Basic Electricity

Appalachian Underground Corrosion Short Course

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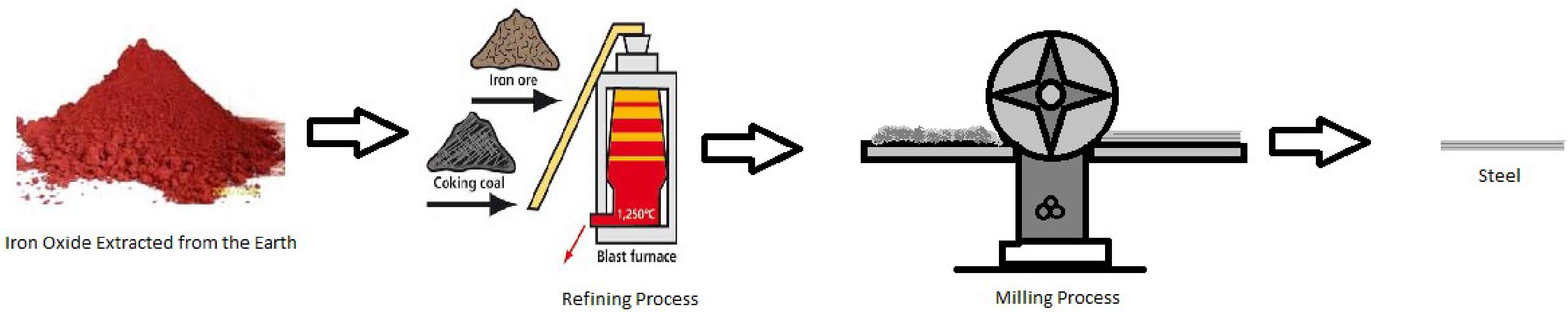
Appalachian Underground Corrosion Short Course

Chapter 1 – Basic Electricity

- Introduction
- Electrical Fundamentals
  - Physical Matter
  - Two General Types of Electricity
- Basic Terms
- Ohm's Law
- Basic Electrical Circuit
- Series Electrical Circuit
- Parallel Electrical Circuit
- Combination Circuits

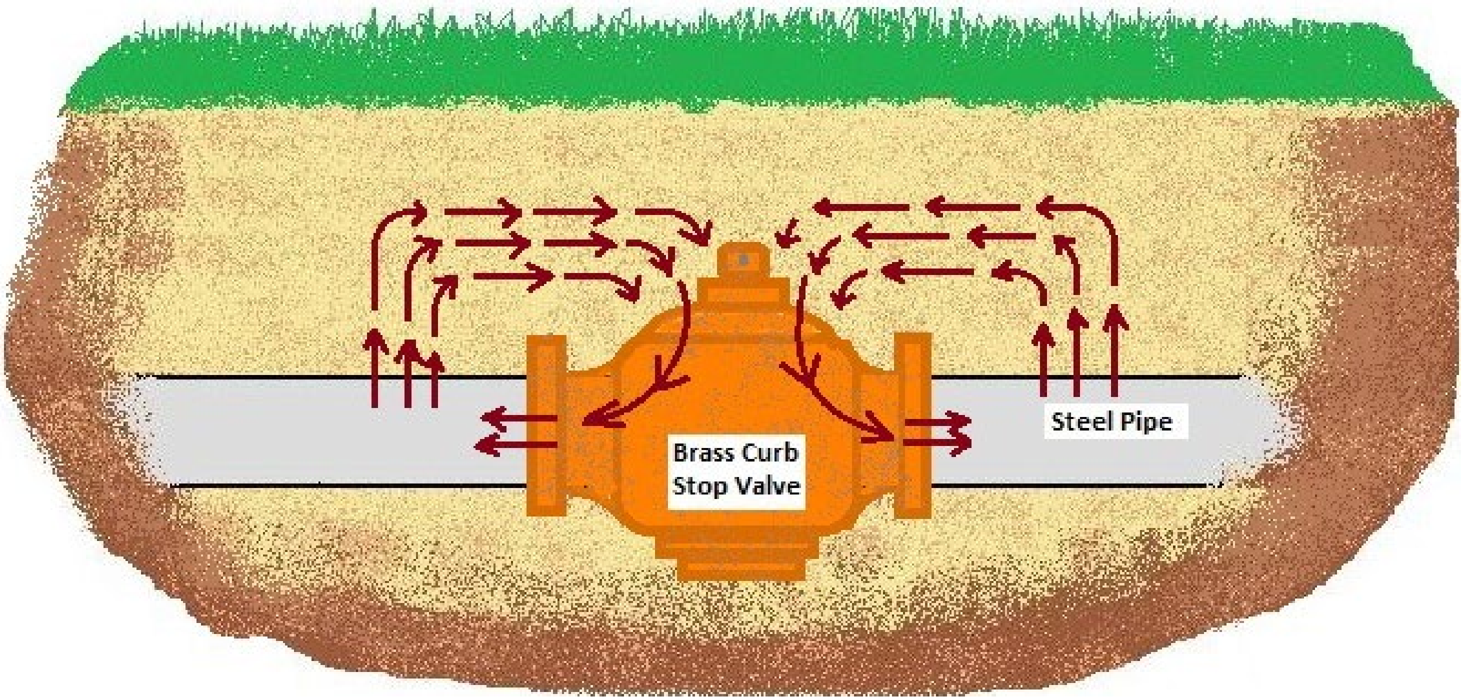
Introduction: What is Corrosion?



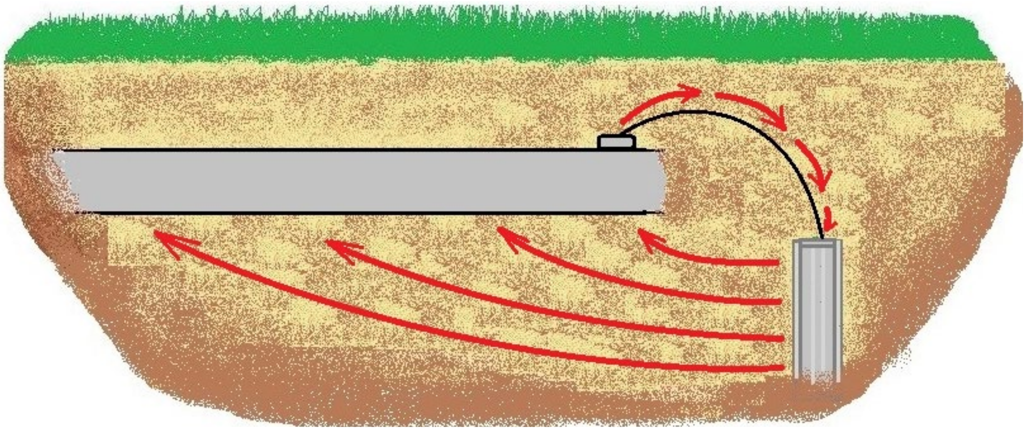
Corrosion Is The Destruction Or <u>Deterioration</u> Of A Material <u>Due To A Reaction</u> With Its Environment

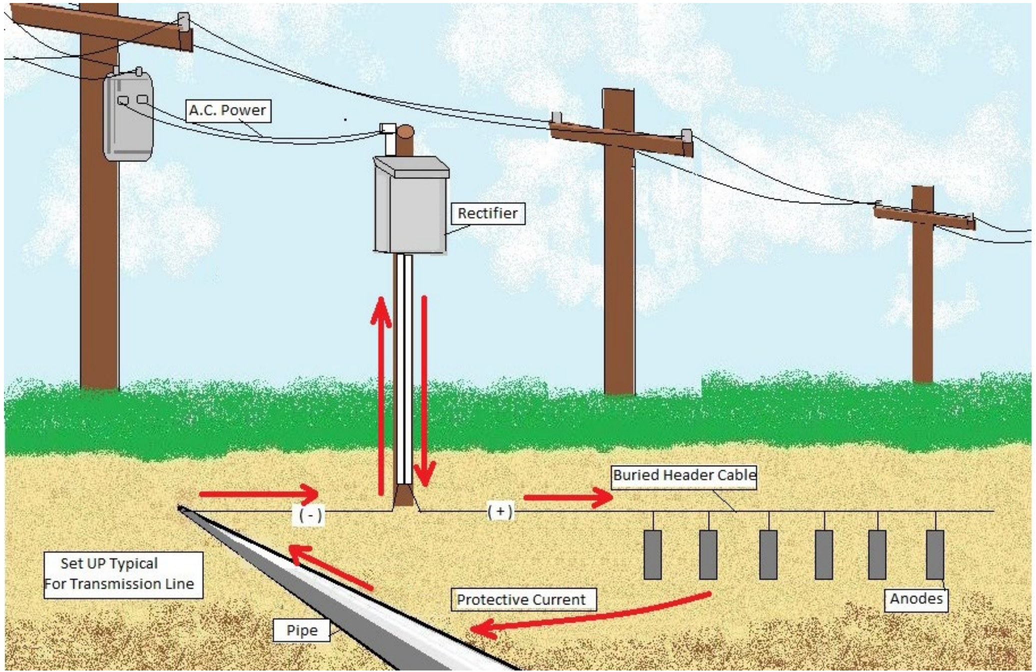
- **Corrosion of metals and alloys involves flow of electrical current**

Current flow in Corrosion

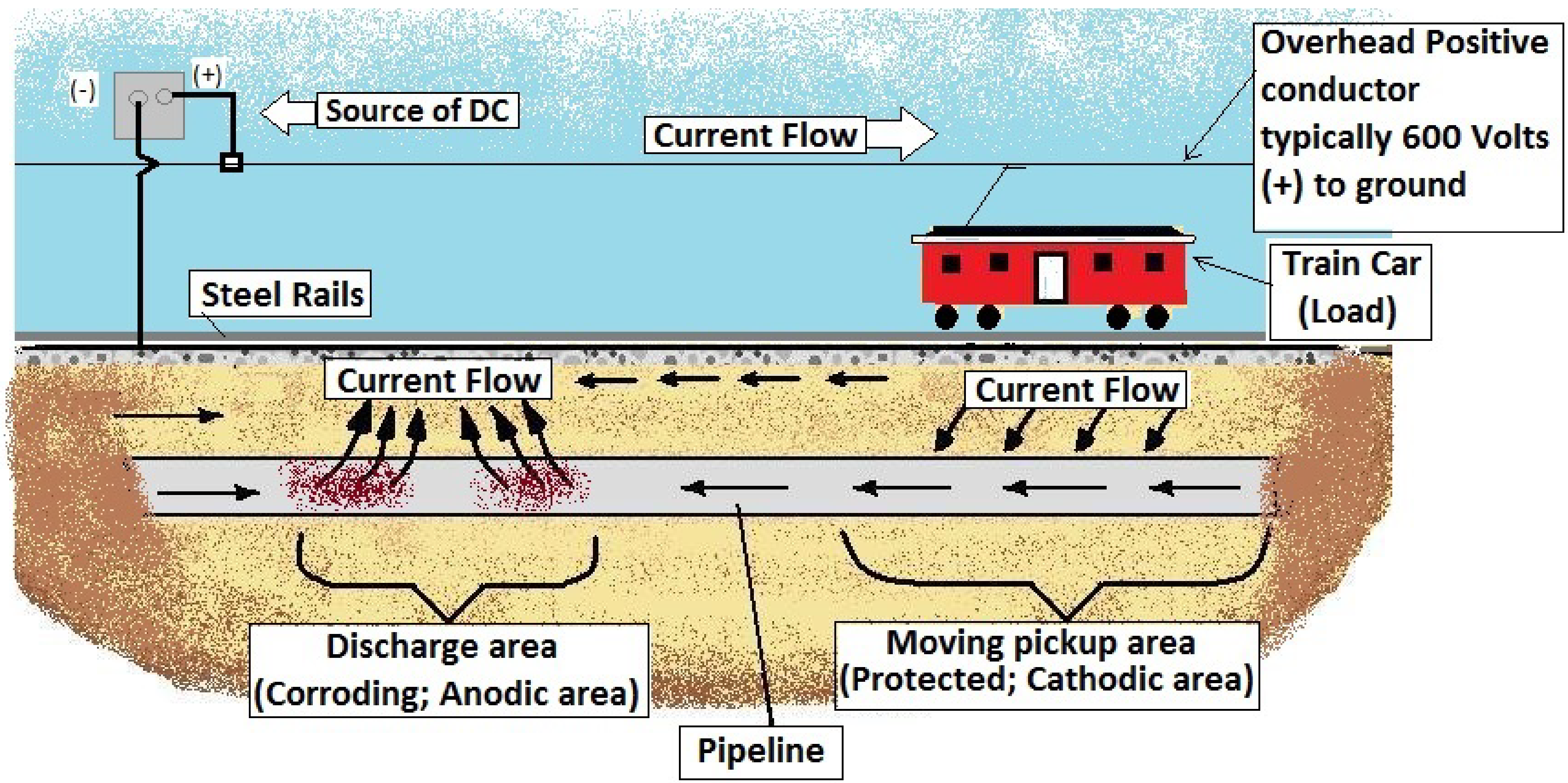


Current flow in Corrosion





Current flow in Corrosion



Corrosion Chemistry: Matter

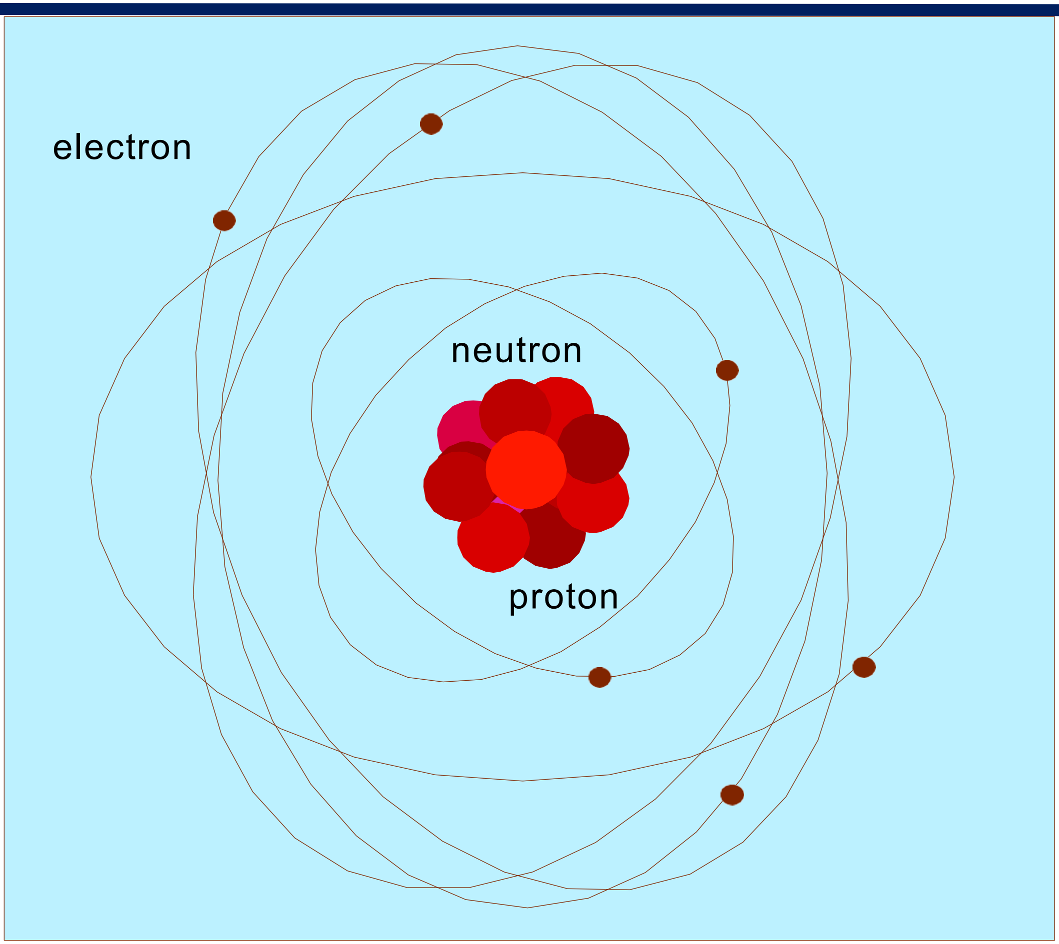
- Substance that occupies space and has mass
  - Solids
  - Liquids
  - Gases
- Whatever the form, matter is made up of chemical elements

Corrosion Chemistry: Elements

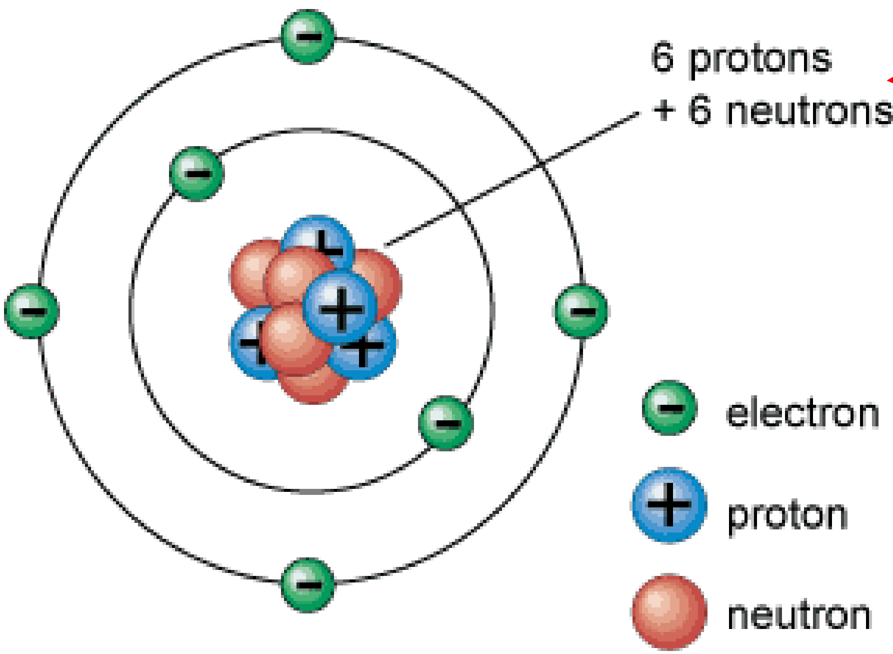
The Periodic Table

1 H																	2 He
3 Li	4 Be											5 B	6 C	7 N	8 O	9 F	10 Ne
11 Na	12 Mg											13 Al	14 Si	15 P	16 S	17 Cl	18 Ar
19 K	20 Ca	21 Sc	22 Ti	23 V	24 Cr	25 Mn	26 Fe	27 Co	28 Ni	29 Cu	30 Zn	31 Ga	32 Ge	33 As	34 Se	35 Br	36 Kr
37 Rb	38 Sr	39 Y	40 Zr	41 Nb	42 Mo	43 Tc	44 Ru	45 Rh	46 Pd	47 Ag	48 Cd	49 In	50 Sn	51 Sb	52 Te	53 I	54 Xe
55 Cs	56 Ba	57-71	72 Hf	73 Ta	74 W	75 Re	76 Os	77 Ir	78 Pt	79 Au	80 Hg	81 Tl	82 Pb	83 Bi	84 Po	85 At	86 Rn
87 Fr	88 Ra	89-103	104 Rf	105 Db	106 Sg	107 Bh	108 Hs	109 Mt	110 Ds	111 Rg	112 Cn	113 Nh	114 Fl	115 Mc	116 Lv	117 Ts	118 Og
		57 La	58 Ce	59 Pr	60 Nd	61 Pm	62 Sm	63 Eu	64 Gd	65 Tb	66 Dy	67 Ho	68 Er	69 Tm	70 Yb	71 Lu	
		89 Ac	90 Th	91 Pa	92 U	93 Np	94 Pu	95 Am	96 Cm	97 Bk	98 Cf	99 Es	100 Fm	101 Md	102 No	103 Lr	

Corrosion Chemistry: The Atom



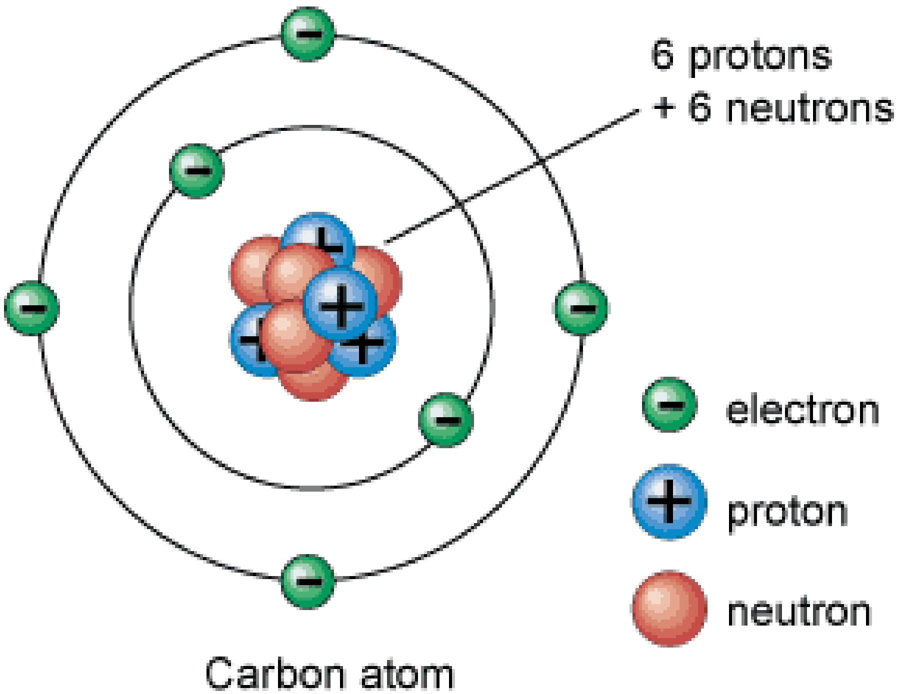
Corrosion Chemistry: The Atom



Carbon atom

	5 B	6 C	7 N	8 O
	13 Al	14 Si	15 P	16 S
30 Zn	31 Ga	32 Ge	33 As	34 Se
48 Cd	49 In	50 Sn	51 Sb	52 Te
80 Hg	81 Tl	82 Pb	83 Bi	84 Po

Corrosion Chemistry: The Atom



Protons (+) and Neutrons (no charge) make up the ***nucleus***.

Electrons (-) very light and orbit around the nucleus.

The number of positively-charged *protons* equals the number of negatively charged *electrons*.
Therefore, the atom has no net electrical charge.

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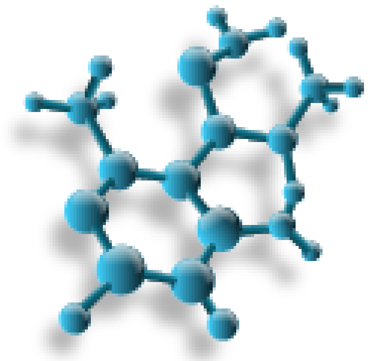
Corrosion Chemistry: Molecules and Compounds

- **Molecule** - combination of two or more atoms.
  - Molecules are held together by a force called chemical bonding.
  - Example;



(H_2)

Molecule Only

Hydrogen (H)

Hydrogen (H)

Corrosion Chemistry: Molecules and Compounds

- **Compound** - combination of two or more ***DIFFERENT*** atoms.

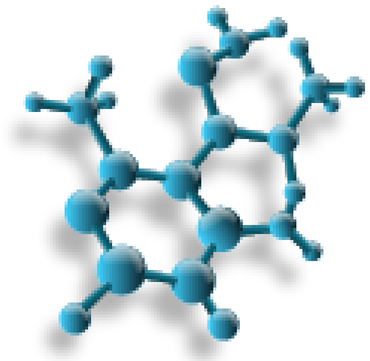
- Example;

Molecule and Compound

(H_2O)

Hydrogen (H)

Oxygen (O)



Corrosion Chemistry: Molecules and Compounds

Molecule / Compound: the smallest part of copper sulfate ($CuSO_4$)

($CuSO_4$)

Molecule and Compound

copper (Cu)

Sulphur (S)

oxygen (O)

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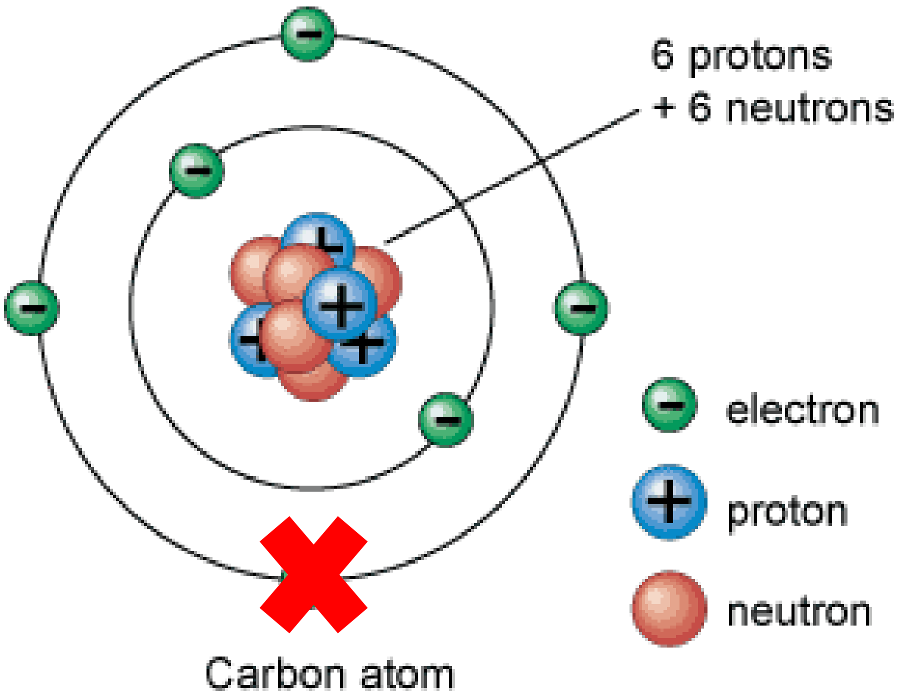
Corrosion Chemistry: Ions



- Ions form when atoms or molecules lose or gain electrons

- Electrically charged atoms are referred to as ***<u>ions</u>*.**

  - An atom that becomes an ion by **GAINING** electron(s) yields a negative charge – this is called an **anion**.
  - An atom that becomes an ion by LOSING electron(s) yields a positive charge – this is called a **cation**.

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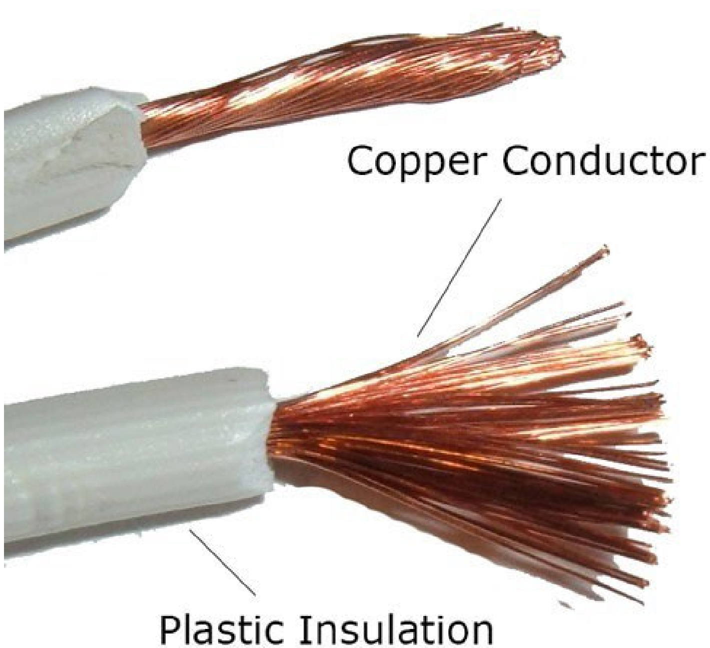
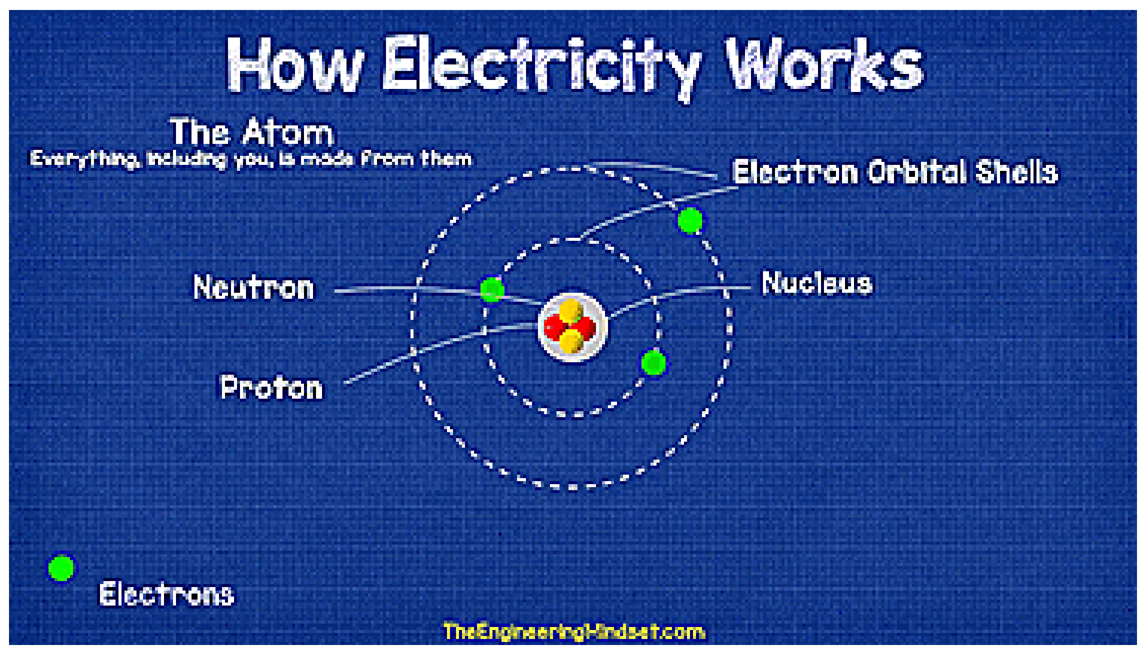
Corrosion Chemistry: Ions

Cations (+)	Anions (-)
Hydrogen ions – H^+	Hydroxyl ions – OH^-
Sodium ions – Na^+	Chloride ions – Cl^-
Calcium ions – Ca^{2+}	Fluoride ions – F^-
Ferrous ions – Fe^{2+}	Sulfate ions – SO_4^{2-}
Ferric ions – Fe^{3+}	Nitrate ions – NO_3 -
Aluminum ions – Al^{3+}	Phosphate ions – $PO_4$2-

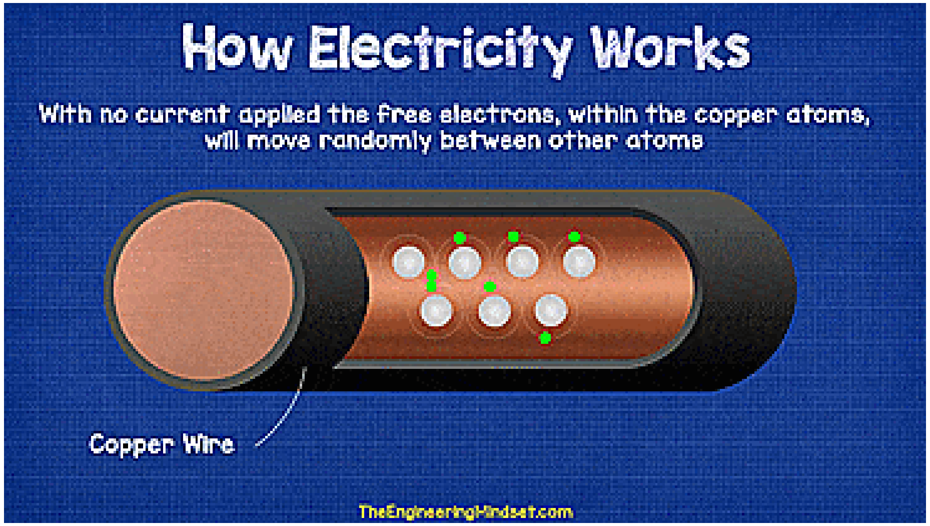
Corrosion Chemistry: Electron Movement

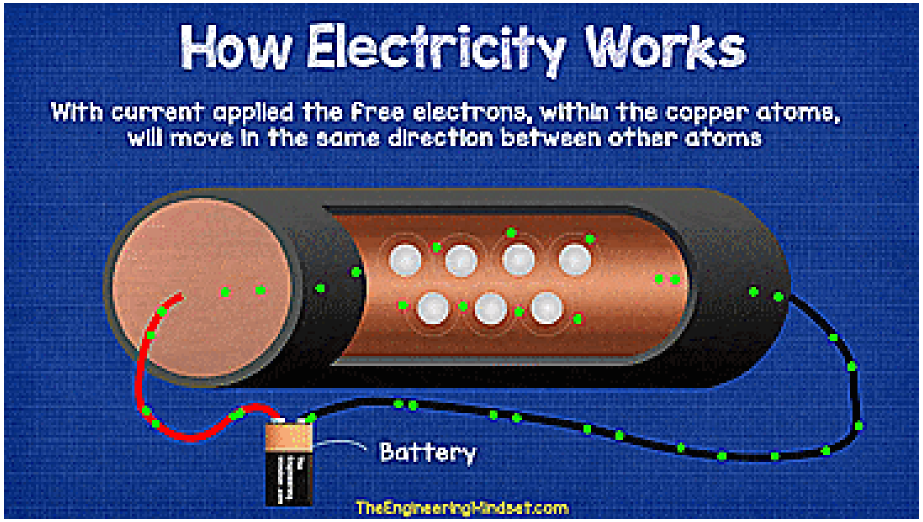
- Some materials can pass electrons between atoms
- Materials that can pass electrons are called *conductors*
- Most metals are conductors
- Atoms which do NOT pass electrons are known as insulators
- Insulator examples; Rubber and Glass





Corrosion Chemistry: Electron Movement





Electricity through a solid conductor is the flow, or movement, of electrons!

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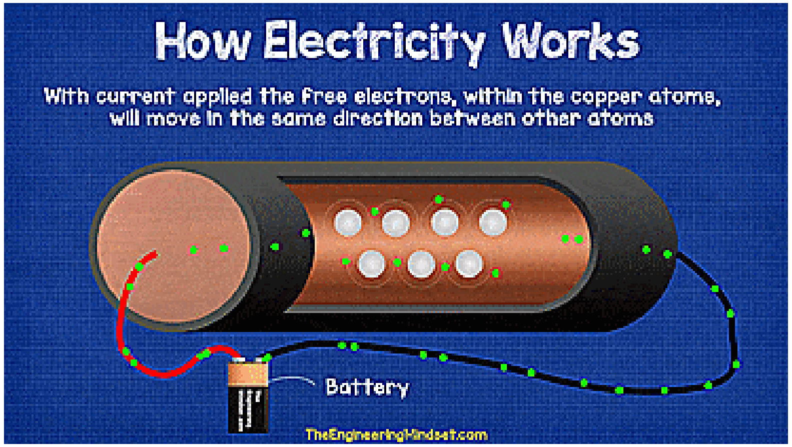
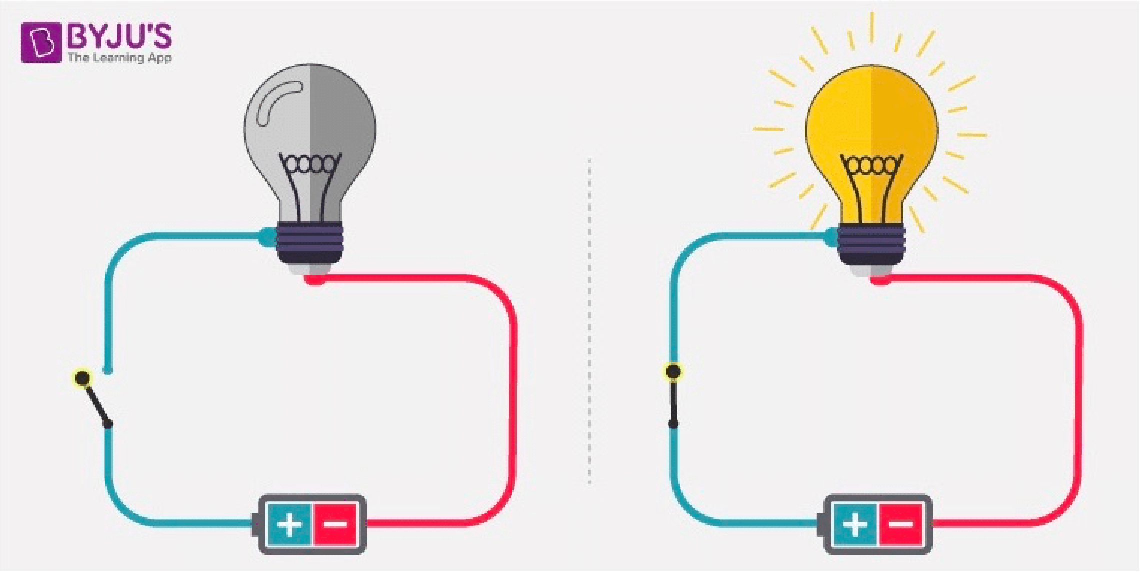
Corrosion Chemistry: Completed Circuit

- For movement of charge, the circuit needs to be complete.

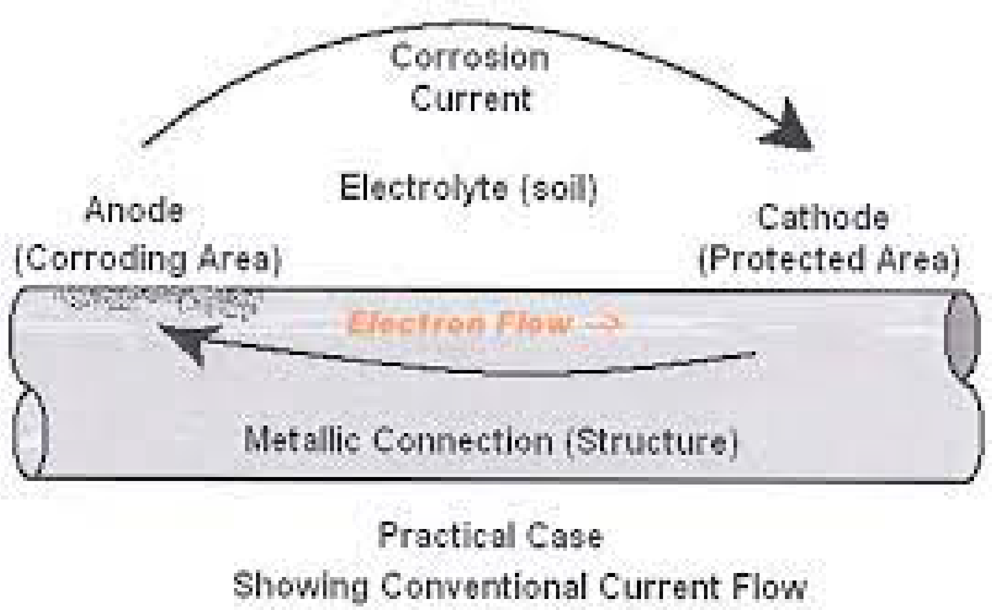


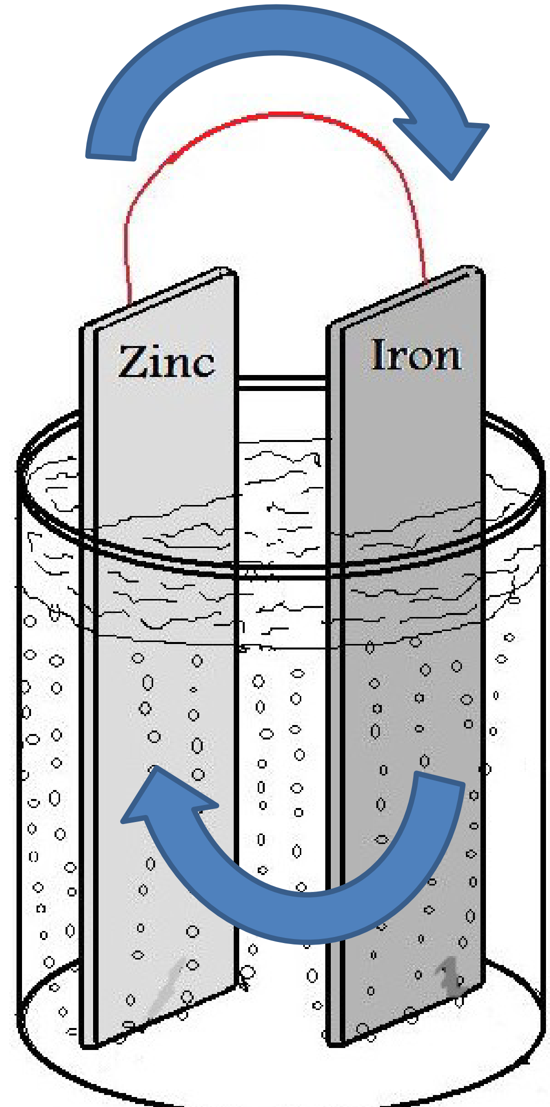


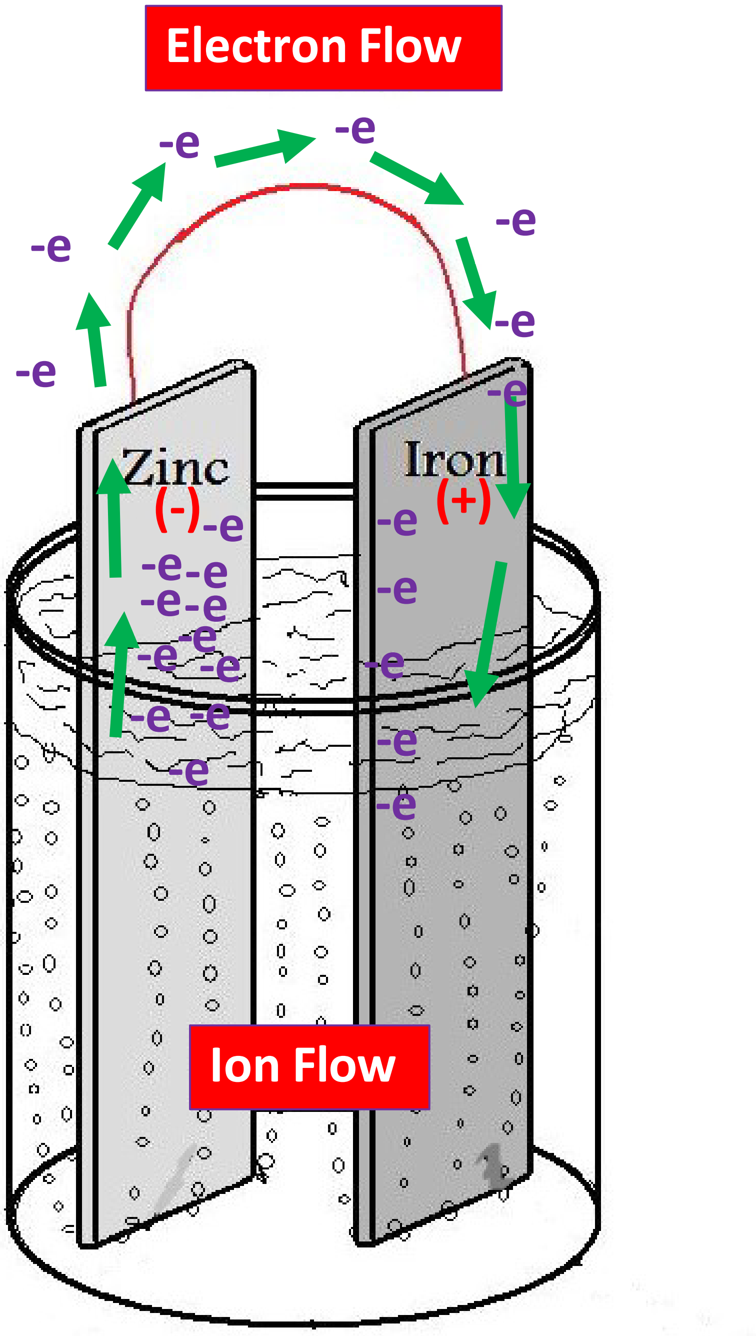
Corrosion Chemistry: Electron and Ion Movement

<u>Corrosion Cell</u>

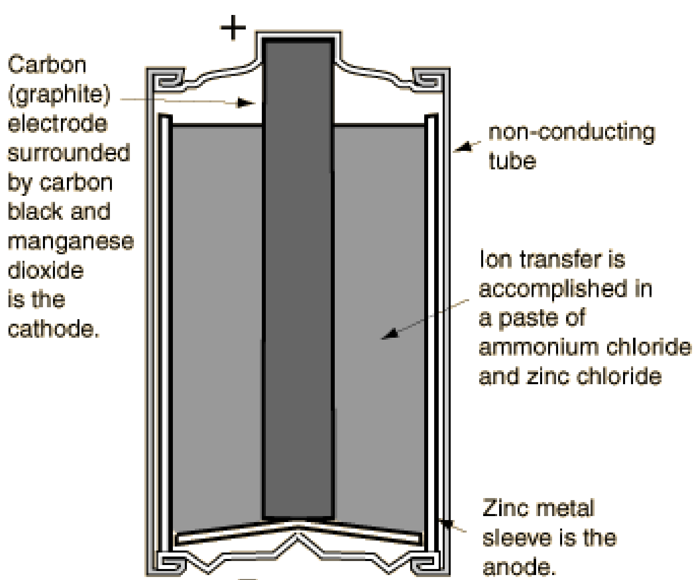
1. Anode
2. Cathode
3. Metallic Path
4. Electrolyte

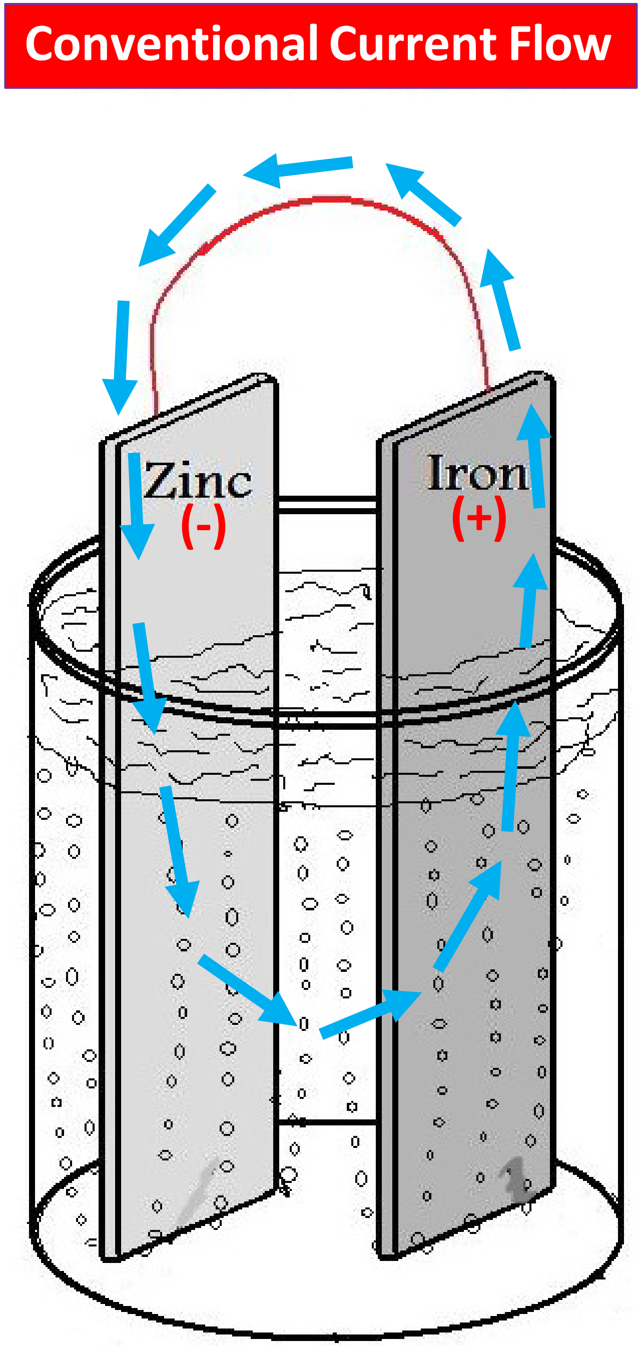





Electron Flow
-e
Zinc
(-)
Iron
(+)
Ion Flow

- Conventional current Flow - is the flow of current from positive to negative in an electrical circuit.
- In a circuit, the current must *return to the original source.*
- Electromotive Force is the potential difference between the two structures.
- Flows in the opposite direction of the movement of electrons

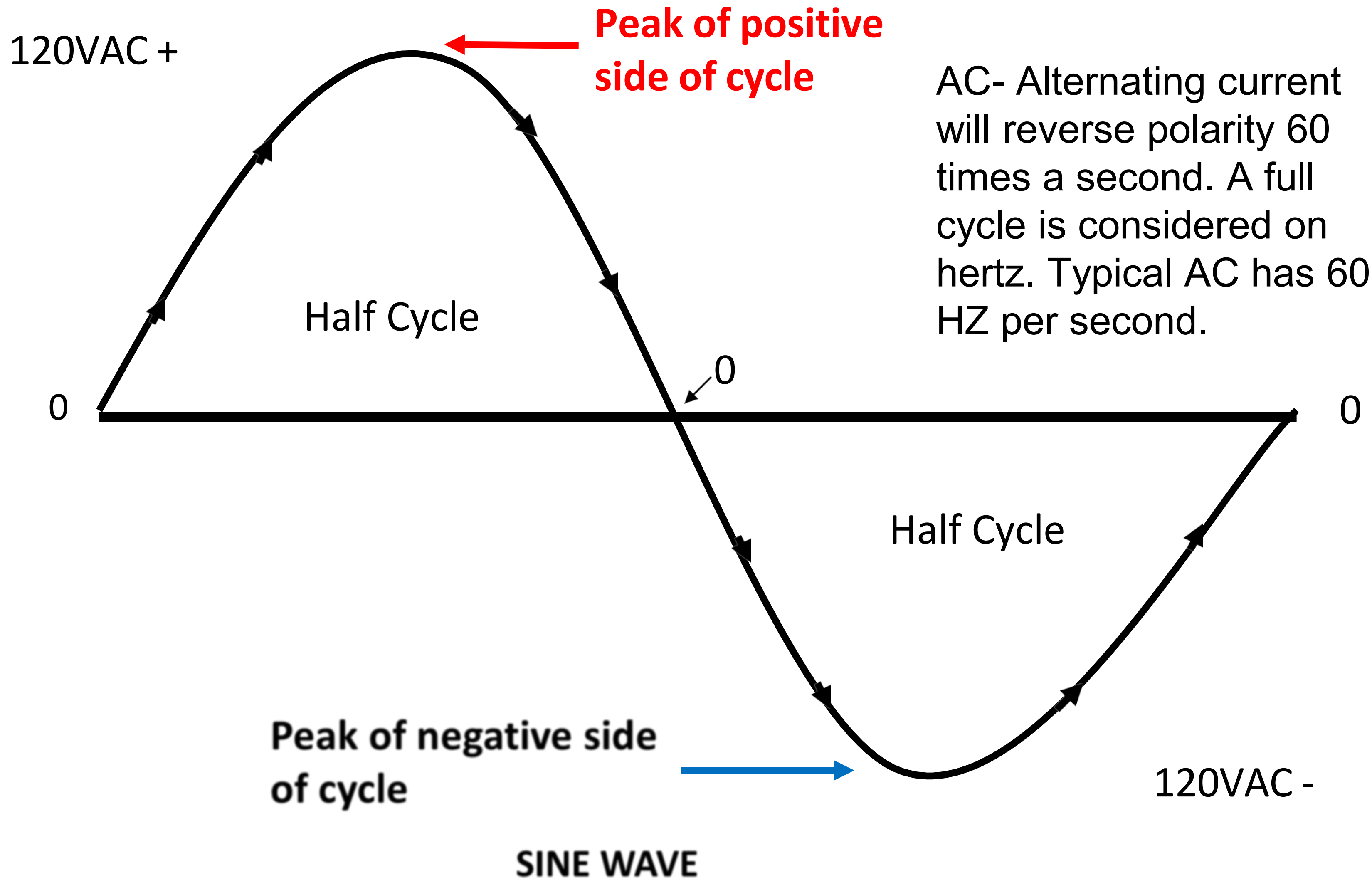




Electricity

- Two types of electricity
  - Alternating Current (AC)
  - Direct Current (DC)

Alternating Current (AC)



AC- Alternating current will reverse polarity 60 times a second. A full cycle is considered on hertz. Typical AC has 60 HZ per second.

Alternating Currents (AC)

- Current flows first in one direction then in the opposite direction in accord with an established pattern
- Hertz – is a single cycle of the produced wave form
- Alternating current, in the US, has a frequency of 60 cycles per second, referred to as 60 Hertz (or 60 Hz)

Significance of Alternating Current

- AC is a relatively insignificant factor as a cause of corrosion except in very special cases

- AC is used for a power source for Cathodic Protection such as rectifiers (which converts AC power to DC power)

Direct Current (DC)

- Flows in one direction
  - Examples
    - Flash light battery
    - Car battery

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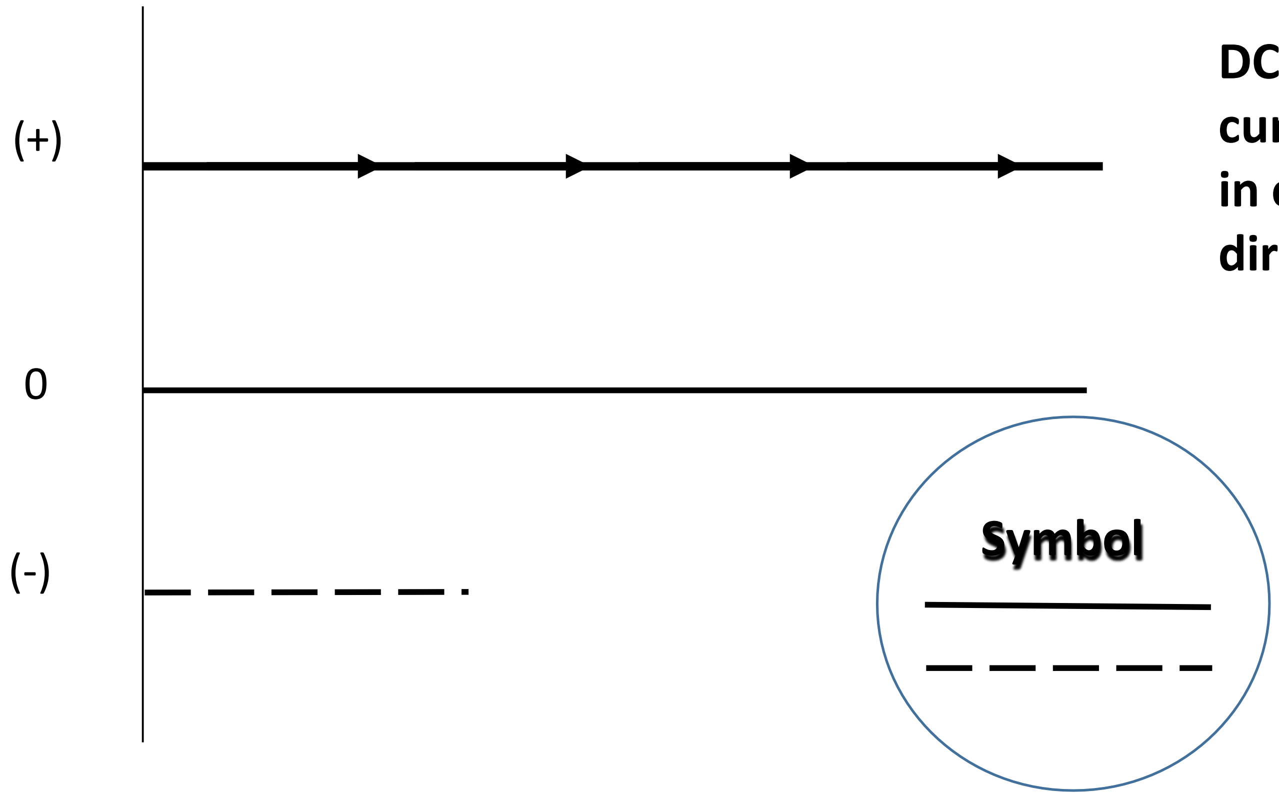
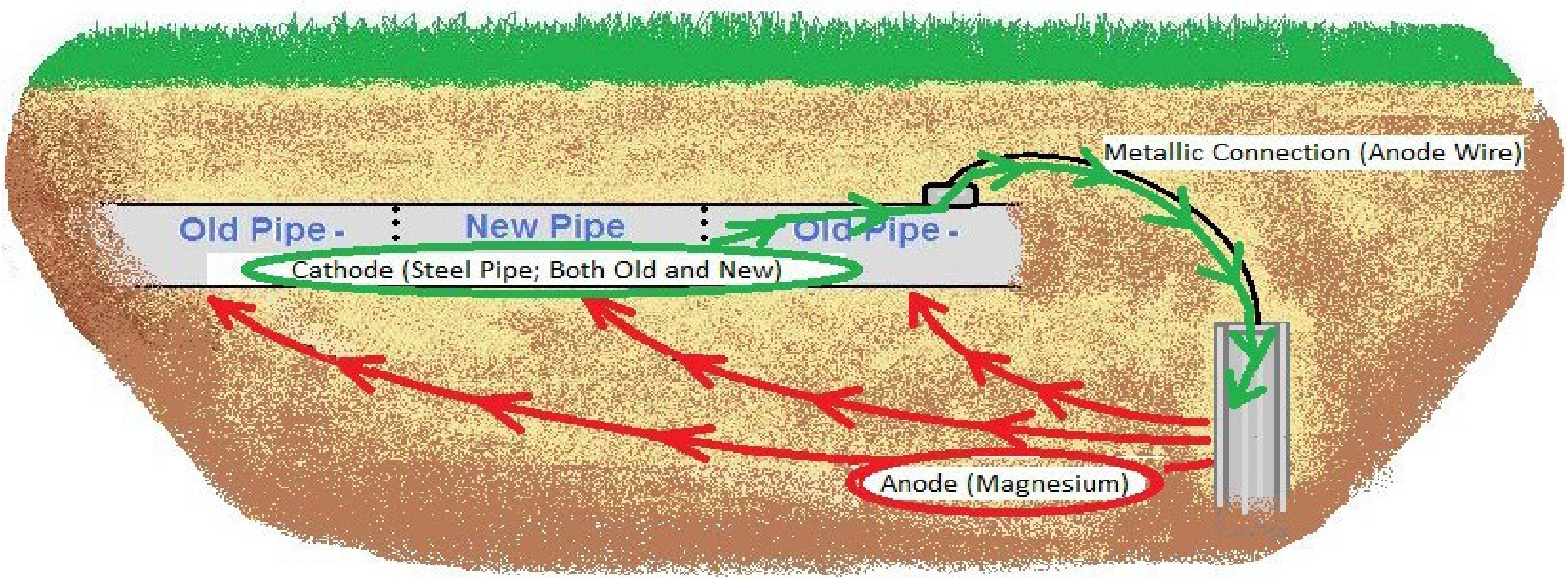
Direct Current (DC)



DC - direct current flows in one direction

Significance of Direct Current

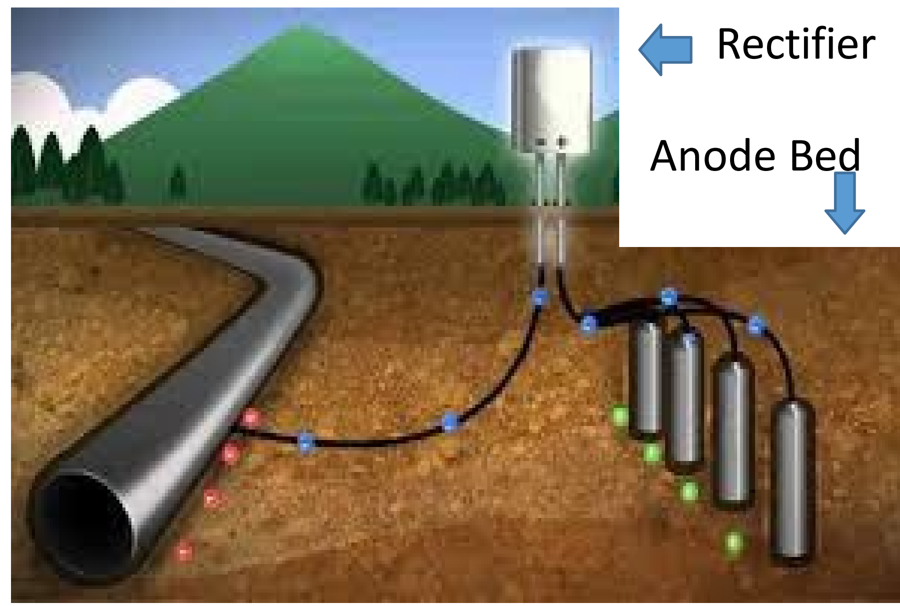
- DC current is very important in the corrosion process
  - Involved in various types of corrosion cells
  - Involved in corrosion control – especially in cathodic protection



Transformer Rectifier

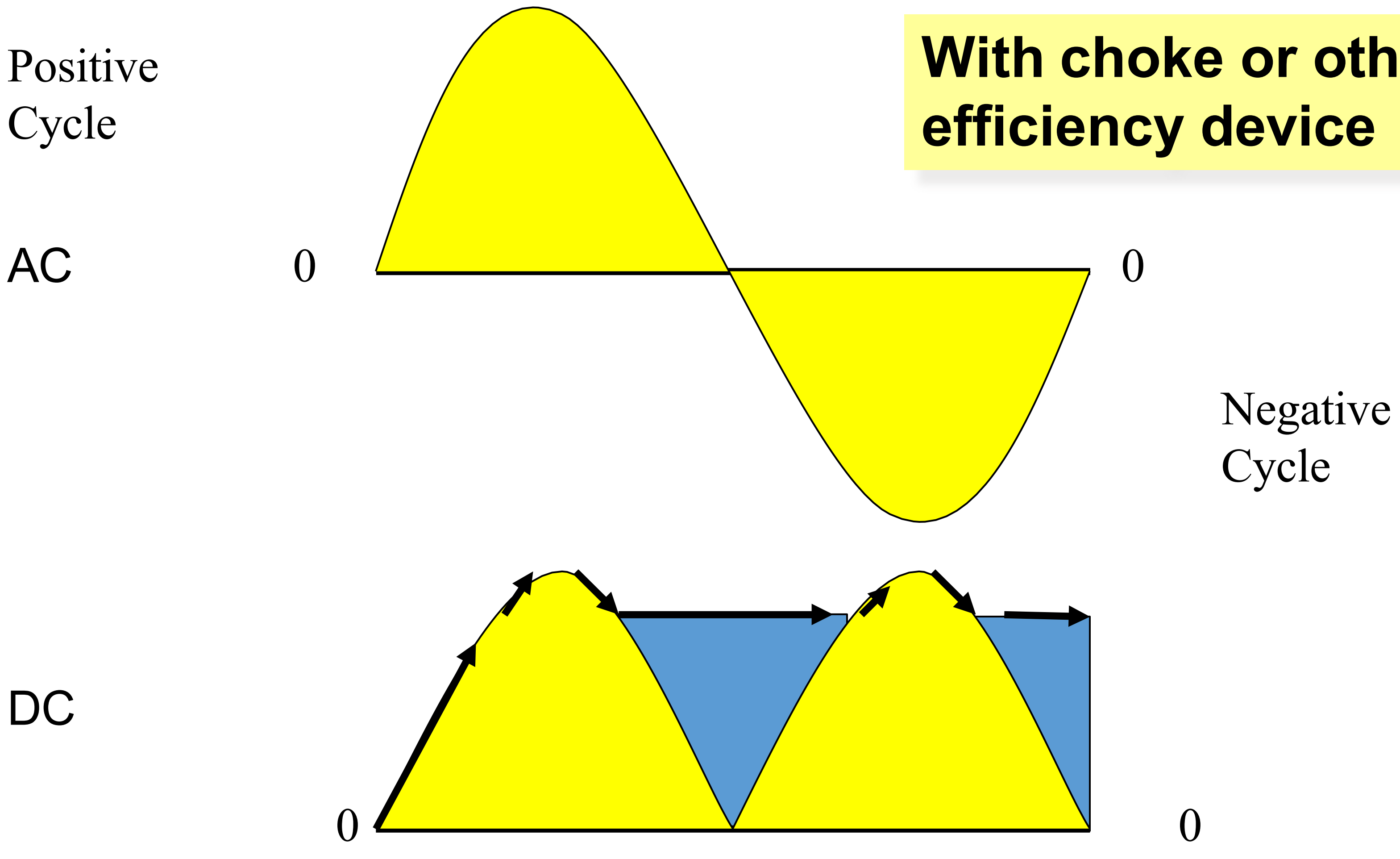
Steps down AC voltage and

Converts AC to DC



Electrical Rectification

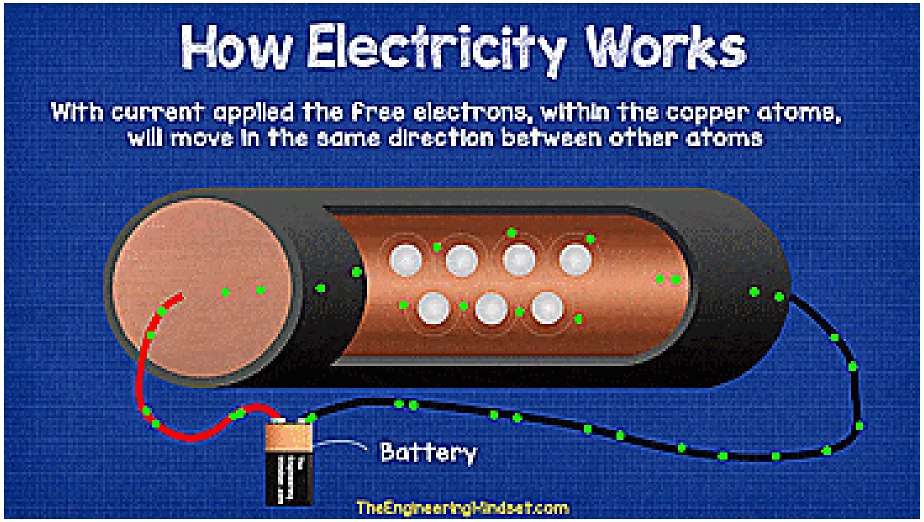
With choke or other efficiency device



Basic Electricity Terms

- Electrical Circuits
  - Voltage – Volts (V)
  - Current – Amps (A)
  - Resistance – Ohms (R or Ω)
- Other Related Electrical Terms
  - Conductivity
  - Resistivity
  - Impedance
  - Power

Electrical Circuits & Voltage



Voltage:

- pushing <u>force</u> of electrons within a circuit
- Electrical <u>pressure</u>
- More pressure (Voltage) = More electron flow
- Measured in Volts- commonly represented with a (V or E)

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Voltage

- Although 1 volt is the basic unit, there are instances where much smaller units are used in Corrosion work.

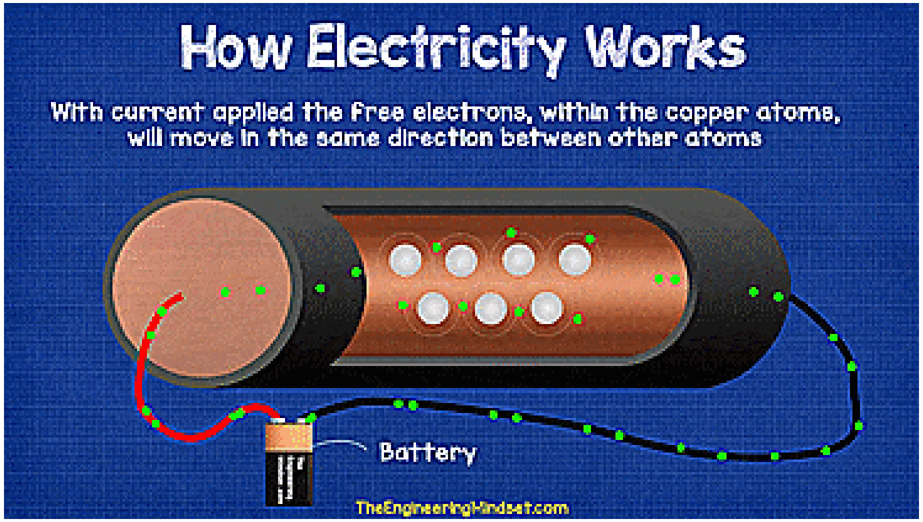
•	1.000 volts	=	1000 millivolts
•	0.100 volts	=	100 millivolts
•	0.010 volts	=	10 millivolts
•	0.001 volts	=	1 millivolt
•	0.000001 volts	=	1 microvolt

Voltage

- **DC voltage sources used to provide cathodic protection current:**

  - **Galvanic anodes**
    - **Zinc**
    - **Aluminum**
    - **Magnesium**
  - **Driving voltage of anodes may be measured in tenths of a volt or in millivolts.**
  - **Higher capacity sources such as AC to DC rectifiers or DC generators of various types**

Electrical Circuits & Current Flow



***Current*:**

- **Flow of charge through a conductor (electron flow)**
- **More pressure (Voltage) = FASTER electron flow**
- **Measured in Amperes (Amps)- commonly represented with an (I)**

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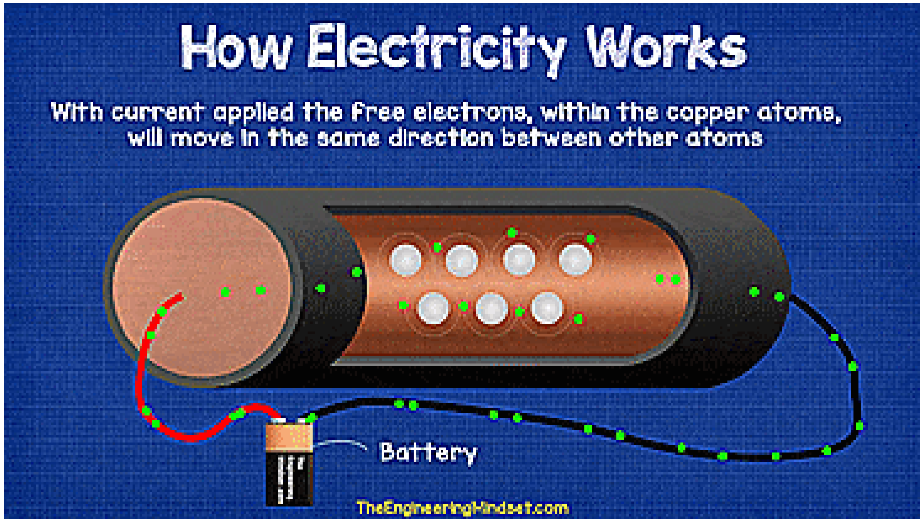
Current Flow

- Although one ampere or amp is the basic unit, there are instances where much smaller units are used.

1.000 ampere	=	1000 milliamperes
0.100 ampere	=	100 milliamperes
0.010 ampere	=	10 milliamperes
0.001 ampere	=	1 milliampere
0.000001 ampere	=	1 microampere

Electrical Circuits & Resistance



Resistance:

- Resisting the flow of electrons
- More resistance = LOWER flow of electrons
- Measured in Ohms (Ω)- commonly represented with an (R)

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Resistance

- Although One ohm (R) is the basic unit of resistance. Other units may also be involved in corrosion work

10,000,000 Ohms	=	10 Megaohms
1,000,000 Ohms	=	1 Megaohms
10,000 Ohms	=	10 kiloohms
1,000 Ohms	=	1 kiloohms
1 Ohms	=	1000 milliohms
0.1 Ohms	=	100 milliohms
0.01 Ohms	=	10 milliohms

Resistance: Material, Temperature, and Size Does Matter

Size

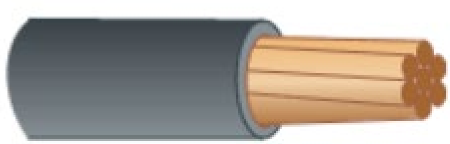
Length

Short; Less Resistance

Long; More Resistance

Thickness

Thin; More Resistance



Thick; Less Resistance

Temperature

40° F; Less Resistance

200° F; More Resistance

Material

Copper; Less Resistance

Aluminum; More Resistance

Resistivity

- ***resistivity*** is used to indicate the characteristic ability of a material to conduct electricity.
- ***resistivity*** is resistance along a unit distance.
- The symbol used for resistivity is ρ (Greek letter rho).
- Measured in *ohm-centimeter* (Ω-cm).

Resistance to current flow is lowest when:

- Low resistivity (high-conductivity) media
- Short length for current flow to travel
- Large area of current flow

Resistance to current flow is highest when:

- High-resistivity (low-conductivity) media
- Long path for current flow to travel
- Small cross-sectional area of current flow

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Conductivity

- Is the **inverse** (opposite) of resistivity.
- Conductivity is the ability to conduct a flow of current
- Measured in Siemens per meter (S/m)
- Different materials have different values of conductance.

<u>Current conducting capability</u>

(based on Copper being 100%)

Copper -	100%
Aluminum -	60%
Magnesium -	36.8%
Zinc -	27.6%
Brass -	24.6%
Steel -	9.6%
Lead -	8.0%

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Additional concepts

Impedance

- Impedance is the total opposition that a circuit presents to alternating current, similar to resistance in a direct current circuit.
- Impedance is measured in ohms, as is DC resistance.

Power

- Power is the energy used by an electrical device.
- Power is measured in watts or wattage.

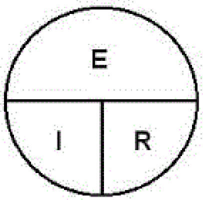
Ohm's Law

Ohm's Law

- **Voltage is measured in Volts, with one volt being defined as the electrical pressure required to force an electrical current of one ampere through a resistance of one Ohm.**

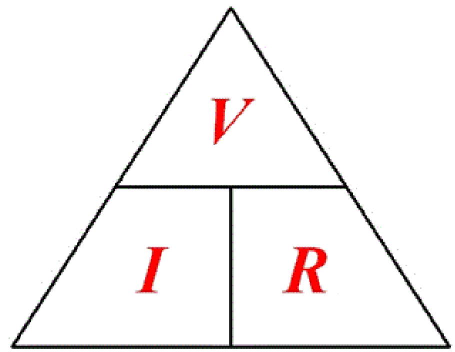
- **With a fixed driving voltage applied to an electrical circuit**
  - **The amount of current flowing through the circuit <u>decreases</u> as the circuit resistance <u>increases</u>**
  - **The amount of current flowing through the circuit <u>increases</u> as the circuit resistance <u>decreases</u>**

Ohms Law is E= IR

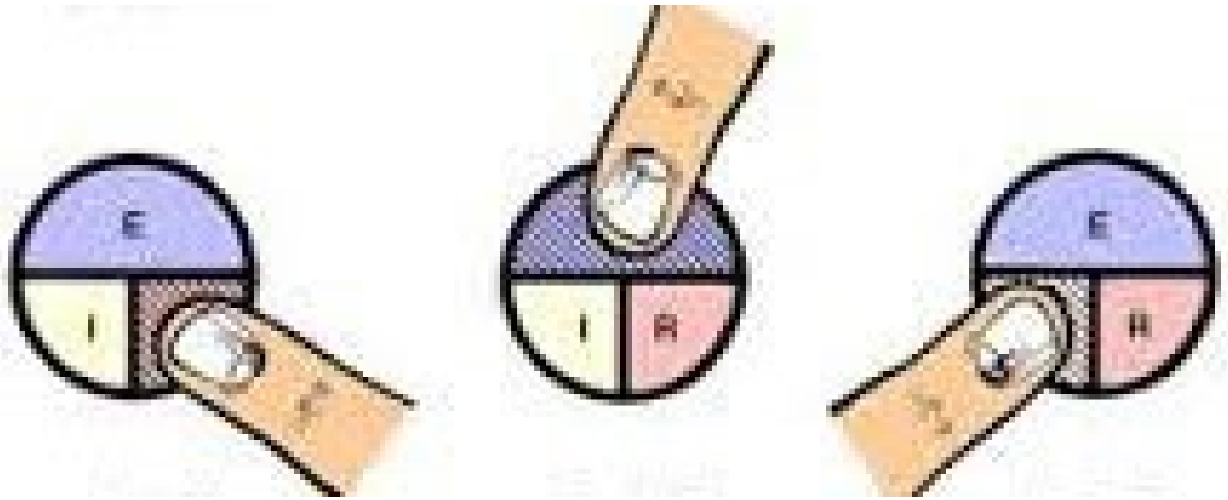


E = Volts
I = Amps
R = Resistance

$$V = I\,R$$

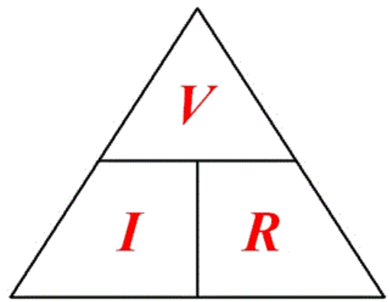


$$I = \frac{V}{R} \qquad R = \frac{V}{I}$$



Example of Consistency: Same Units of Measure

$$V = I\,R$$



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

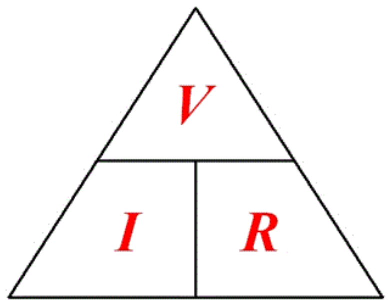
Volts (V) = ? V
Resistance (Ω) = 3.5 Ω
Current (I) = 3.42 A

$$V = I\ x\ R$$

$$V = 12\ V$$

Example of Consistency: Same Units of Measure

$$V = I\,R$$



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

Volts (V) = ? V
Resistance (Ω) = 3.5 Ω
Current (I) = 3420 mA

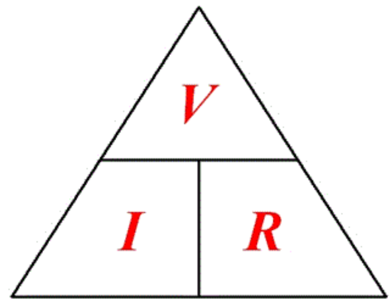
$$V = I\ x\ R$$
$$V = 3420\ mA\ x\ 3.5\ \Omega$$
$$V = 11970\ V$$

$$V = 3420\ \cancel{mA}\ x\ 3.5\ \Omega$$
$$V = 3.420\ A\ x\ 3.5\ \Omega$$
$$V = 12\ V$$

- **1 Volt = 1000 millivolts**

Example of Consistency: Same Units of Measure

$$V = I\,R$$



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

Volts (V) = 4000 mV
Resistance (Ω) = 3.5 Ω
Current (I) = ?

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

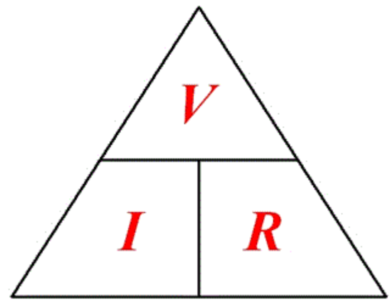
$$I = \frac{4000mV}{3.5\ \Omega}$$

$$I = 1142.8\ A$$

INCORRECT!!!!

Example of Consistency: Same Units of Measure

$$V = I\,R$$



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

Volts (V) = 4000 mV
Resistance (Ω) = 3.5 Ω
Current (I) = ?

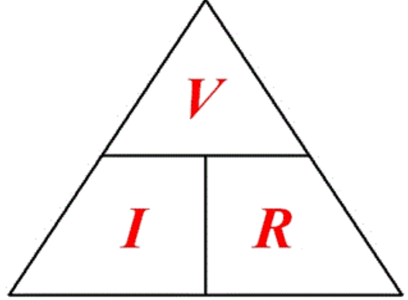
$$I = \frac{mV}{R}$$

$$I = \frac{4V}{3.5\ \Omega}$$

$$I = 1.14\ A$$

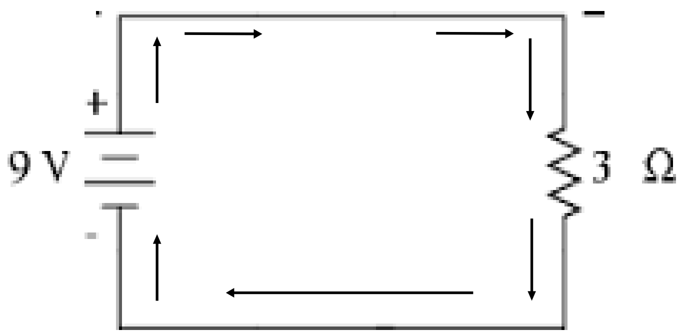
CORRECT!!!!

- **1 ampere = 1000 milliamperes**

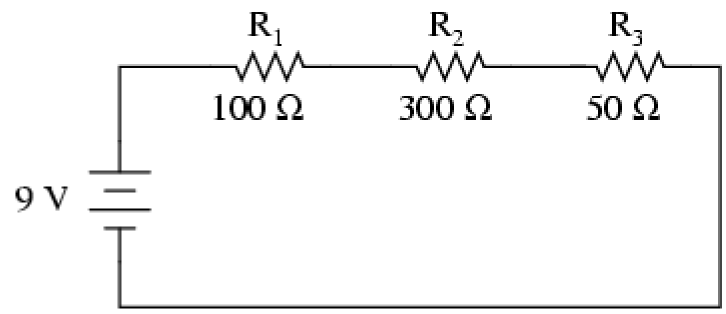


Volts = 16 V Resistance = 3.5 Ω Current = ? A	$I = \frac{V}{R}$	$I = 4.57\ A$
Volts = 6 V Resistance = ? Ω Current = 1.5 A	$R = \frac{V}{I}$	$R = 4\ \Omega$
Volts = ? V Resistance = 5 Ω Current = .4 A	$V = I\ X\ R$	$V = 2\ V$
Volts = 2 mV Resistance = .04 Ω Current = ? A	$I = \frac{V}{R}$	$I = .05\ A$
Volts = 2 V Resistance = ? Ω Current = 54 mA	$R = \frac{V}{I}$	$R = 37.04\ \Omega$

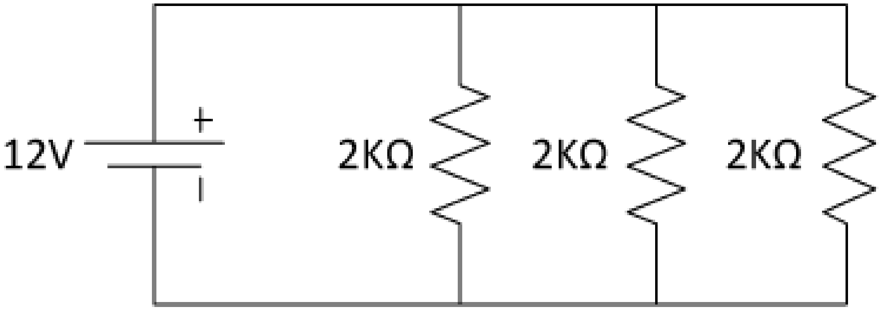
Ohms Law



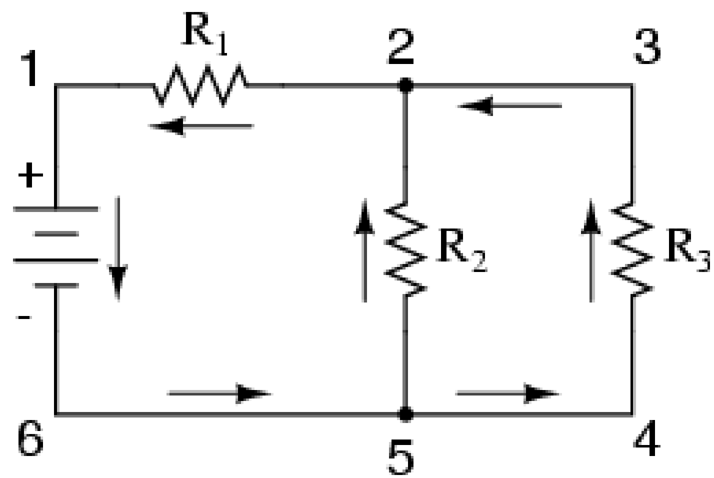
Basic Circuit



Series Circuit

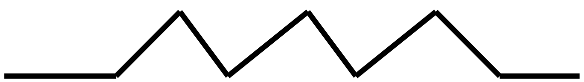


Parallel Circuit

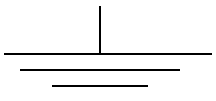


Series-Parallel Circuit

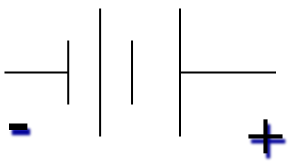
Components / Schematic Symbols



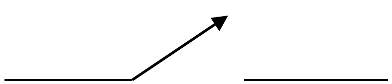
Resistor



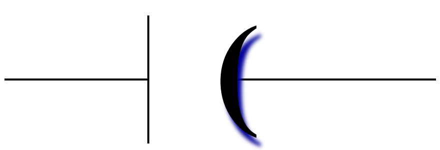
Ground



Battery or Power source

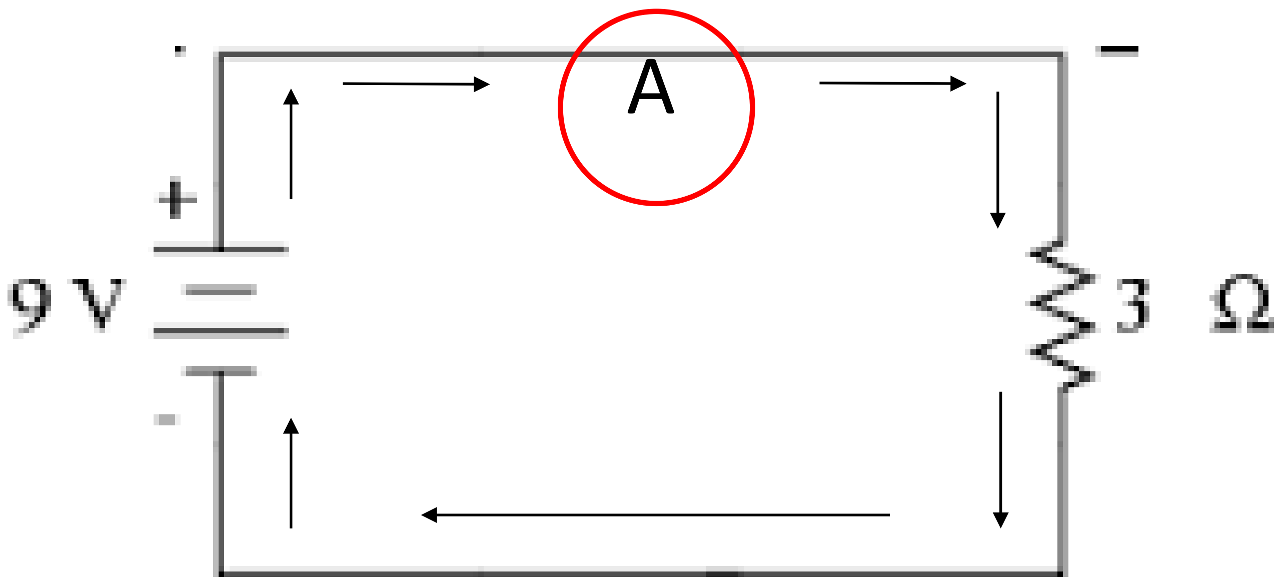


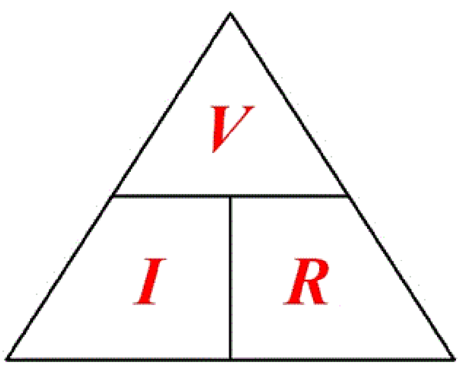
Switch



Capacitor

Basic Circuit





Volts = 9 V

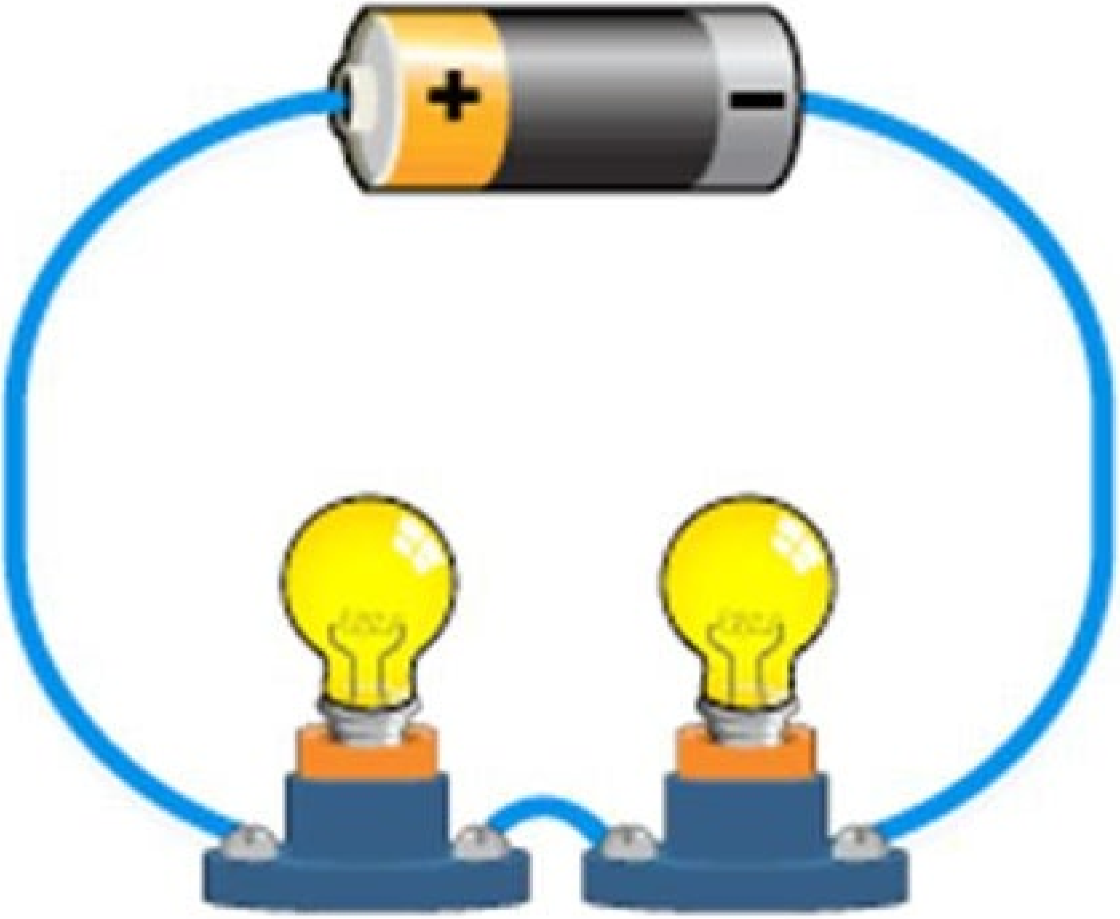
Resistance = 3 Ω

Current = ? A

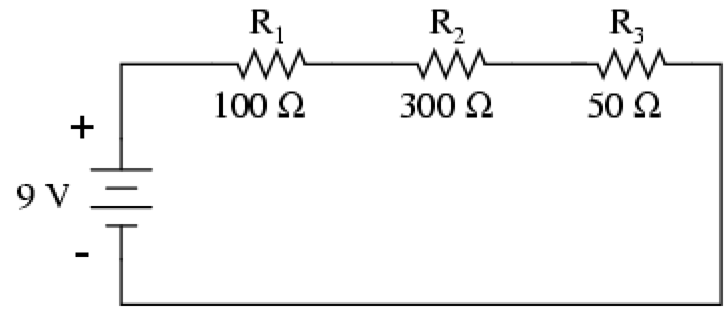
$$I = \frac{V}{R}$$

Answer = 3A

Series Circuits



Series Circuit



Property	Series Circuit
Current	Current is the same everywhere $I_T = I_1 = I_2 = I_3$
Resistance	Total resistance is additive $R_T = R_1 + R_2 + R_3$
Voltage	Voltage Drops may be different depending on the values of each resistance, but the sum of the voltage drops (V_T or E_T) must add up to the voltage of the source (Kirchoff's Voltage Law) $V_T = V_1 + V_2 + V_3$
Kirchoff's Law	**Voltage Law:** The sum of the source voltages around any circuit equals the sum of the voltage drops across the resistances in the circuit

Property	Series Circuit
Current	$I_T = I_1 = I_2 = I_3$
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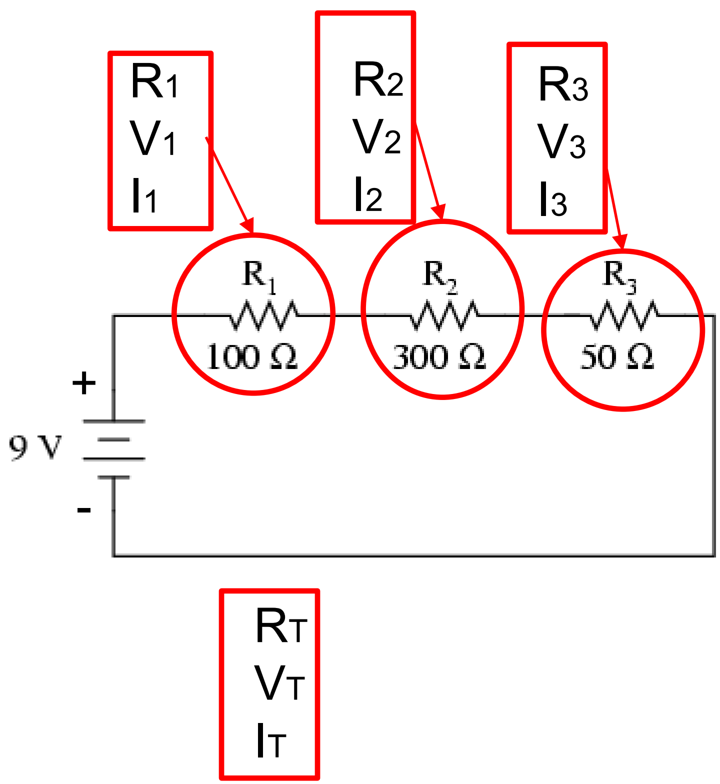
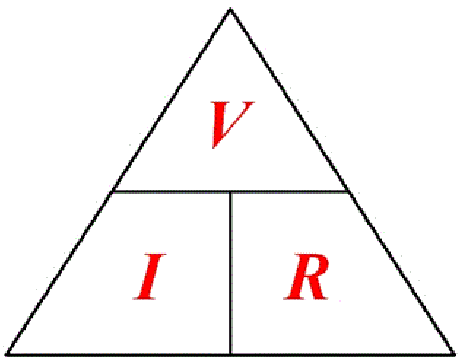


1. Series or Parallel?
2. Build a Chart
3. Fill in what you are given/fill in quick grabs
4. Calculate the rest using Ohm's Law

Resistor	V	I	R
1	2 V	.02 A	100 Ω
2	6 V	.02 A	300 Ω
3	1 V	.02 A	50 Ω
Total	9 V	.02 A	450 Ω

Property	Series Circuit
Current	$I_T = I_1 = I_2 = I_3$
Resistance	$R_T = R_1 + R_2 + R_3$
Voltage	$V_T = V_1 + V_2 + V_3$
Kirchoff's Law	**Voltage Law:** The sum of the source voltages around any circuit equals the sum of the voltage drops across the resistances in the circuit



1. Series or Parallel?
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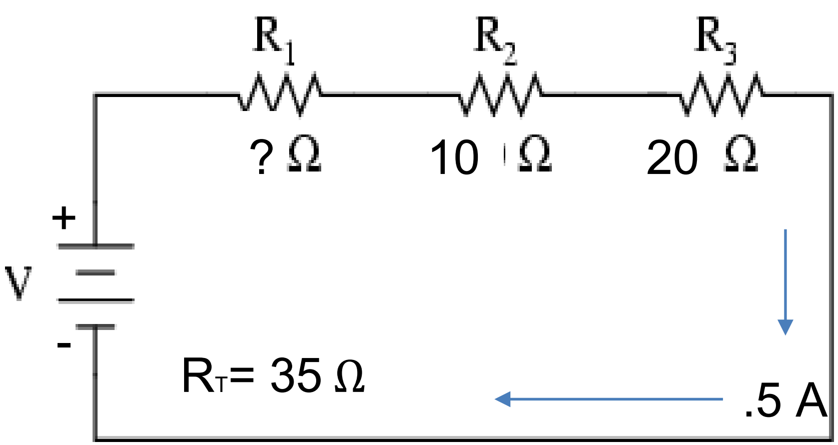
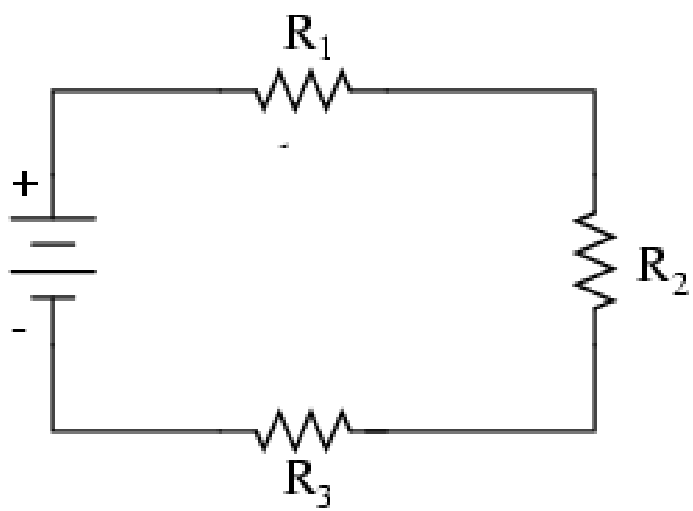
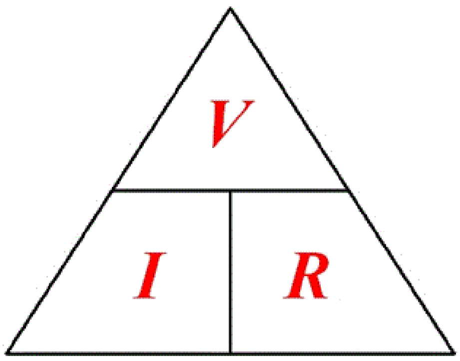


Resistor	V	I	R
1	2.5 V	.5 A	5 Ω
2	5 V	.5 A	10 Ω
3	10 V	.5 A	20 Ω
Total	17.5 V	.5 A	35 Ω

Series Circuit

$R_T = 100\ \Omega$
$E_T = 10$ v
$V_1 = 2$ v
$V_2 = 5$ v





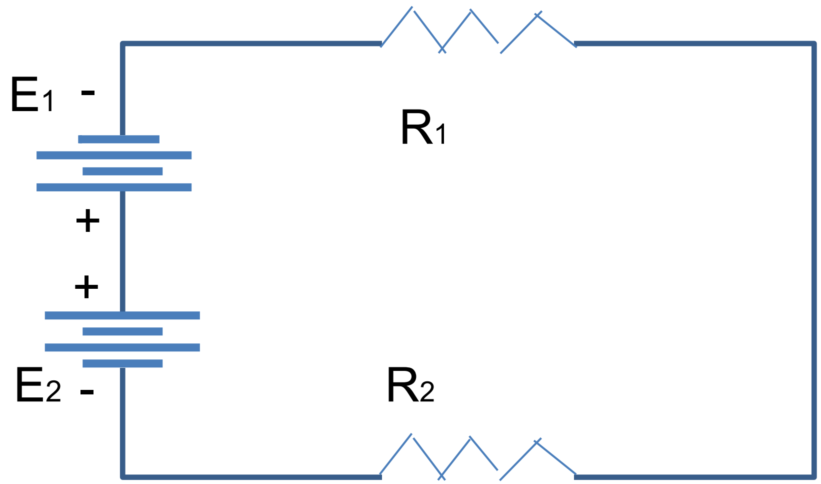
V_3 = 3 V
R_1 = 20 Ω
R_2 = 50 Ω
R_3 = 30 Ω
I_T = .1 A

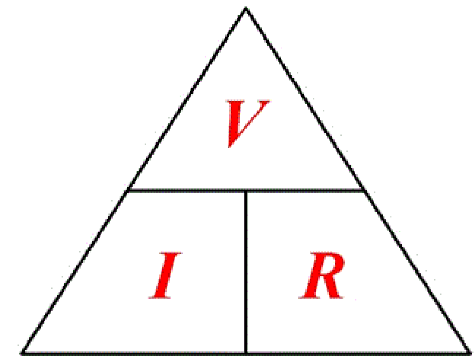
Resistor	V	I	R
1	2 V	.1 A	20 Ω
2	5 V	.1 A	50 Ω
3	3 V	.1 A	30 Ω
Total	10 V	.1 A	100 Ω

Series Circuit

E_1= <u>8V</u>
E_2= <u>4V</u>
R_1= <u>2 Ω</u>
R_2= <u>4 Ω</u>

I_T = <u>0.67A</u>
V_1 = <u>1.34 V</u>
V_2 = <u>2.68V</u>
R_T = <u>6 Ω</u>





Which Direction?

<u>Counter-Clockwise</u>

Resistor	V	I	R
1	1.34 V	0.67 A	2 Ω
2	2.68 V	0.67 A	4 Ω
Total	4 V	0.67 A	6 Ω

Series Circuit

Property	Series Circuit
Current	Current is the same everywhere $I_T = I_1 = I_2 = I_3$
Resistance	Total resistance is additive $R_T = R_1 + R_2 + R_3$
Voltage	Voltage Drops may be different depending on the values of each resistance, but the sum of the voltage drops (V_T or E_T) must add up to the voltage of the source (Kirchoff's Voltage Law) $V_T = V_1 + V_2 + V_3$
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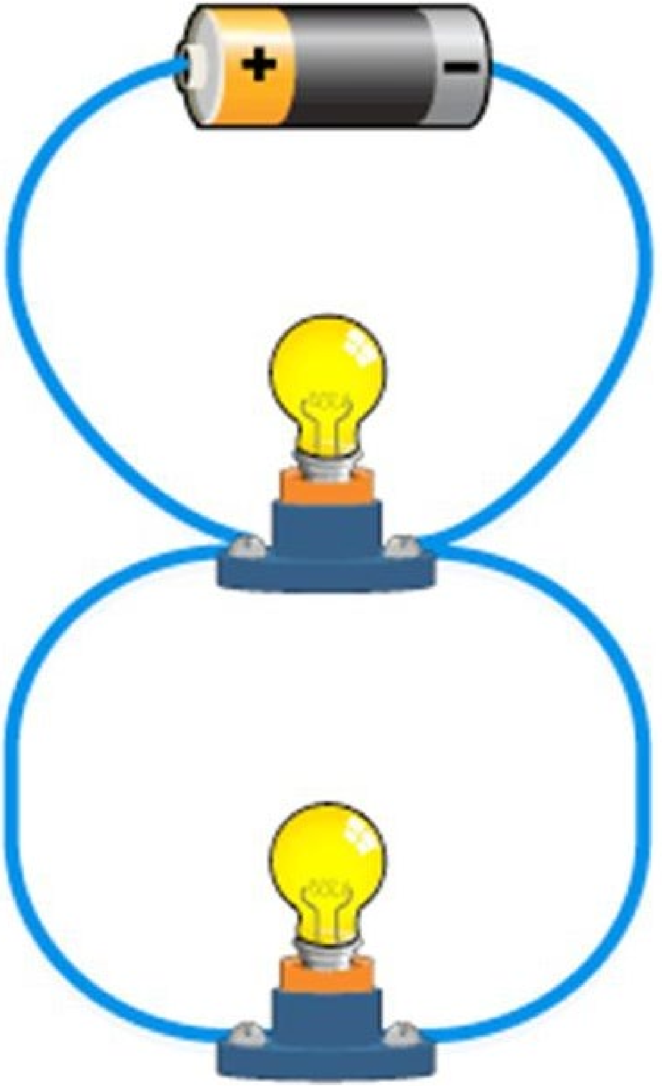
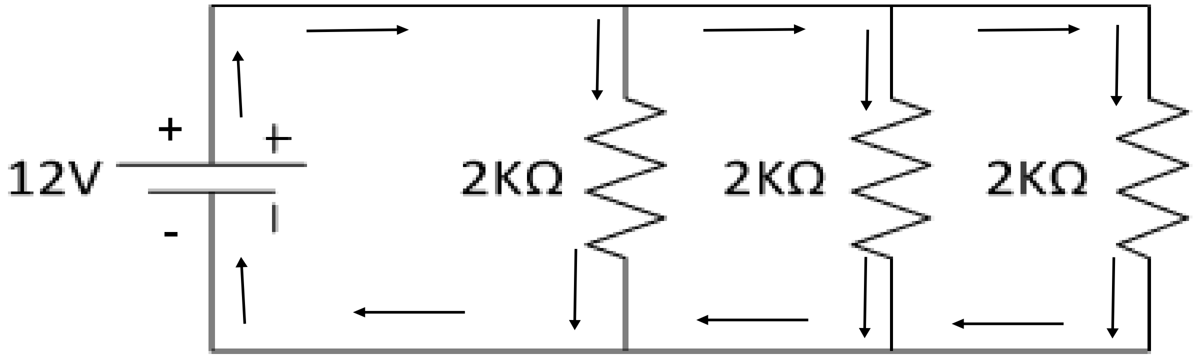
Parallel Circuits

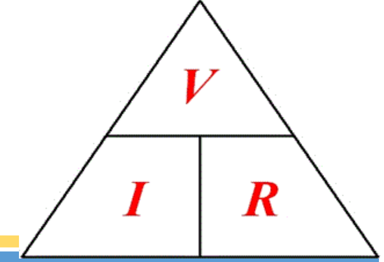


Parallel Circuits



Property	Parallel Circuit
Current	Total current flowing into and out of the junction point of the branches equals the sum of branch currents (Kirchhoff's Current Law). $I_T = I_1 + I_2 + I_3$
Resistance	Total resistance is always less than the smallest resistance in the circuit. $R_T = \frac{1}{1/R_1 + 1/R_2 + 1/R_3}$
Voltage	Voltage drop across each branch is the same and is equal to source voltage. $V_T = V_1 = V_2 = V_3$
Kirchoff's Law	**Current Law:** The law states that as much current flows away from a point as flows toward it. (Parallel Circuit)

Parallel Circuit



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Current	Total current flowing into and out of the junction point of the branches equals the sum of branch currents (Kirchhoff's Current Law). $I_T = I_1 + I_2 + I_3$
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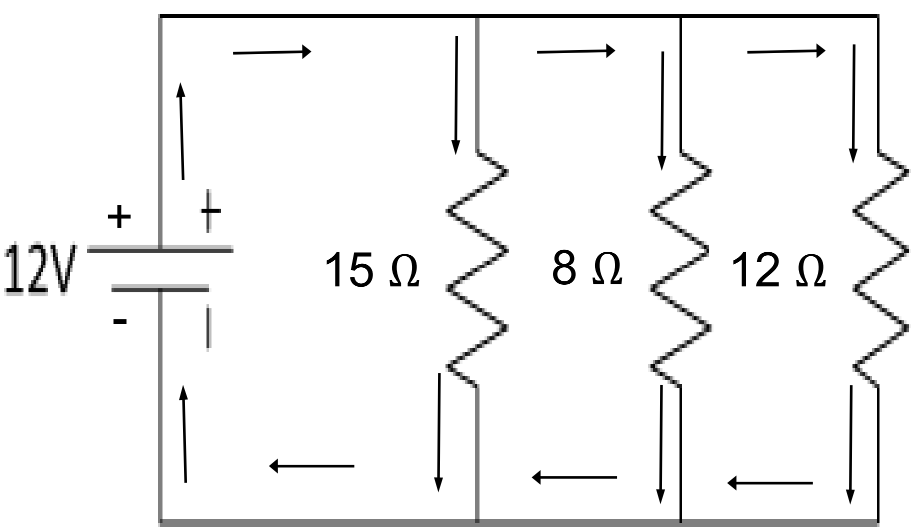
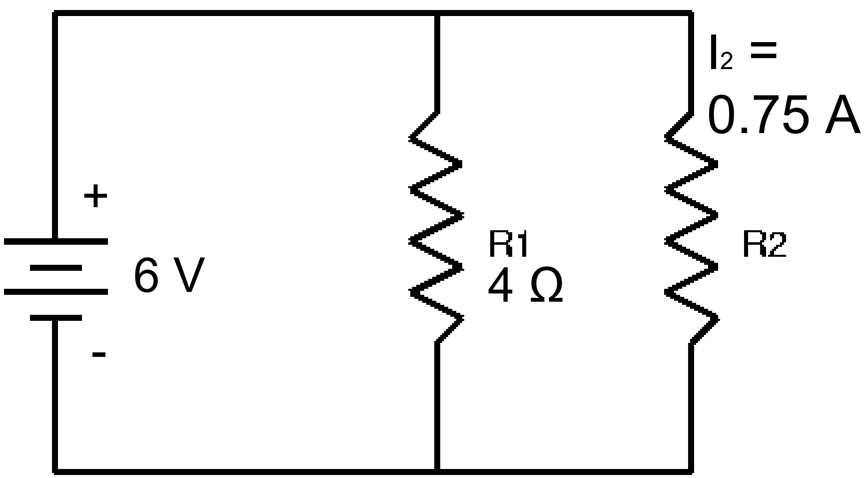


Resistor	V	I	R
1	12 V	0.8 A	15 Ω
2	12 V	1.5 A	8 Ω
3	12 V	1 A	12 Ω
Total	12V	3.3 A	3.64 Ω

Parallel Circuit

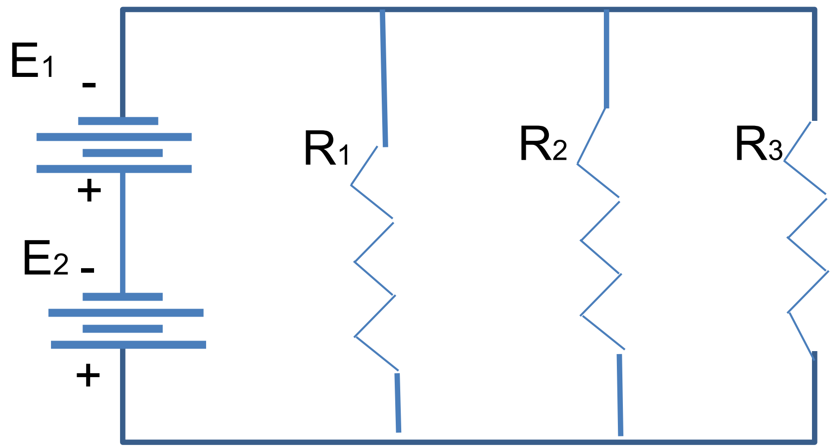
Property	Parallel Circuit
Current	Total current flowing into and out of the junction point of the branches equals the sum of branch currents (Kirchhoff's Current Law). $I_T = I_1 + I_2 + I_3$
Resistance	Total resistance is always less than the smallest resistance in the circuit. $$R_T = \frac{1}{1/R_1 + 1/R_2 + 1/R_3}$$
Voltage	$V_T = V_1 = V_2 = V_3$
Kirchoff's Law	**Current Law:** The law states that as much current flows away from a point as flows toward it. (Parallel Circuit)

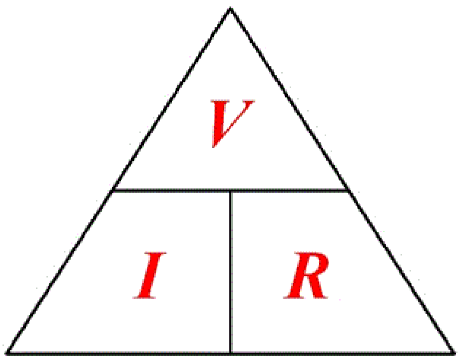


Resistor	V	I	R
1	6 V	1.5 A	4 Ω
2	6 V	0.75 A	8 Ω
Total	6 V	2.25 A	2.67 Ω

Parallel Circuit

E_1= 10 V
E_2= 20 V
R_T= 1000 Ω
I_1= 5 mA
I_2= 10 mA





V_T= 30 V
I_T = 0.03 A
I_3 = 0.015 A

Which Direction?

Counter-Clockwise

Resistor	V	I	R
1	30 V	0.005 A	6000 Ω
2	30 V	0.01 A	3000 Ω
3	30 V	0.015 A	2000 Ω
Total	30 V	0.03 A	1000 Ω

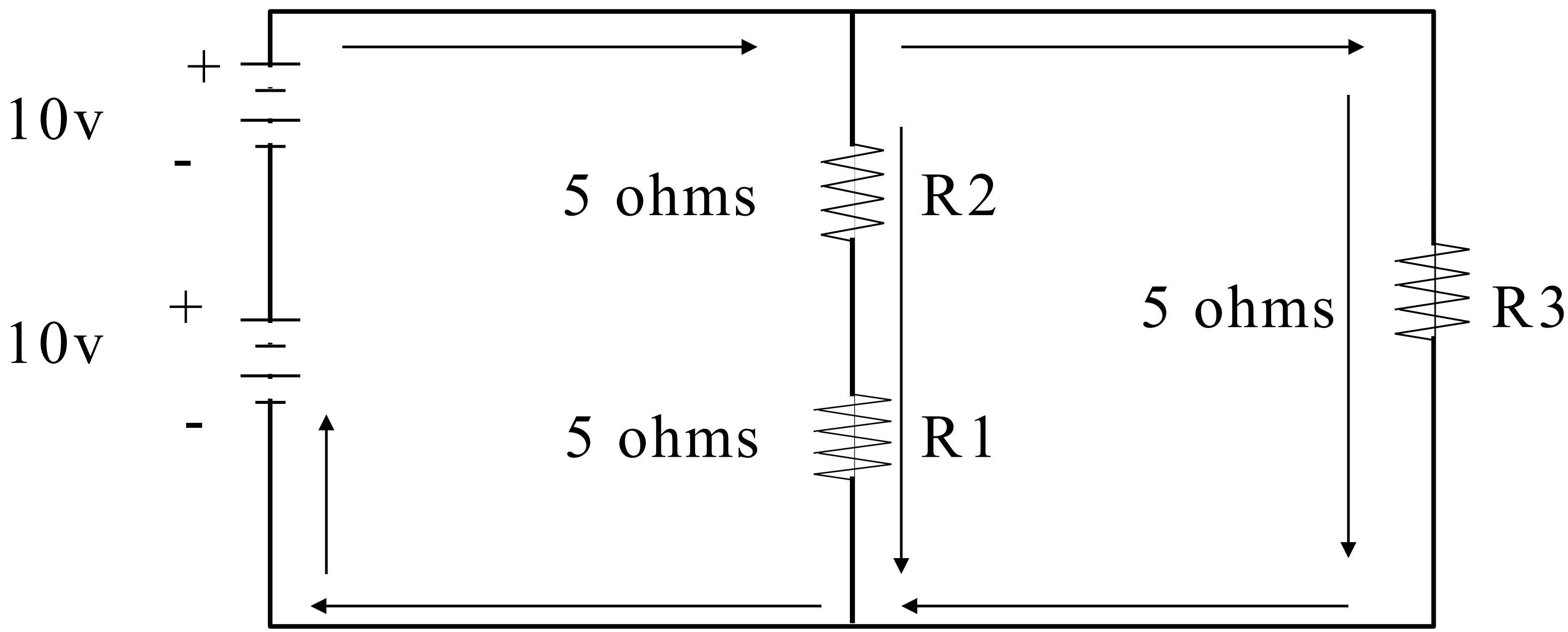
Parallel Circuit

Property	Series Circuit
Current	Total current flowing into and out of the junction point of the branches equals the sum of branch currents (Kirchhoff's Current Law). $I_T = I_1 + I_2 + I_3$
Resistance	Total resistance is always less than the smallest resistance in the circuit. $R_T = \dfrac{1}{1/R_1 + 1/R_2 + 1/R_3}$
Voltage	Voltage drop across each branch is the same and is equal to source voltage. $V_T = V_1 = V_2 = V_3$
Kirchoff's Law	**Current Law:** The law states that as much current flows away from a point as flows toward it. (Parallel Circuit)

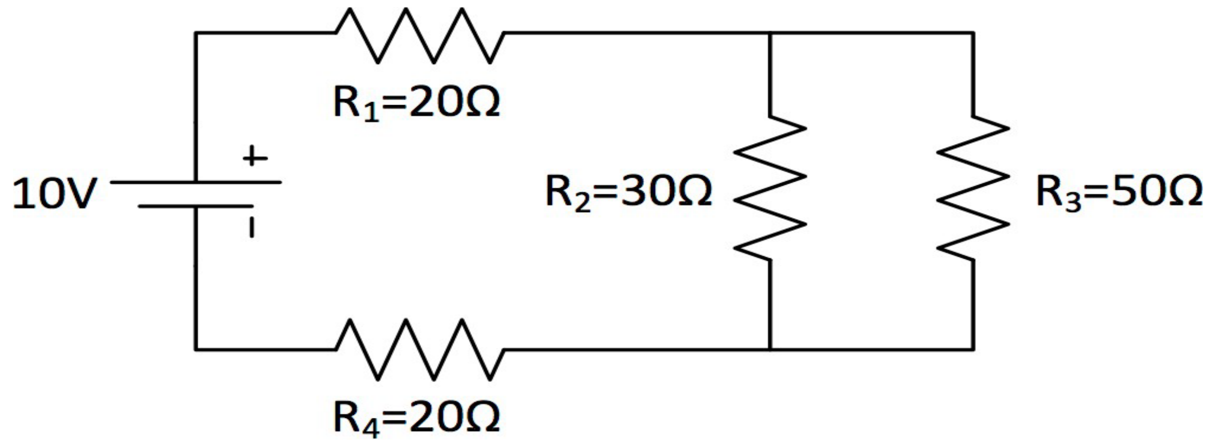
Parallel-Series Circuit

Resistor	V	I	R
1			5 Ω
2			5 Ω
Total			10 Ω

Resistor	V	I	R
1,2	20 V	2 A	10 Ω
3	20 V	4 A	5 Ω
Total	20 V	6 A	3.33 Ω



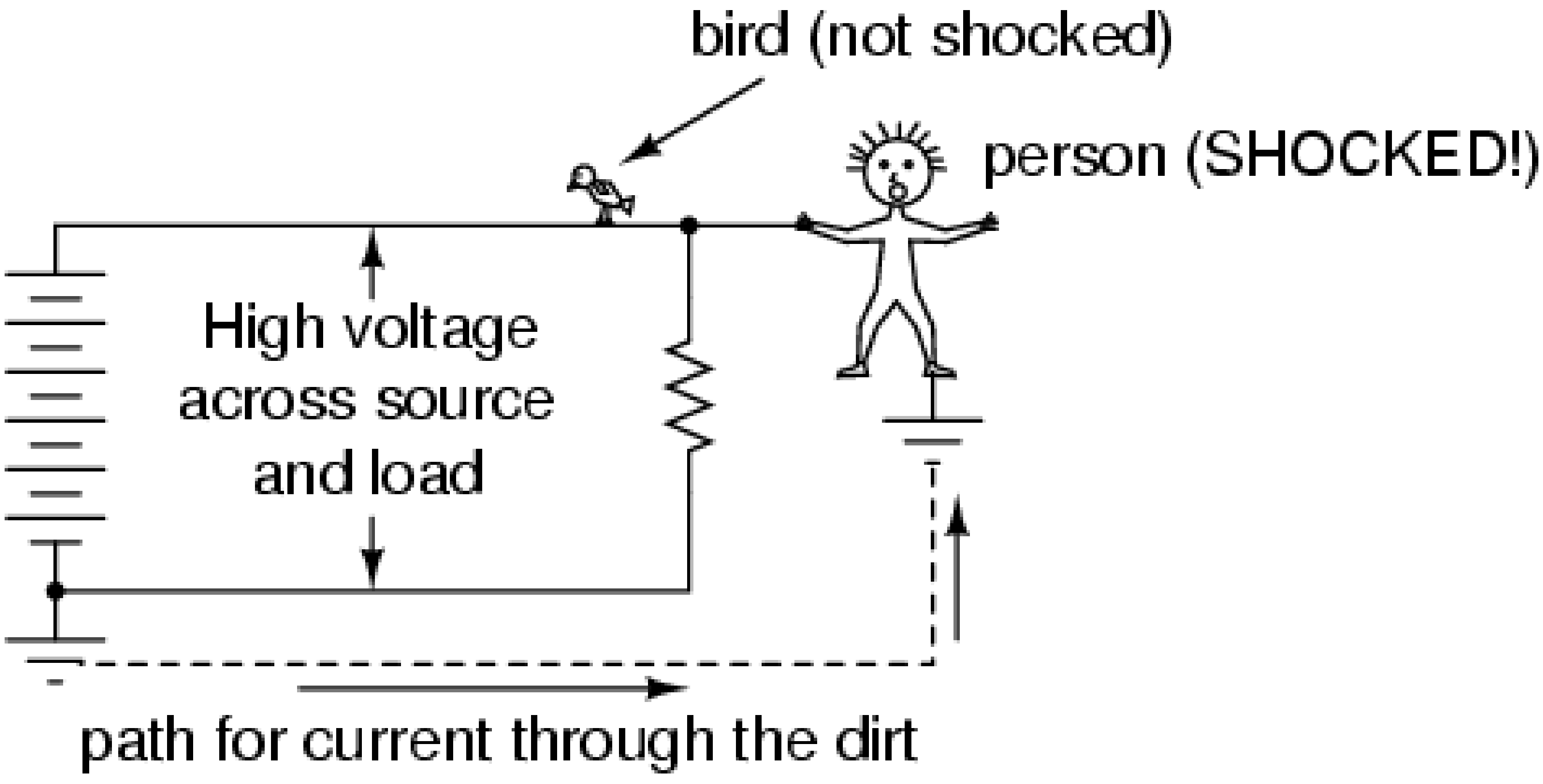
Parallel-Series Circuit



Resistor	V	I	R
2			30 Ω
3			50 Ω
Total			18.75 Ω

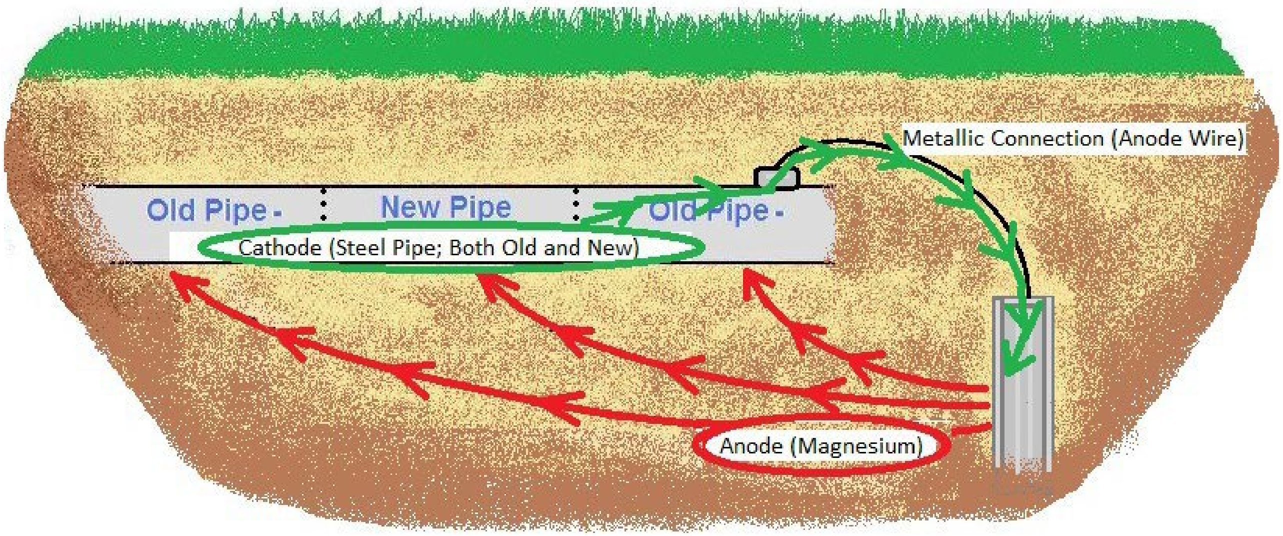
Resistor	V	I	R
1	3.4 V	0.17 A	20 Ω
2,3	3.2 V	0.17 A	18.75 Ω
4	3.4 V	0.17 A	20 Ω
Total	10 V	0.17 A	58.75 Ω

The Risks!

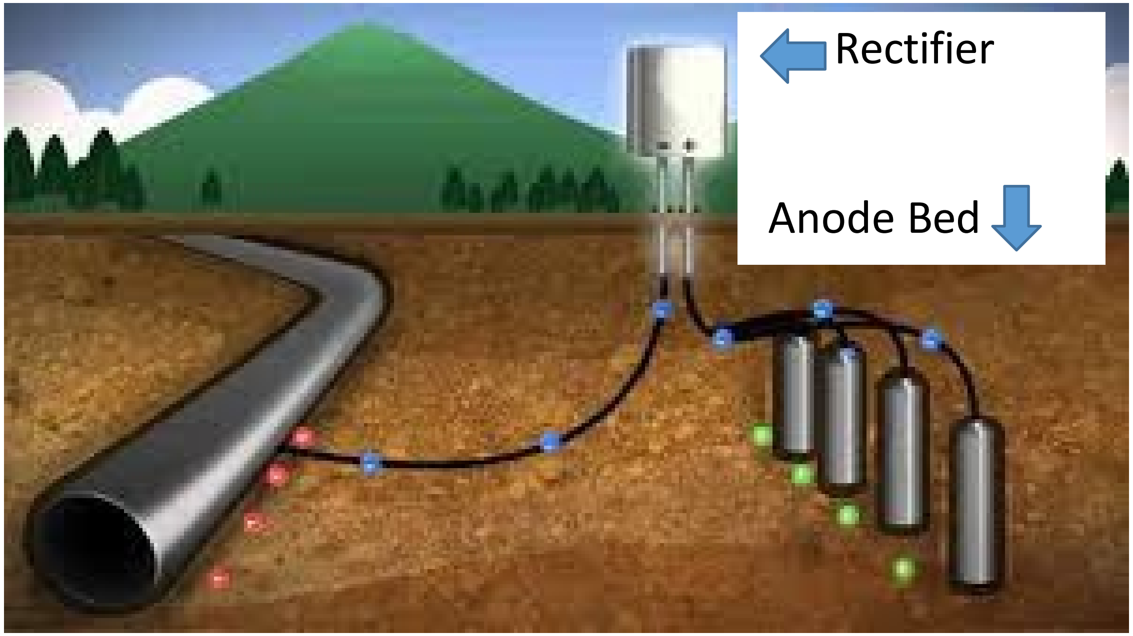

bird (not shocked)
person (SHOCKED!)
High voltage across source and load
path for current through the dirt

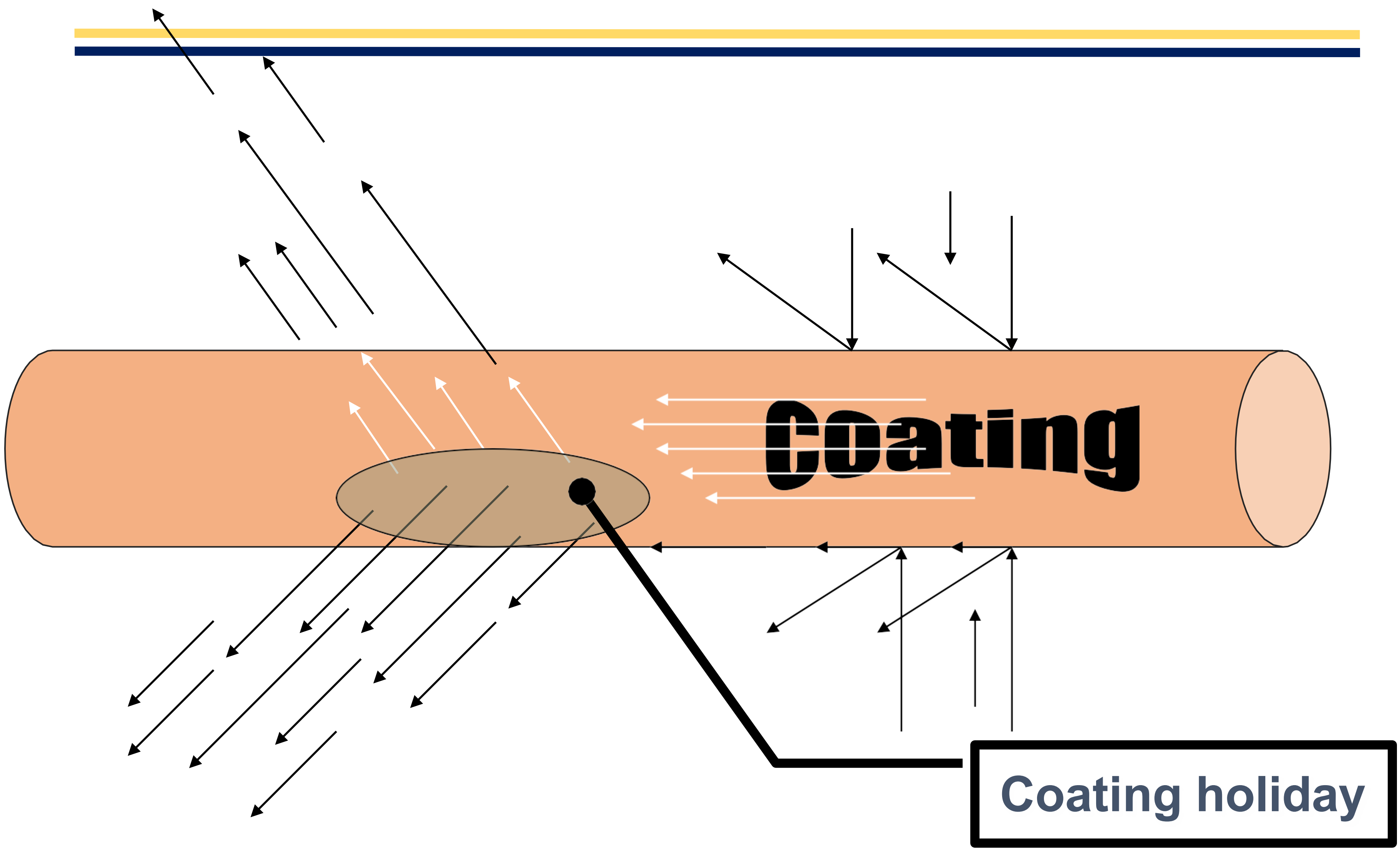
How can we use what we know to mitigate corrosion?

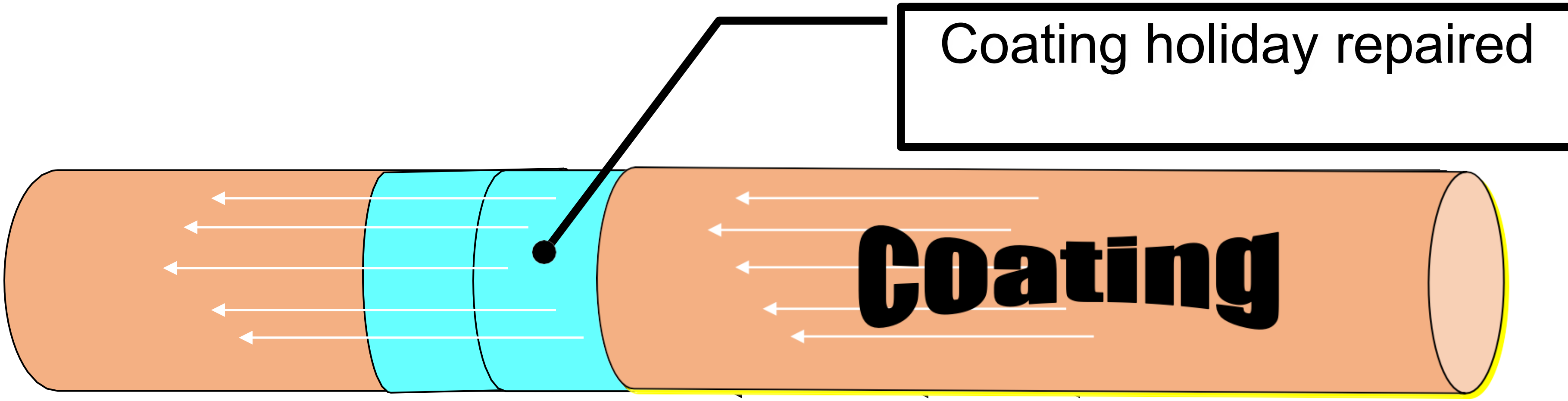
Sacrificial Anode System



Impressed Current System




Coating
Coating holiday


Coating holiday repaired
Coating

Electrical Insulation / Isolation

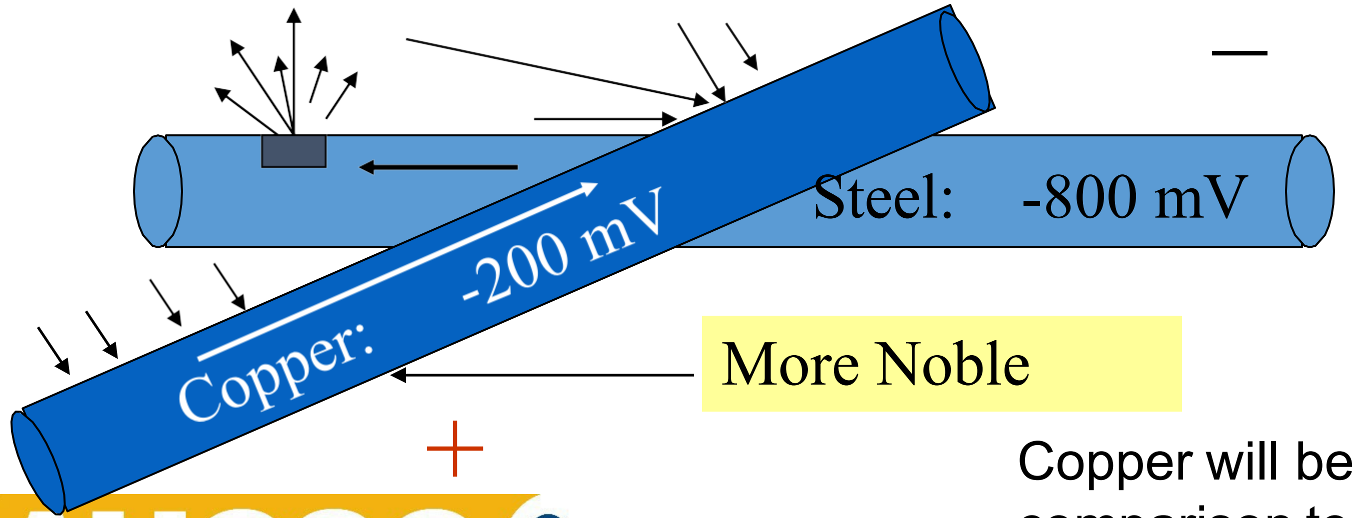
Isolation devices are fittings or devices used metallic structures to break any paths between the structure and any metallic connectors. Weld ends, dielectric couplings, isolation unions, and bolted flange isolation kits are examples.

- ***Insulation*** is a form of resistance to current flow.
- Normally materials with high resistance are used for electrical insulation / isolation.
- Insulators should always measure "OL" or as an open circuit when using a conventional voltmeter.

AUCSC
Appalachian Underground Corrosion Short Course

Polarity

- Determines the direction of conventional current flow
- Determines which is the Cathode and which is the Anode.
- Instrument such as digital or analog meter will help in determine the polarity.



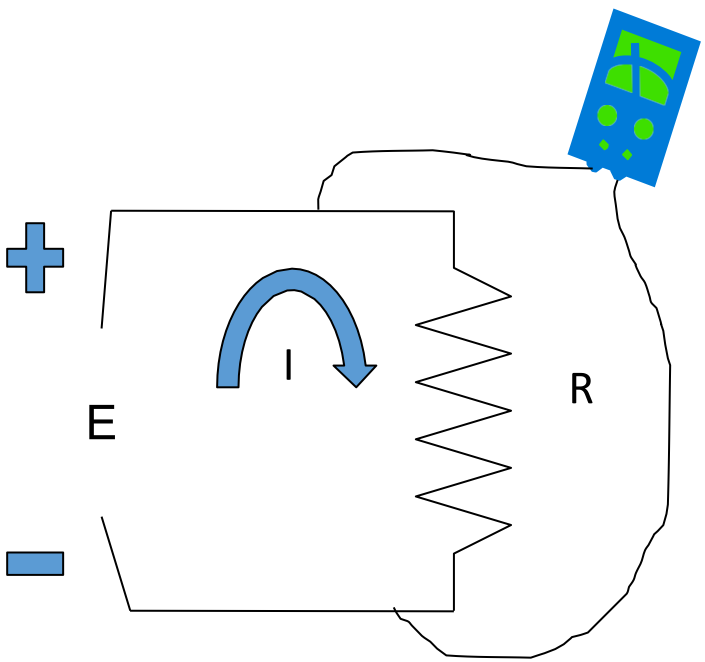
Copper will be more positive in comparison to the steel pipe.

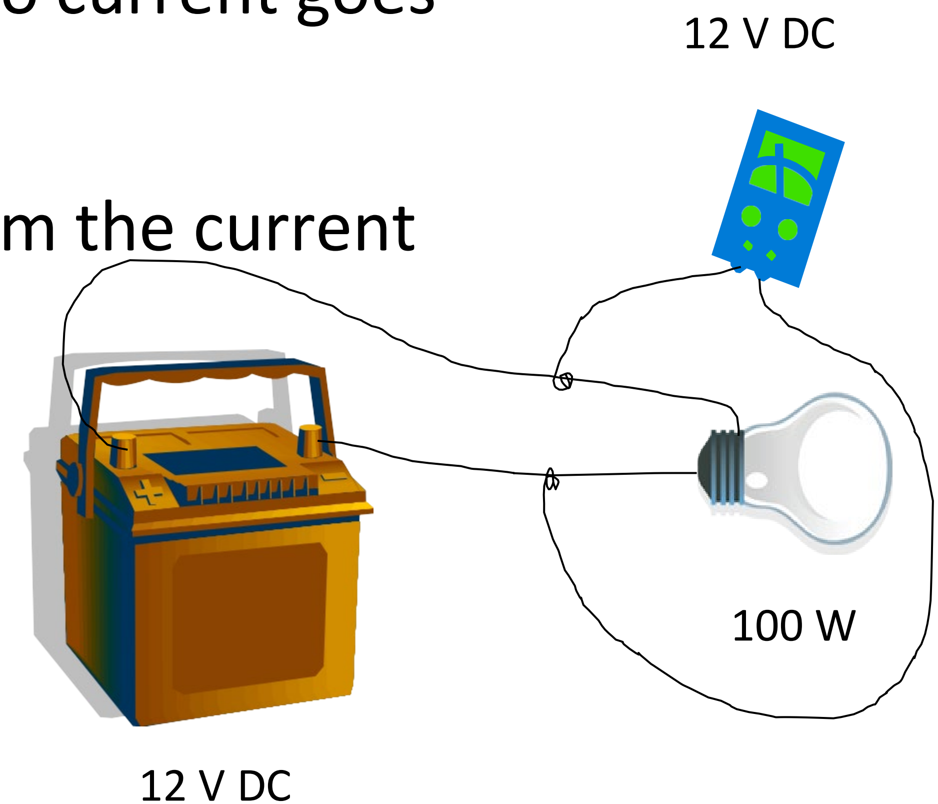
Appalachian Underground Corrosion Short Course

Measuring electrical voltage (potential)

In order to measure voltage, no current goes through the meter

The meter is kept separate from the current flow.



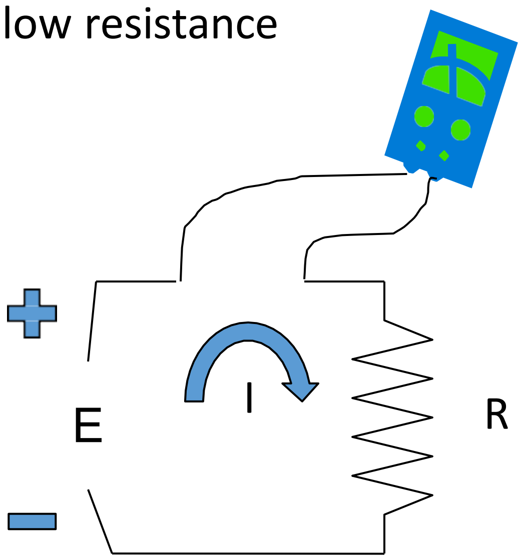


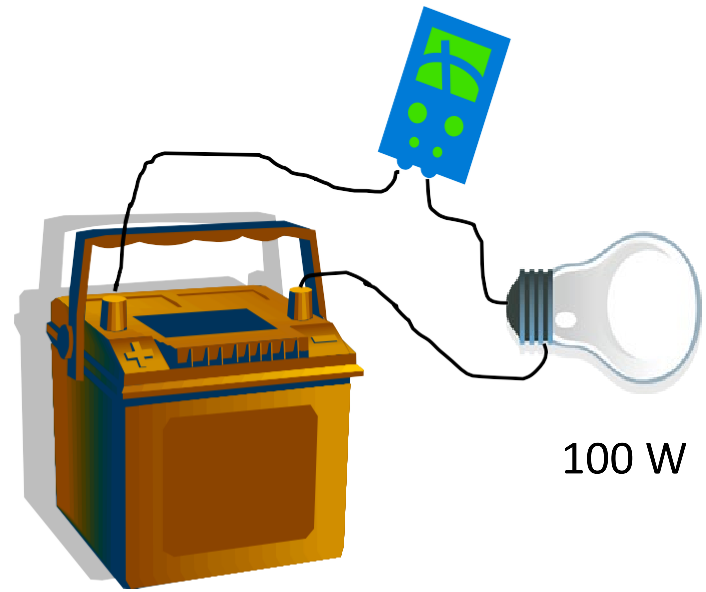
Measuring electrical current

In order to measure current,
all current must go through a meter

The meter is inserted and becomes part of the circuit.

Amp meter –
very low resistance





INDUCTION meter

Questions

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