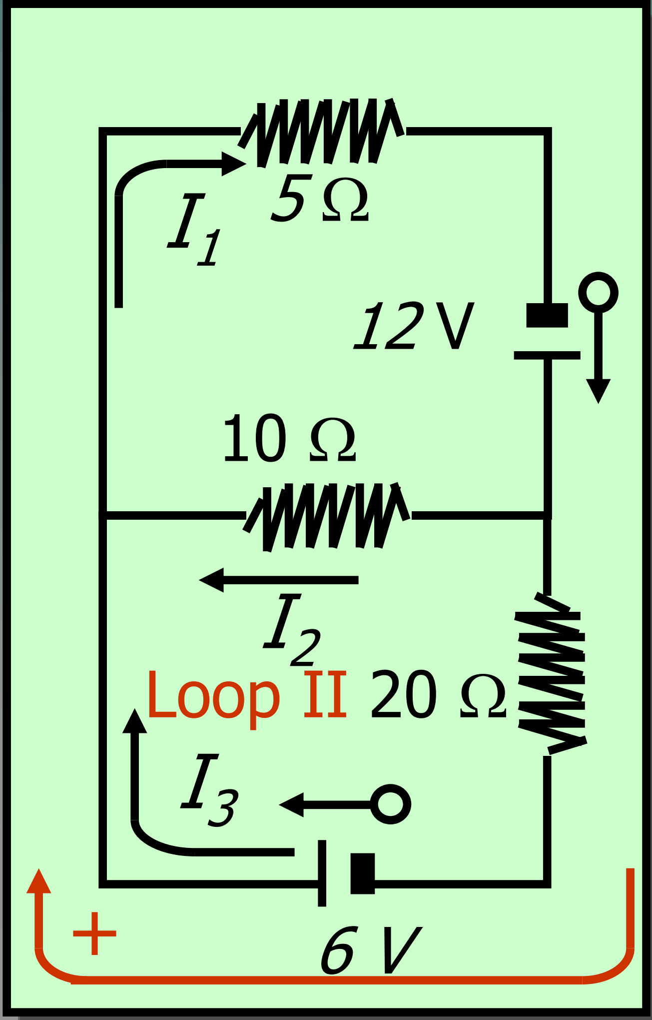


Example 5 (Cont.) Three independent equations can be solved for I_1, I_2, and I_3.

$$(1) \quad I_2 + I_3 = I_1$$

$$(2) \quad 5I_1 + 10I_2 = 12 \text{ A}$$

$$(3) \quad 10I_3 - 5I_2 = 3 \text{ A}$$



Substitute Eq.(1) for I_1 in (2):

$$5(I_2 + I_3) + 10I_3 = 12 \text{ A}$$

Simplifying gives:

$$5I_2 + 15I_3 = 12 \text{ A}$$

Example 5 (Cont.) Three independent equations can be solved.

$$\boxed{(1)\quad I_2 + I_3 = I_1}$$

$$\boxed{(3)\quad 10I_3 - 5I_2 = 3\text{ A}}$$

$$\boxed{(2)\quad 5I_1 + 10I_2 = 12\text{ A}}$$

$$\boxed{15I_3 + 5I_2 = 12\text{ A}}$$

Eliminate I_2 by adding equations above right:

$$10I_3 - \cancel{5I_2} = 3\text{ A}$$

$$15I_3 + \cancel{5I_2} = 12\text{ A}$$

$$25I_3 = 15\text{ A}$$

$$\boxed{I_3 = 0.600\text{ A}}$$

Putting $I_3 = 0.6$ A in (3) gives:

$$10(0.6\text{ A}) - 5I_2 = 3\text{ A}$$

$$\boxed{I_2 = 0.600\text{ A}}$$

Then from (1): $\boxed{I_1 = 1.20\text{ A}}$

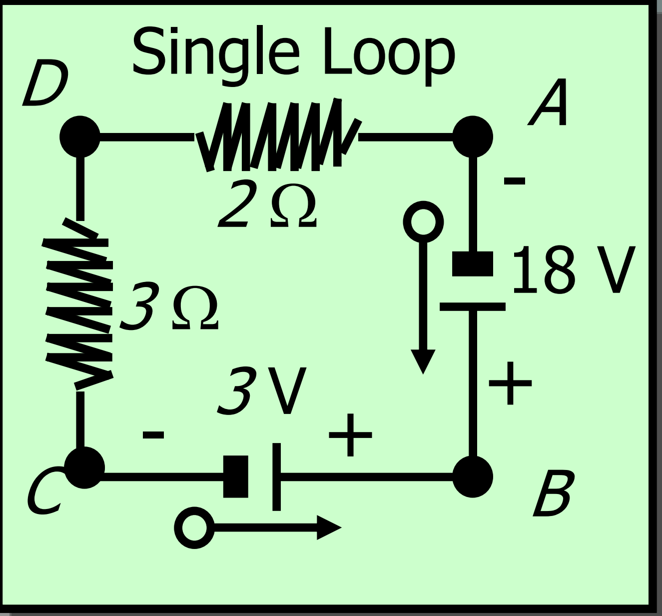
Summary of Formulas:

Rules for a simple, single loop circuit containing a source of emf and resistors.

Resistance Rule: $R_e = \Sigma R$

Current: $I = \dfrac{\Sigma \mathcal{E}}{\Sigma R}$

Voltage Rule: $\Sigma \mathcal{E} = \Sigma IR$



Summary (Cont.)

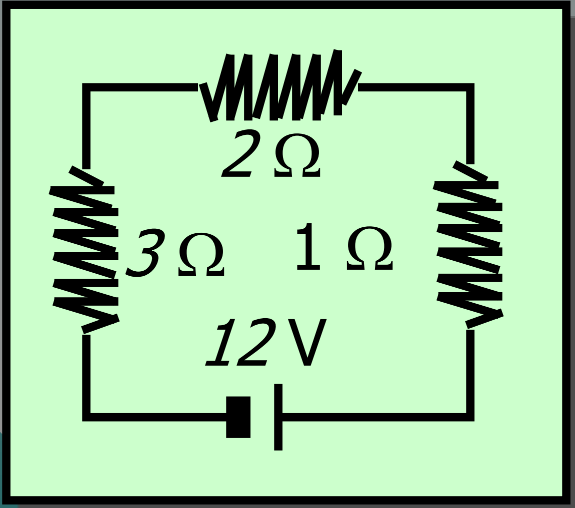
For resistors connected in series:

For series connections:

$$I = I_1 = I_2 = I_3$$
$$V_T = V_1 + V_2 + V_3$$

$$R_e = R_1 + R_2 + R_3$$

$$R_e = \Sigma R$$



Summary (Cont.)

Resistors connected in parallel:

For parallel connections:

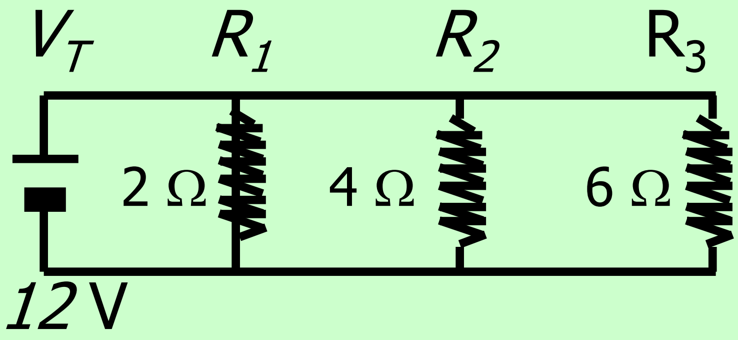
$$V = V_1 = V_2 = V_3$$

$$I_T = I_1 + I_2 + I_3$$

$$\frac{1}{R_e} = \sum_{i=1}^{N} \frac{1}{R_i}$$

$$R_e = \frac{R_1 R_2}{R_1 + R_2}$$

Parallel Connection



Summary Kirchoff's Laws

<u>Kirchoff's first law:</u> The sum of the currents entering a junction is equal to the sum of the currents leaving that junction.

Junction Rule: ΣI *(enter)* $= \Sigma I$ *(leaving)*

<u>Kirchoff's second law:</u> The sum of the emf's around any closed loop must equal the sum of the IR drops around that same loop.

Voltage Rule: $\Sigma \mathcal{E} = \Sigma IR$

The Battery

The Battery

- Main Entry: storage battery
- Function: noun
- Date: 1881
- : a cell or connected group of cells that converts chemical energy into electrical energy by reversible chemical reactions and that may be recharged by passing a current through it in the direction opposite to that of its discharge -- called also storage cell.

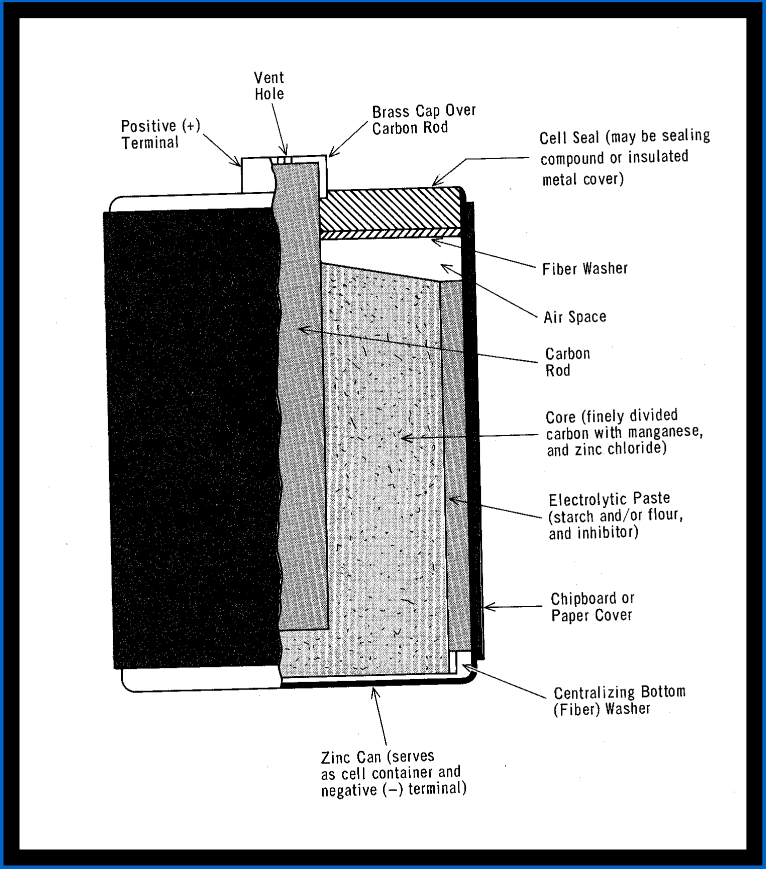
Battery

HAZARDOUS CONSTITUENT	***POSSIBLE EFFECTS***
SULFURIC ACID	Corrosive, causes severe skin burns, and can cause blindness.
LEAD	Causes nerve and kidney damage, suspected carcinogen

Types of Batteries

- The ***primary battery*** converts chemical energy to electrical energy ***directly***, using the chemical materials within the cell to start the action.
- The ***secondary battery*** must first be ***charged*** with electrical energy before it can convert chemical energy to electrical energy.
- The ***secondary battery*** is frequently called a ***storage battery***, since it stores the energy that is supplied to it.

DRY CELL



- Uses An electrolytic paste.
- The electrolytic paste reacts with the electrodes to produce a negative charge on one electrode and a positive charge on the other.
- The difference of potential between the two electrodes is the output voltage.

Lead Acid Battery

- Electrolyte for the most part distilled (pure) water, with some sulfuric acid mixed with the water.
- Electrodes must be of dissimilar metals.
- An active electrolyte.

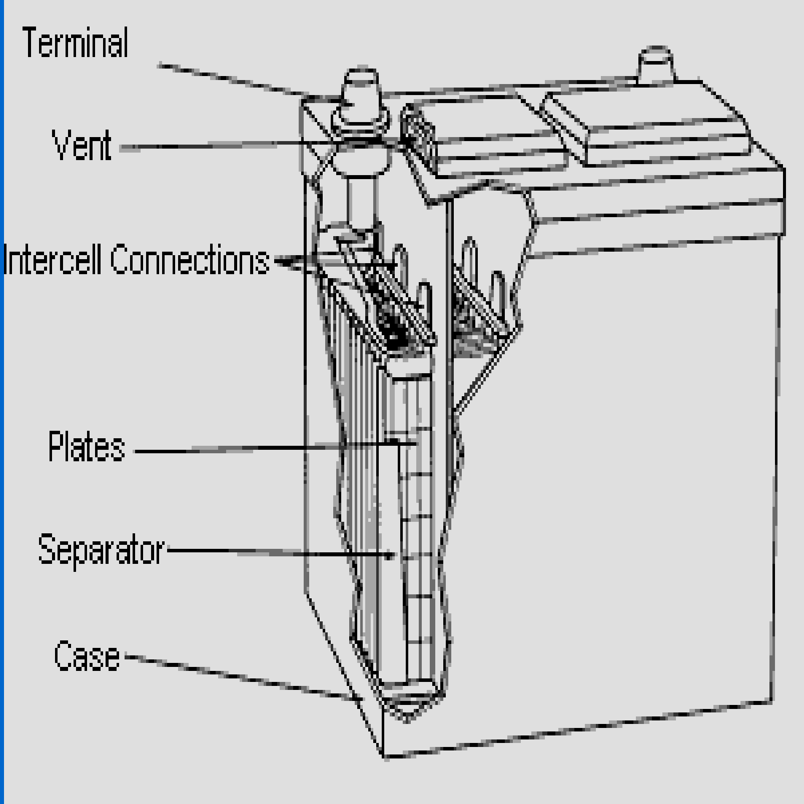


Figure 6 - Flodded Lead-Acid Battery

Cells

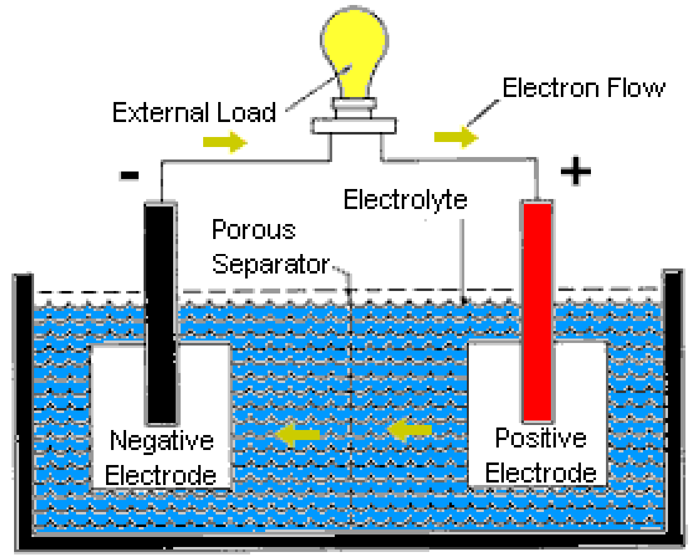
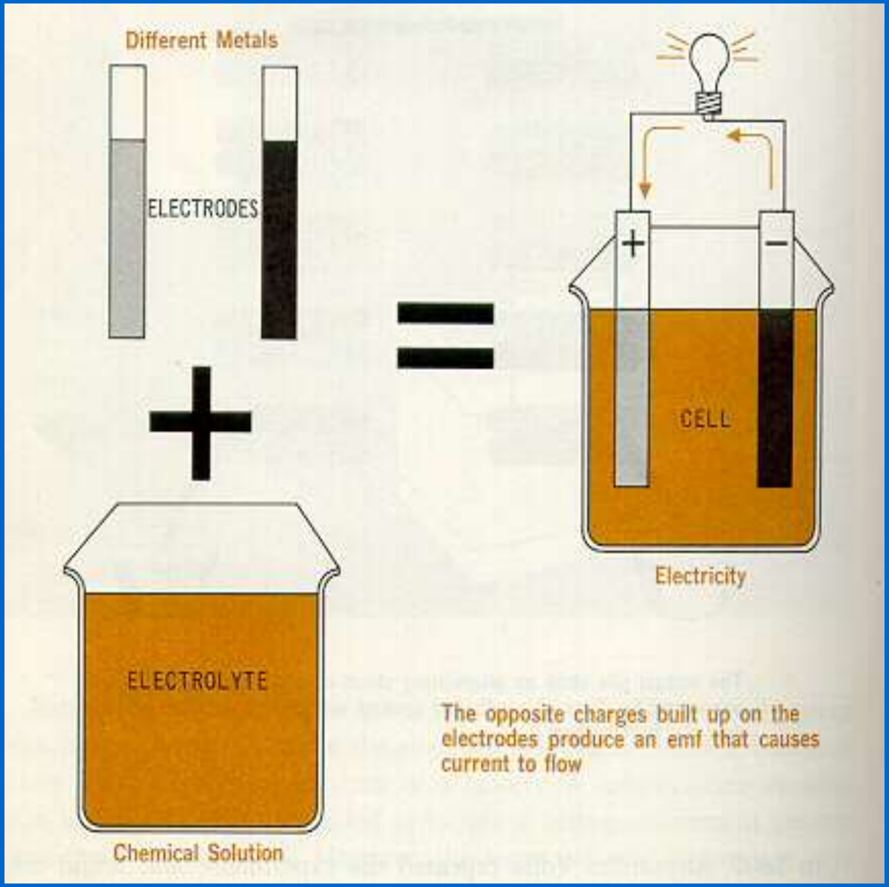


Figure 1 - Components of a Battery Cell (Discharge Circuit)

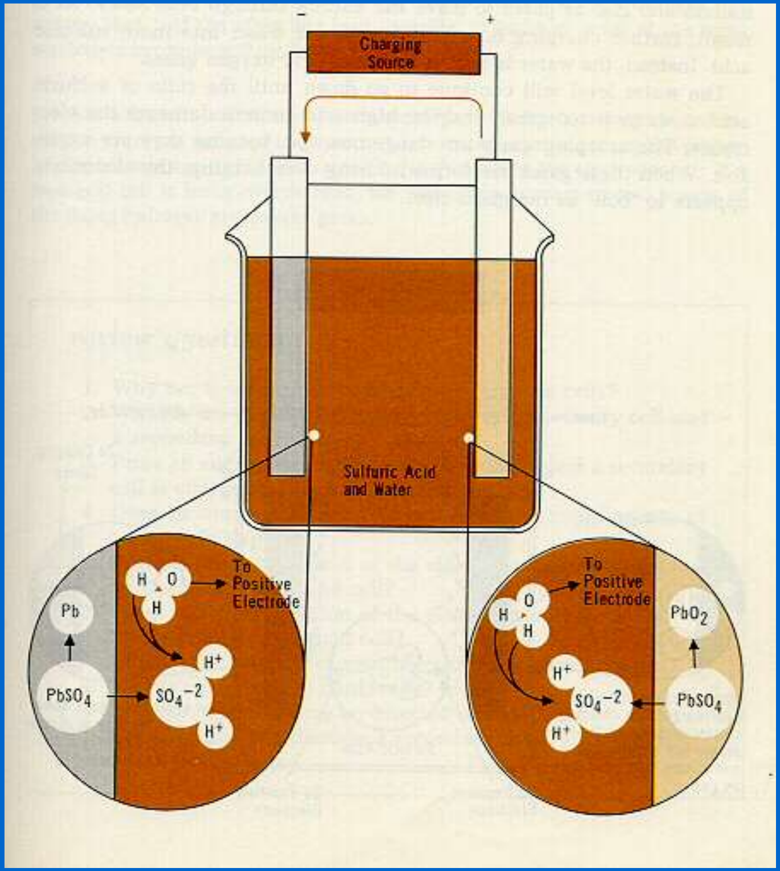
- Positive electrode
- Negative electrode
- Electrolyte
- Separator

The basic primary wet cell



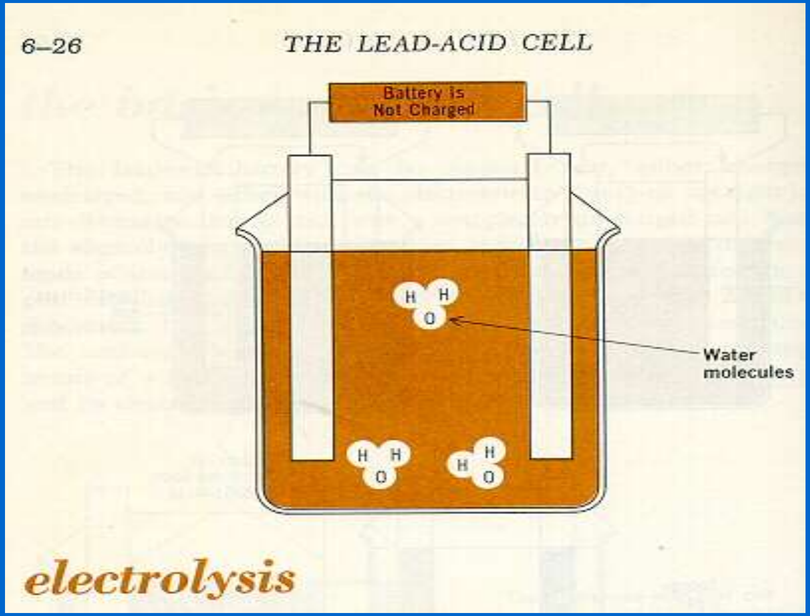
- The metals in a cell are called the *electrodes*, and the chemical solution is called the *electrolyte*.
- The electrolyte reacts oppositely with the two different electrodes
- It causes one electrode to lose electrons and develop a *positive charge*; and it causes one other electrode to build a surplus of electrons and develop a *negative charge*.
- The difference in potential between the two electrode charges is the cell *voltage*.

The Electrolyte

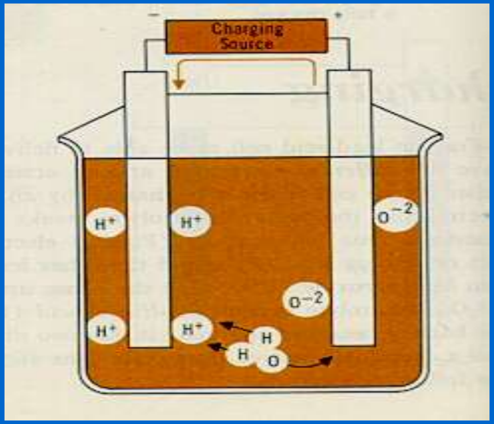


- When charging first started, electrolysis broke down each water molecule (H_2O) into two hydrogen ions (H^+) and one oxygen ion (O^{-2}).
- The positive hydrogen ions attracted negative sulfate ions (SO_4^{-2}) from each electrode.
- These combinations produce H_2SO_4, which is *sulfuric acid*.

Electrolysis



- The producing of chemical changes by passage of an electric current through an electrolyte.



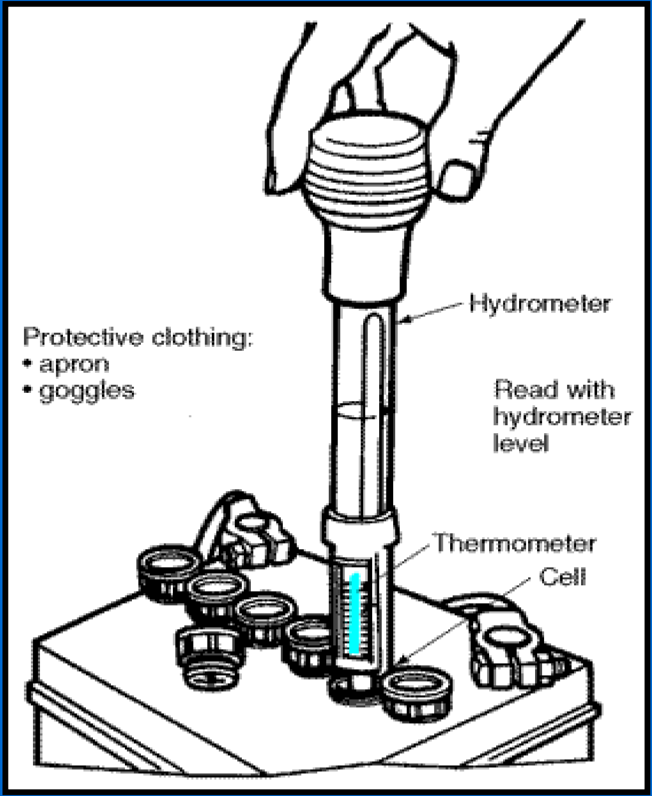
Specific Gravity

- Ratio of the weight of a given volume of a substance to the weight of an equal volume of some reference substance, or, equivalently, the ratio of the masses of equal volumes of the two substances.
- Example: It is the weight of the sulfuric acid - water mixture compared to an equal volume of water. Pure water has a specific gravity of 1,000.

Hydrometer

- Device used to determine directly the **specific gravity** of a liquid.

Hydrometer



The chart below gives state of charge vs. specific gravity of the electrolyte.

State of Charge	Specific Gravity
100% Charged	1.265
75% Charged	1.239
50% Charged	1.200
25% Charged	1.170
Fully Discharged	1.110

- These readings are correct at 75° F

Voltmeter = Hydrometer

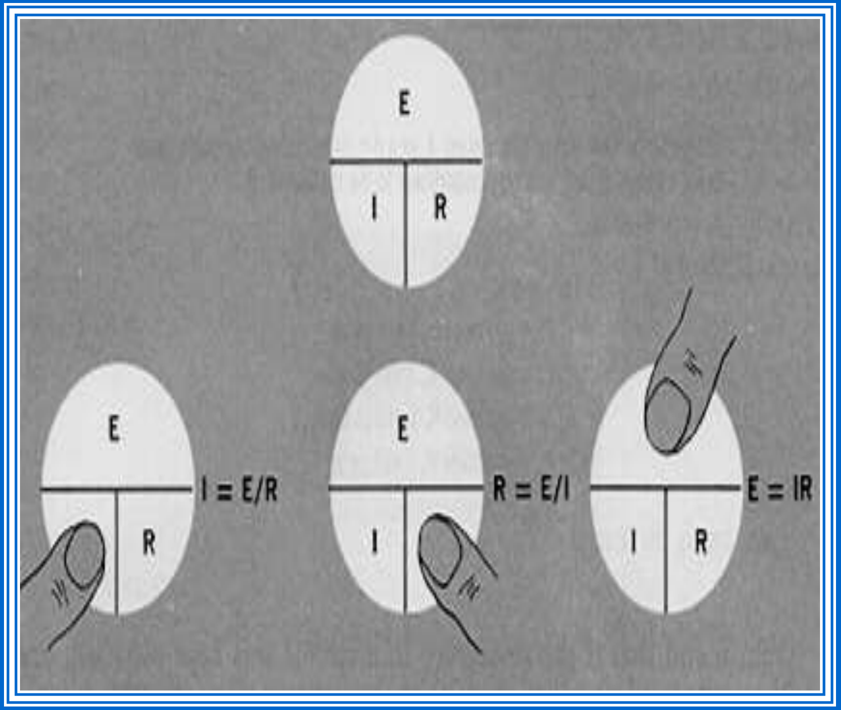
•If you are simply using an **accurate** voltmeter, along with occasional checks with your hydrometer, this chart should be helpful in determining your batteries state of charge.

Charge Level	Specific Gravity	Voltage 2V n	Voltage 6V n	Voltage 12V n	Voltage 24V n
100.00%	1.270	2.13	6.38	12.75	25.50
75.00%	1.224	2.08	6.24	12.48	24.96
50.00%	1.170	2.02	6.06	12.12	24.24
20.00%	1.097	1.94	5.82	11.64	23.28
0.00%	1.045	1.89	5.67	11.34	22.68

n stands for nominal voltage

Ohm's Law

- Ohm's Law can be expressed by the equation:
  - E = IR
  - I = E/R
  - R = E/I



Ohm's Law

- Series circuits, the total voltage is equal to the sum of the individual voltages. The current is constant.
- Parallel circuits, the voltage is constant. The current is equal to the sum of the individual currents.

Currents

- If one volt of potential difference across a device causes on ampere of current to flow, then the device has a resistance of

  1 ohm = 1Ω = 1V/A

- Most of your electrical resistance is in your skin and varies from 500 ohms (clean) to several million ohms (dirty).

Currents

Current Amperes	Physiological Phenomena	Effect on Man
< 0.001	None	Imperceptible
0.001	Perception Threshold	Mild Sensation
0.003	Pain Threshold	Painful Sensation
0.010	Paralysis Threshold of Arms and Hands	Person cannot release grip; if no grip, victim may be thrown clear. Tighter grip because of paralysis may allow more current to flow; may be fatal.
0.030	Respiratory Paralysis	Stoppage of breathing, frequently fatal.
0.075	Fibrillation Threshold	Heart action uncoordinated, probably fatal.
4.000	Heart Paralysis Threshold	Heart stops on current passage, normally restarts when current interrupted.
5.000	Tissue Burning	Not fatal unless vital organs are burned

Series Connected Batteries

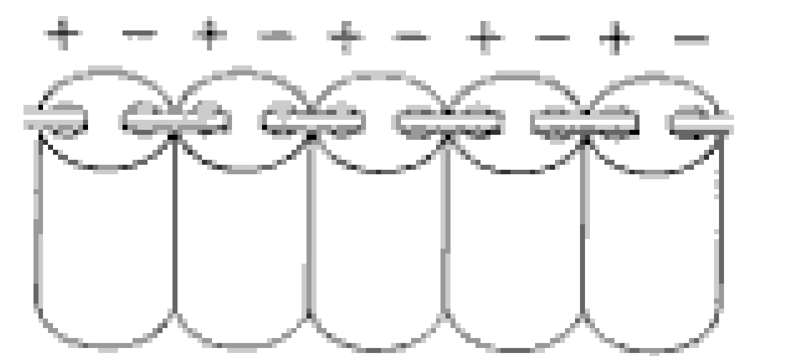


Figure 2 - Series-Connected Batteries

- Positive terminal of one cell is connected to the negative terminal of the next, is called a series connected battery.
- The voltage of this type of battery is the sum of a individual cell voltages.

Parallel Connected Batteries

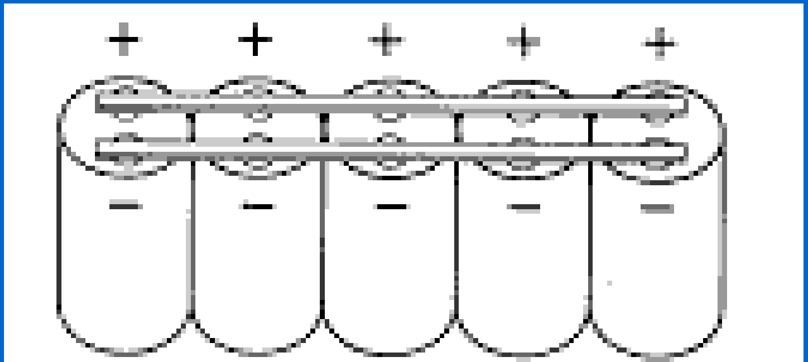
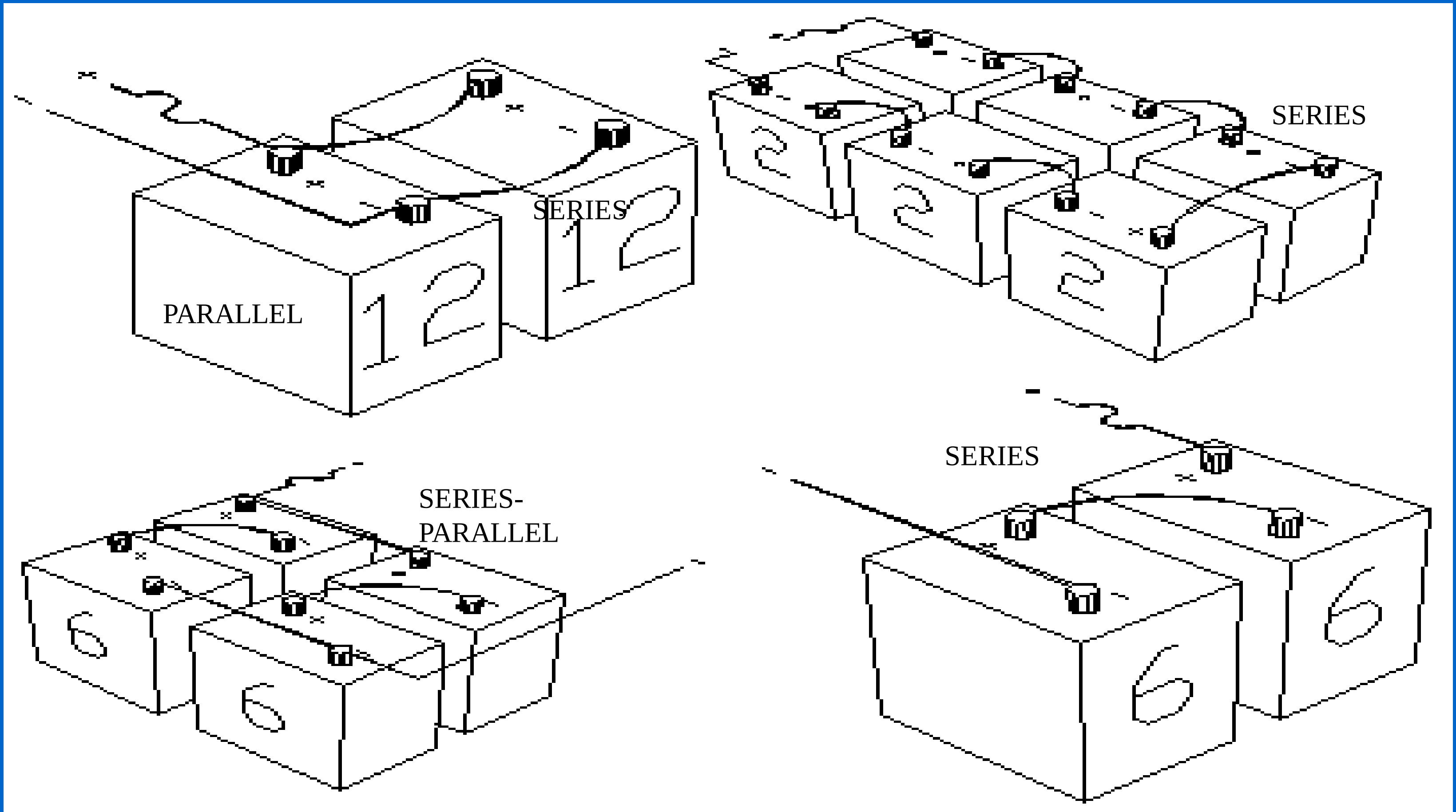


Figure 3 - Parallel-Connected Battery

- Connect the negative terminal from one cell to the negative of the next cell
- Connect the positive terminal to the positive terminal, is parallel connected.
- Voltage remains constant and the current is cumulative.

Series-Parallel Connections



Capacity Rating System

- The Society of Automotive Engineers (SAE) has established two ratings for domestic made batteries:
  - Reserve Capacity (RC)
  - Cold Cranking Amps (CCA)

Reserve Capacity

- Reserve capacity is the time required (in minutes) for a fully charged battery at 80° F under a constant 25 amp draw to reach a voltage of 10.5 volts.

Cold Cranking Amps (CCA)

- CCA is an important measurement of battery capacity.
- This rating measures the discharge lead (in amps) that a battery can supply for 30 seconds at 0° F (-17° C), while maintaining a voltage of 1.2 volts per cell (7.2 volts per battery or higher).

Preventive Maintenance

- When the top of a battery is “dirty or looks damp.
- Give a battery a general cleaning, use hot water (130°F to 170°F) with a neutralizer / detergent solution.

Charging

- Chemical reaction occur during charging.
- Lead sulfate on both plates is separated into Lead (Pb).
- Sulfate (SO_4) leaves both plates.
- It combines with hydrogen (H) in the electrolyte to form sulfuric acid (H_2SO_4).
- Oxygen (O) combines with the lead (Pb) at the positive plate to form lead oxide (PbO_2).
- The negative returns to original form of lead (Pb.

Charging

- Clean Battery Terminals.
- Attach clamps to the battery in proper polarity.
- Keep open flames and sparks away from battery.
- Ventilate the battery well while charging.

Charging

- The charge a battery receives is equal to the charge rate in amperes multiplied by the time in hours.
- Measure the specific gravity of a cell once per hour during charging to determine full charge.

Overcharging

- Results in warped or broken plates, damaged separators, severe shedding of the active materials pasted to the plates, and excessive loss of water, which cause plates to dry out.

Ventilation Requirements

- The oxygen and hydrogen gases released during the gassing phase of a typical flooded lead-acid battery recharge can be dangerous if allowed to ***exceed 0.8 % (by volume) or 20 percent of the lower explosive range***. *Concentrations of hydrogen between 4 % and 74% are considered explosive (40,000 ppm and 740,000 ppm).*

HYDROGEN

- Chemical Formula: **H_2**
- Specific Gravity: **0.0695**
- Color: None Odor: **None**
- Taste: **None**
- Origin: **Applying water to super hot mine fires, explosions electrolysis of battery acid.**
- Explosive Range: **4.1% - 74%**
- Ignition Temp: **1030º - 1130º F**
- % Oxygen Needed To Burn or Explode: **5%**
- TLV: **None**
- STEL: **None**
- Effect on Body:**Asphxysiant Due to Displacement of Oxygen.**
- How Detected: **Electronic Detectors, Squeeze Tube Detectors, Chemical Analysis.**
- **NOTE:** *Hydrogen is the reason a flame safety lamp is not permitted in a battery*

Ventilation

- All lead acid power batteries give off gases when recharging and also for a period after the charge is completed.
  - A Concentration of hydrogen in excess of 4% (by volume). It is suggested that the concentration be controlled to a maximum of 2% (by volume).

Ventilation (cont.)

- A typical lead acid motive power cell will, evolve approximately .016 cubic feet of hydrogen gas over A.H. overcharge.
- Since this gas is given off at the maximum rate at the end of the charging period, the following calculation assumes a charging current of 5% of the 6 hour A.H. capacity (C6) during this over charge period. (This charging current is excessive but has been used to take account of the worst case.)
- **Gas given off per hour per cell = 0.16 x .05 = .0008 C6 cu / ft. / cell / hr.**

Example:

- Consider a battery of 24 cells, type 75CB-13 (C6 = 450 A.H.).
- From the above formula, the rate of gas evolution during overcharge is 24 x .0008 x 450 A.H. = 8.64 cu. Ft./hr.
- Assume that there are 10 such batteries on charge simultaneously in a room whose dimensions are 25 ft. x 20ft. x 12 ft. high.
- Volume of charging room = 6,000 cu. Ft.
- Volume of Hydrogen gas given off = 8.64 x 10 = 86.4 cu. Ft./hr.
- In order that the concentration of hydrogen is kept at 2% maximum, the air must be changer every 6,000 x 60/83 = 86.4 cu. X 60 = 83 minutes.
- Consequently, fans capable of extracting 6,000 x 60/83 = 4337 cu.ft. per hour should be installed as near the roof as possible.

Jump Starting

- Be sure to turn off accessories.
- Connect the red cable to the positive terminal on the good battery while the engine is running.
- Connect the other end of the red cable to the positive terminal on the dead battery.
- Then connect one end of the black cable to the negative terminal on the good battery.
- Connect the other end of the negative cable to a known good ground in the vehicle with the dead battery.
- After starting the vehicle with the discharged battery, allow the engine to return to idle speed.
- Remove the negative jumper cable starting with the end that is connected to the vehicle ground
- Remove the positive cable.