Basic Electricity

BOPINDER ("BOP") PHULL

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

- This chapter covers:
  - Kinds of electricity encountered in corrosion and corrosion-control work
  - Explanation of various applicable electrical terms
  - How the electrical units represented by these terms interact
  - How the electrical units apply to various types of electrical circuits

Introduction

- Important to understand the principles in this chapter to fully comprehend the other chapters in the Basic Course

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Physical Matter

- Substance that occupies space and has mass
  - Solids
  - Liquids
  - Gases
- Whatever the form, matter is made up of chemical elements
- Electrically conductive matter can allow passage of electricity

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Corrosion Fundamentals

- Corrosion of a metal or alloy is a natural process in moist air, water, soil, etc.
- Metals are extracted from their ores in the earth's crust
- Corrosion returns metals to their natural state
- Corrosion of metals and alloys involves flow of electrical current

For example, let’s review how steel is made

- 1st step - Mining of Iron Ore (iron oxide)

Fe_2O_3

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How steel is made … continued

- 2^{nd} step - Smelting in blast furnace to convert iron-oxide to iron
- $FeO + C \longrightarrow Fe + CO$

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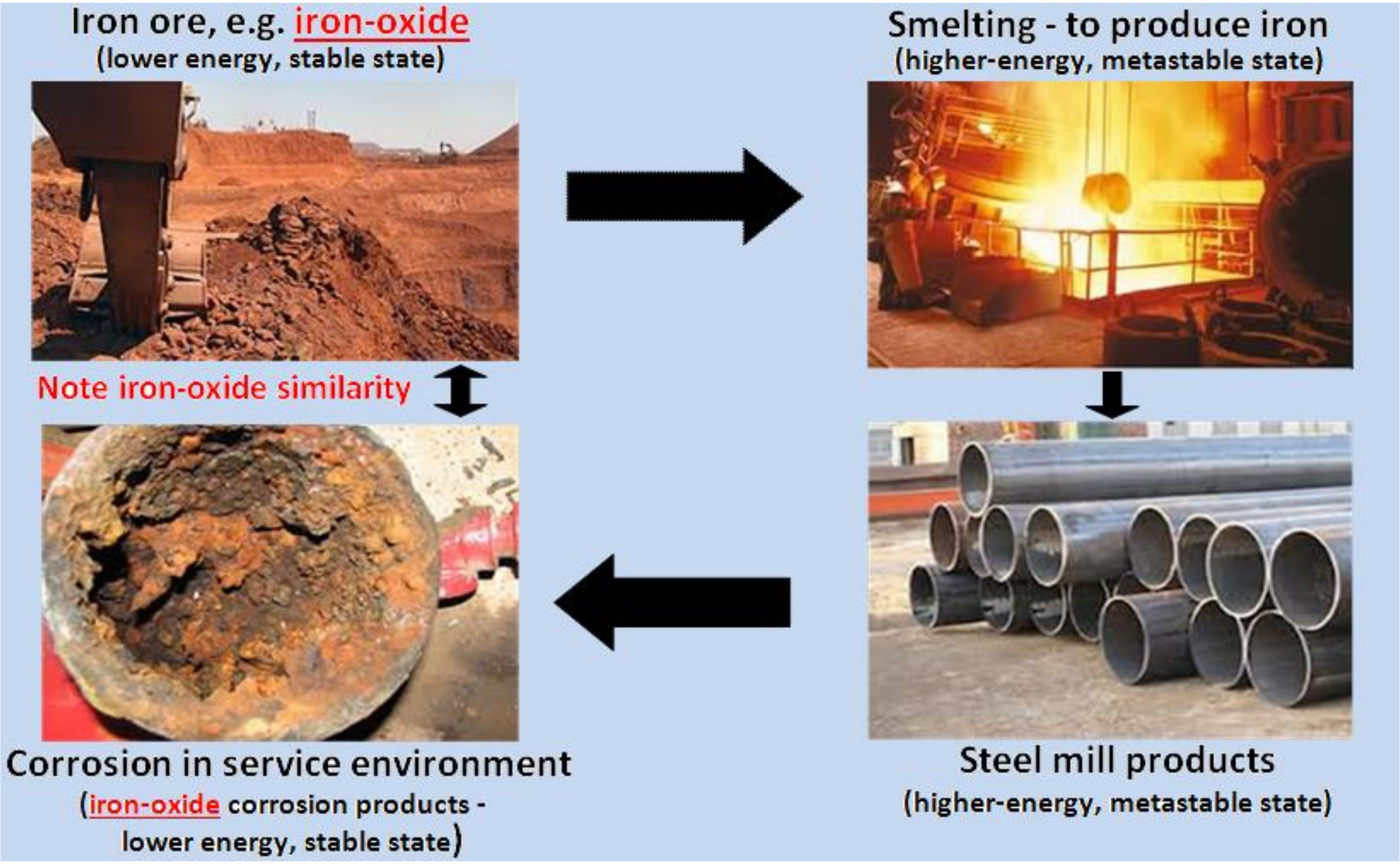
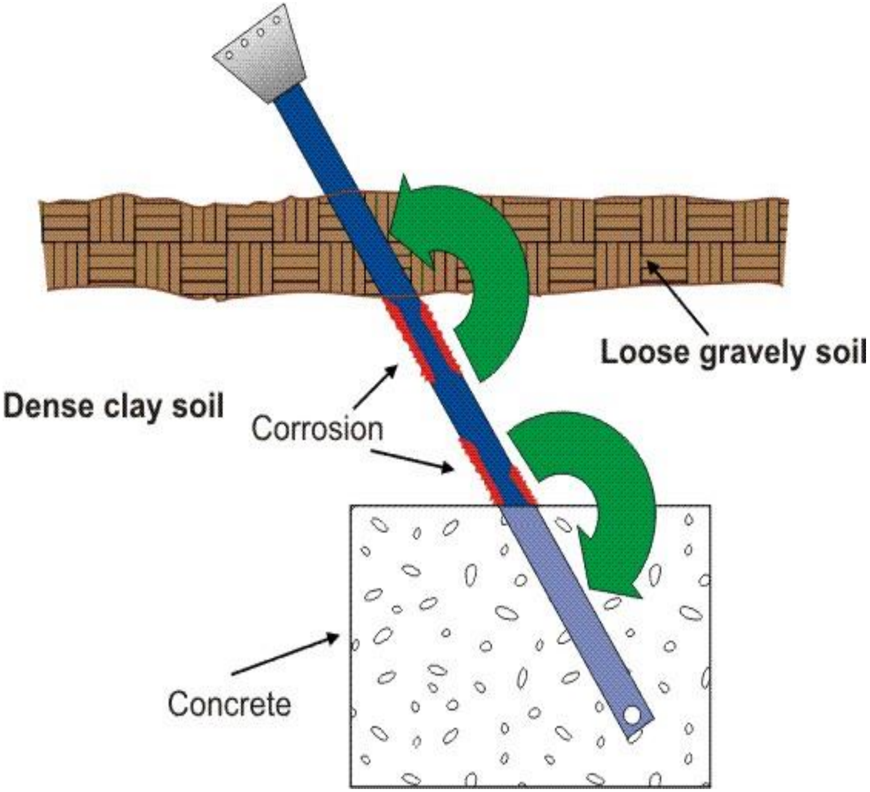
Why steel corrodes

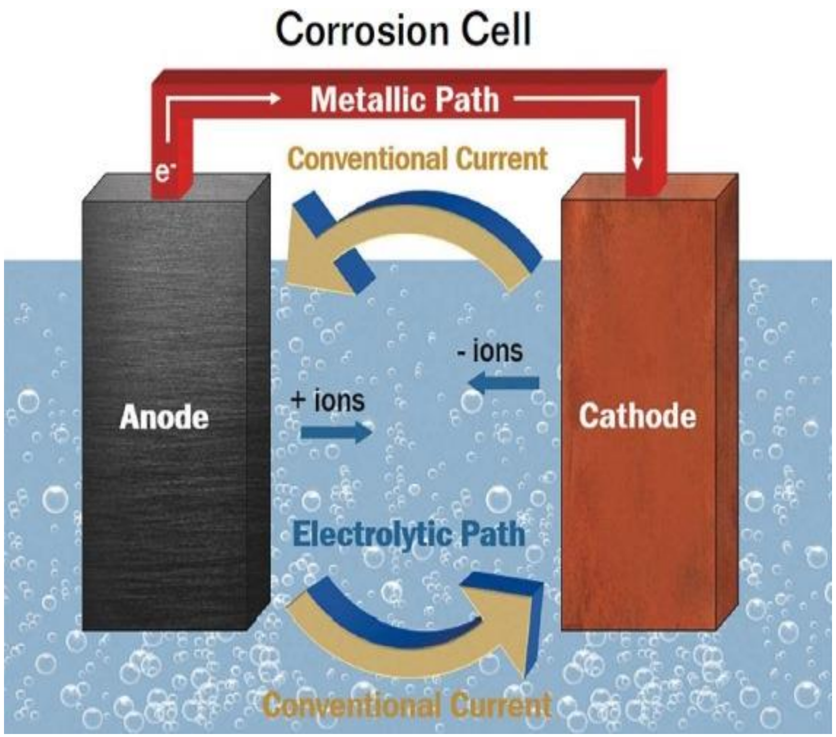
Natural process which returns metal to its native state



Examples of Current Flow in Corrosion Cells

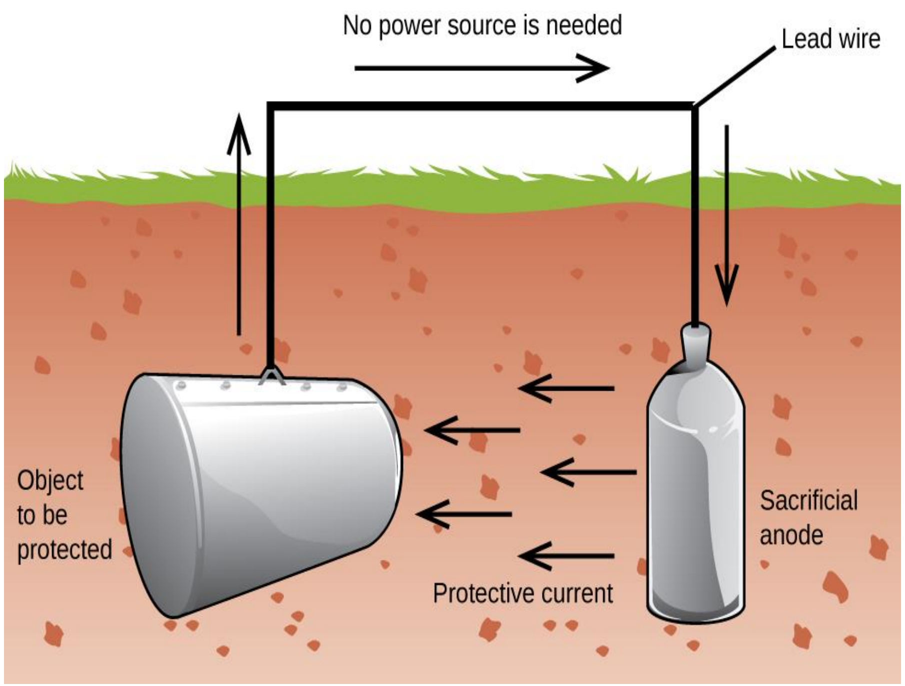


Dissimilar Environments

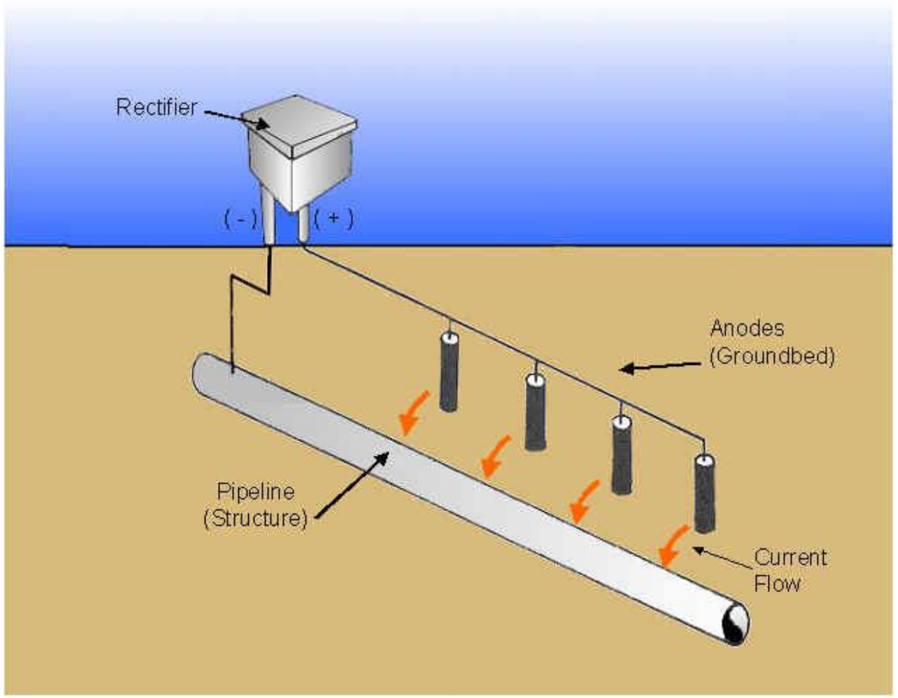


Dissimilar Metals

Examples of Current Flow in Cathodic Protection

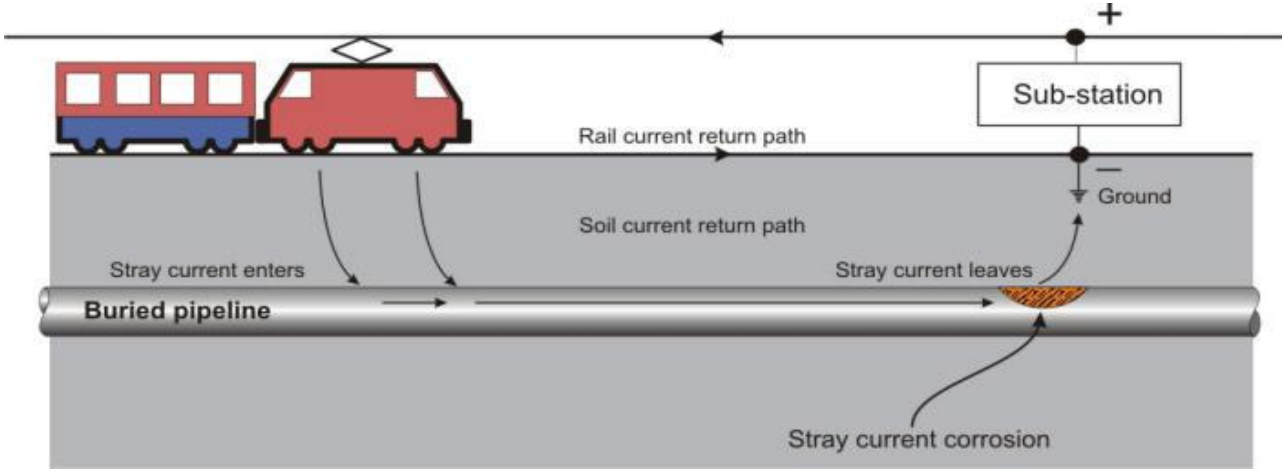


Galvanic Anode



Impressed Current

Examples of Current Flow that can cause corrosion



Stray Currents

AC Interference

Physical Matter

- **What are Elements ?**
  - **Primary constituents of matter**
  - **Cannot be broken down into simpler substances**
  - **Examples of elements**
    - **Hydrogen (chemical symbol H)**
    - **Iron (chemical symbol Fe)**
    - **Copper (chemical symbol Cu)**
    - **Oxygen (chemical symbol O)**

Atoms

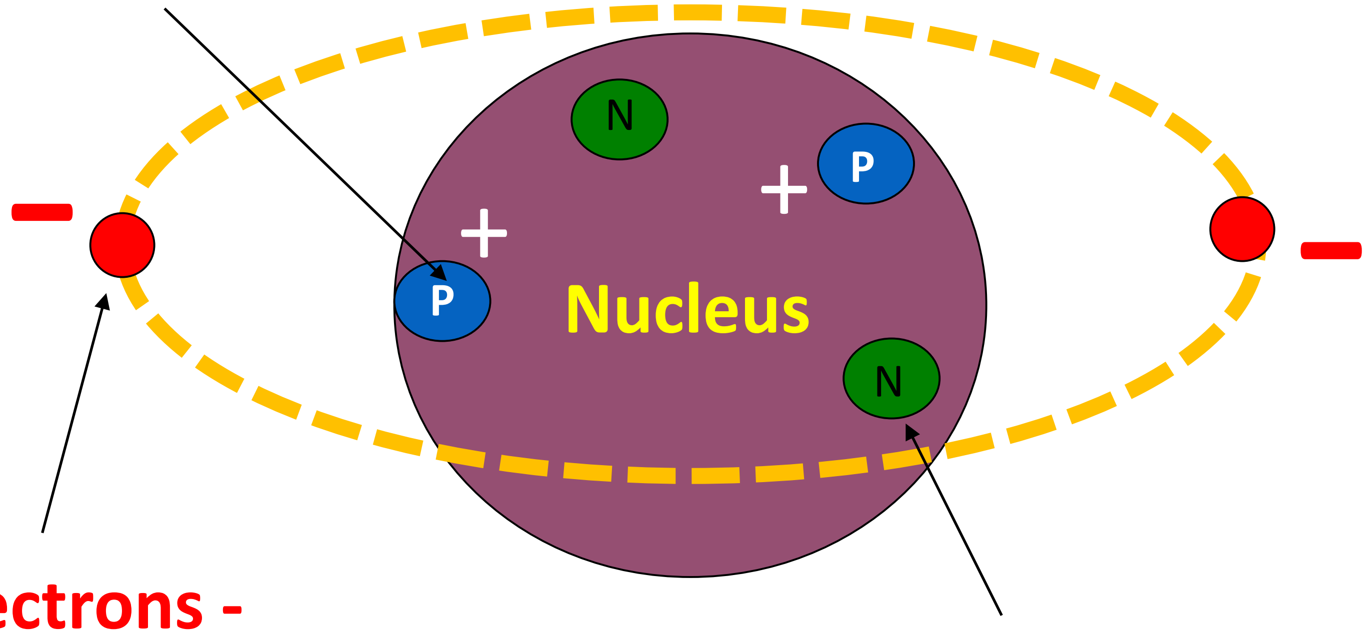
- Atoms are building blocks of chemical elements

- **Each element distinguished by its Atomic Number**

  - Number of Protons (+) in the nucleus

Atom

Protons -
positive charge



Electrons -
negative charge

Neutrons – no
charge

Periodic Table of the Elements

Normal boiling points are in °C.
SP = Triple Point
Pressure is listed if not 1 atm.
Allotrope is listed if more than one allotrope.

Atomic Number	Boiling Point
Symbol	
Name	
Atomic Mass	

1 IA 1A	2 IIA 2A	3 IIIB 3B	4 IVB 4B	5 VB 5B	6 VIB 6B	7 VIIB 7B	8 VIII 8	9 VIII 8	10 VIII 8	11 IB 1B	12 IIB 2B	13 IIIA 3A	14 IVA 4A	15 VA 5A	16 VIA 6A	17 VIIA 7A	18 VIIIA 8A
1 -252.762 **H** Hydrogen 1.008																	2 -268.93 **He** Helium 4.003
3 1342 **Li** Lithium 6.941	4 2471 **Be** Beryllium 9.012											5 4000 **B** Boron 10.811	6 graphite 3825 SP **C** Carbon 12.011	7 -195.798 **N** Nitrogen 14.007	8 -182.953 **O** Oxygen 15.999	9 -188.12 **F** Fluorine 18.998	10 -246.053 **Ne** Neon 20.180
11 882.940 **Na** Sodium 22.990	12 1090 **Mg** Magnesium 24.305											13 2519 **Al** Aluminum 26.982	14 3265 **Si** Silicon 28.086	15 white 280.5 **P** Phosphorus 30.974	16 444.61 **S** Sulfur 32.066	17 -101.5 **Cl** Chlorine 35.453	18 -185.847 **Ar** Argon 39.948
19 759 **K** Potassium 39.098	20 1484 **Ca** Calcium 40.078	21 2836 **Sc** Scandium 44.956	22 3287 **Ti** Titanium 47.88	23 3407 **V** Vanadium 50.942	24 2671 **Cr** Chromium 51.996	25 2061 **Mn** Manganese 54.938	26 2861 **Fe** Iron 55.933	27 2927 **Co** Cobalt 58.933	28 2913 **Ni** Nickel 58.693	29 2562 **Cu** Copper 63.546	30 907 **Zn** Zinc 65.39	31 2204 **Ga** Gallium 69.732	32 2833 **Ge** Germanium 72.61	33 616 SP **As** Arsenic 74.922	34 685 **Se** Selenium 78.972	35 58.8 **Br** Bromine 79.904	36 -153.34 **Kr** Krypton 84.80
37 688 **Rb** Rubidium 84.468	38 1382 **Sr** Strontium 87.62	39 3345 **Y** Yttrium 88.906	40 4409 **Zr** Zirconium 91.224	41 4744 **Nb** Niobium 92.906	42 4639 **Mo** Molybdenum 95.95	43 4265 **Tc** Technetium 98.907	44 4150 **Ru** Ruthenium 101.07	45 3695 **Rh** Rhodium 102.906	46 2963 **Pd** Palladium 106.42	47 2162 **Ag** Silver 107.868	48 767 **Cd** Cadmium 112.411	49 2072 **In** Indium 114.818	50 2602 **Sn** Tin 118.71	51 1587 **Sb** Antimony 121.760	52 988 **Te** Tellurium 127.6	53 184.4 **I** Iodine 126.904	54 -108.09 **Xe** Xenon 131.29
55 671 **Cs** Cesium 132.905	56 1897 **Ba** Barium 137.327	57-71	72 4603 **Hf** Hafnium 178.49	73 5458 **Ta** Tantalum 180.948	74 5555 **W** Tungsten 183.85	75 5596 **Re** Rhenium 186.207	76 5012 **Os** Osmium 190.23	77 4428 **Ir** Iridium 192.22	78 3825 **Pt** Platinum 195.08	79 2856 **Au** Gold 196.967	80 356.62 **Hg** Mercury 200.59	81 1473 **Tl** Thallium 204.383	82 1749 **Pb** Lead 207.2	83 1564 **Bi** Bismuth 208.980	84 962 **Po** Polonium [208.982]	85 337 **At** Astatine 209.987	86 -61.7 **Rn** Radon 222.018
87 677 **Fr** Francium 223.020	88 1737 **Ra** Radium 226.025	89-103	104 unknown **Rf** Rutherfordium [261]	105 unknown **Db** Dubnium [262]	106 unknown **Sg** Seaborgium [266]	107 unknown **Bh** Bohrium [264]	108 unknown **Hs** Hassium [269]	109 unknown **Mt** Meitnerium [268]	110 unknown **Ds** Darmstadtium [269]	111 unknown **Rg** Roentgenium [272]	112 unknown **Cn** Copernicium [277]	113 unknown **Uut** Ununtrium unknown	114 unknown **Fl** Flerovium [289]	115 unknown **Uup** Ununpentium unknown	116 unknown **Lv** Livermorium [298]	117 unknown **Uus** Ununseptium unknown	118 unknown **Uuo** Ununoctium unknown

Lanthanide Series	57 3464 **La** Lanthanum 138.906	58 3443 **Ce** Cerium 140.115	59 3520 **Pr** Praseodymium 140.908	60 3074 **Nd** Neodymium 144.24	61 3000 **Pm** Promethium 144.913	62 1794 **Sm** Samarium 150.36	63 1529 **Eu** Europium 151.966	64 3273 **Gd** Gadolinium 157.25	65 3230 **Tb** Terbium 158.925	66 2567 **Dy** Dysprosium 162.50	67 2700 **Ho** Holmium 164.930	68 2868 **Er** Erbium 167.26	69 1950 **Tm** Thulium 168.934	70 1196 **Yb** Ytterbium 173.04	71 3402 **Lu** Lutetium 174.967
Actinide Series	89 3198 **Ac** Actinium 227.028	90 4788 **Th** Thorium 232.038	91 4027 **Pa** Protactinium 231.036	92 4131 **U** Uranium 238.029	93 4174 **Np** Neptunium 237.048	94 3228 **Pu** Plutonium 244.064	95 2011 **Am** Americium 243.061	96 3100 **Cm** Curium 247.070	97 2627 **Bk** Berkelium 247.070	98 unknown **Cf** Californium 251.080	99 unknown **Es** Einsteinium [254]	100 unknown **Fm** Fermium 257.095	101 unknown **Md** Mendelevium 258.1	102 unknown **No** Nobelium 259.101	103 unknown **Lr** Lawrencium [262]

Alkali Metal | **Alkaline Earth** | **Transition Metal** | **Basic Metal** | **Semimetal** | **Nonmetal** | **Halogen** | **Noble Gas** | **Lanthanide** | **Actinide**

Physical Matter

- What is a molecule ?
  - Molecule is chemical combination of two or more atoms
  - Examples:
    - Hydrogen gas (H_2)
    - Oxygen gas (O_2)
    - Nitrogen gas (N_2)

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Physical Matter

- What is a compound ?
  - Molecule that contains at least two different elements
  - Examples:
    - Carbon dioxide (CO_2)
    - Hydrogen sulfide (H_2S)
    - Iron oxide (Fe_2O_3)
    - Copper sulfate ($CuSO_4$)

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Physical Matter

All compounds are molecules

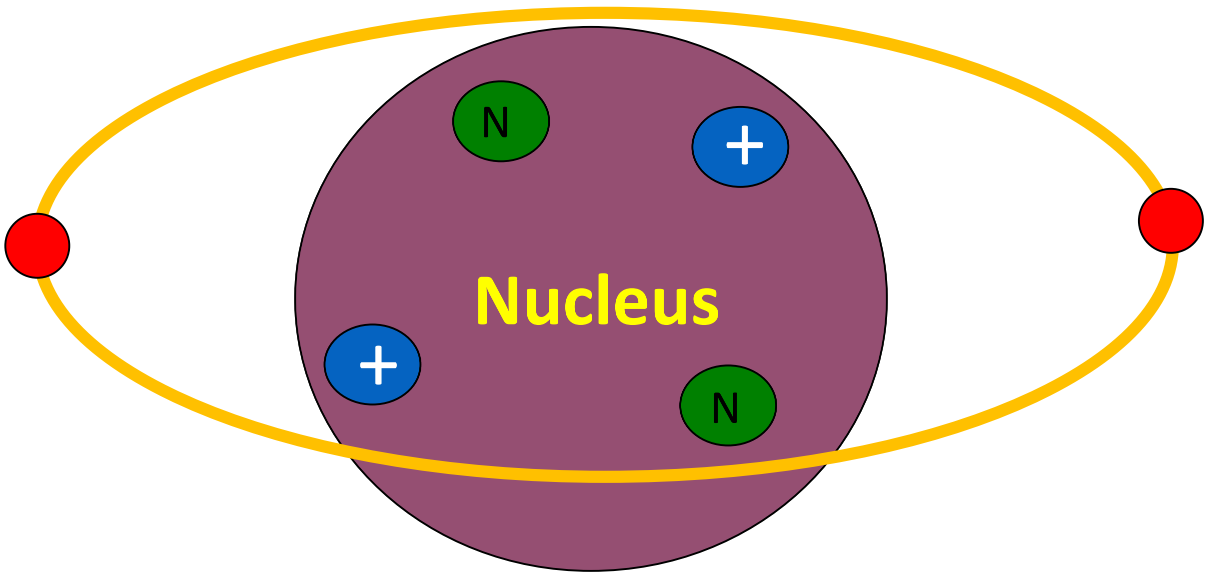
but

Not all molecules are compounds

When an Atom becomes an ION –

What Charge ????

Positive Charge!!!!!



Ions

- Two types of ions
  - Cations - Positively charged (+)
  - Anions – Negatively charged (-)

Ions

- Ions form when atoms or molecules lose or gain excess electrons
  - $Fe^0 - 2e^- \longrightarrow Fe^{2+}$
  - Water : $H_2O \longrightarrow [H^+] + [OH^-]$
  - Sodium Chloride : $NaCl \longrightarrow [Na^+] + [Cl^-]$

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Ions

- Cations – Positively charged
  - Hydrogen ions – H^{+}
  - Sodium ions – Na^{+}
  - Calcium ions – Ca^{2+}
  - Ferrous ions – Fe^{2+}
  - Ferric ions – Fe^{3+}
  - Aluminum ions – Al^{3+}

Ions

- Anions – Negatively charged
  - Hydroxyl ions – OH^-
  - Chloride ions – Cl^-
  - Fluoride ions – F^-
  - Sulfate ions – SO_4^{2-}
  - Nitrate ions – NO_3^-
  - Phosphate ions – PO_4^{2-}

Basic Corrosion Process

- Oxidation - Metal ions go into solution at ANODIC areas by loss of electrons, e.g.

$$M^0 \; - \; n\,e^- \longrightarrow M^{n+}$$

$$Fe^0 \; - \; 2\,e^- \longrightarrow Fe^{2+}$$

- Reduction - Occurs at CATHODIC areas by consumption of electrons, e.g.

$$2\,H^+ + 2\,e^- \longrightarrow H_2$$

$$O_2 + \tfrac{1}{2}\,H_2O + 2\,e^- \longrightarrow 2\,OH^-$$

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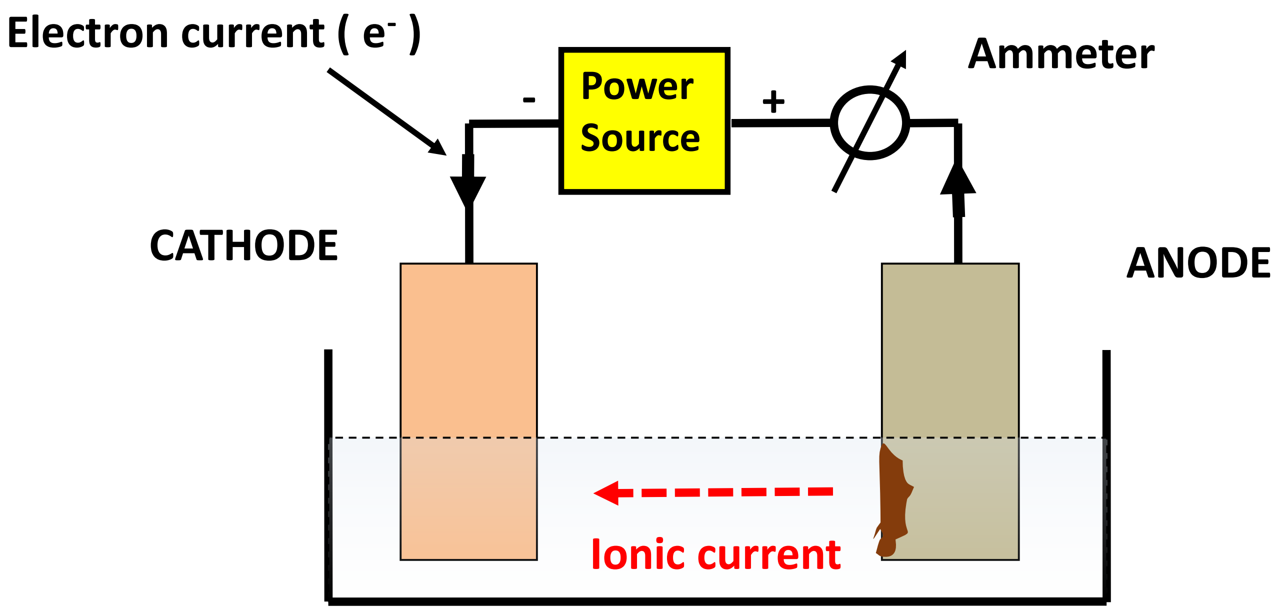
Electrical Current

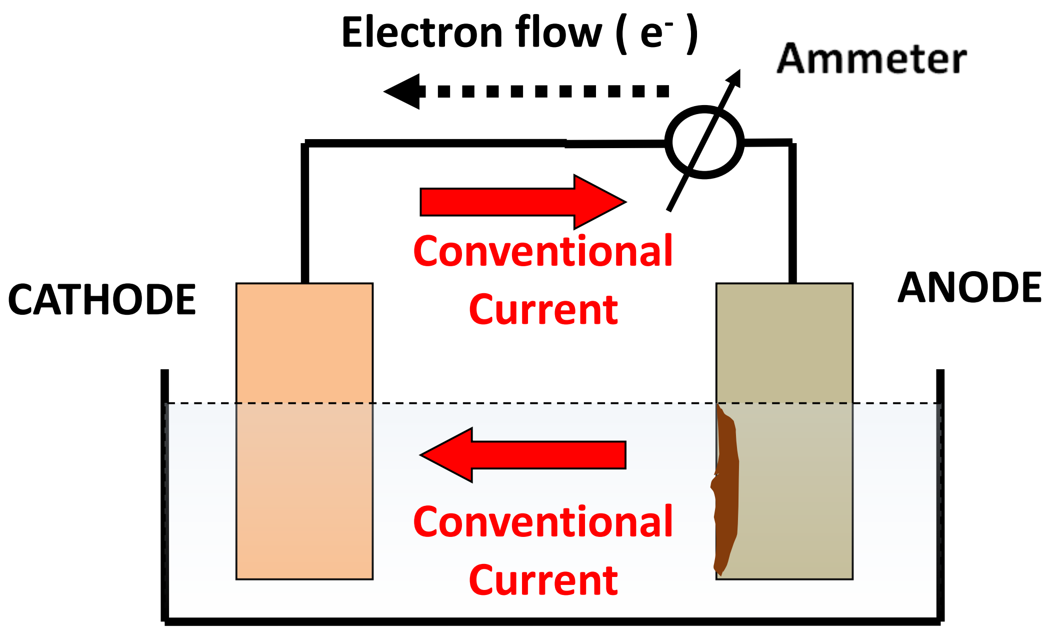
- Electrical current involves the flow of electrons in the metallic path of an electrical circuit
  - Also known as electronic current
- Electrical current flow in electrolytes is due to movement of ions

  \- Also known as ionic or electrolytic current

Electrical Current



Conventional Current vs. Electron Flow



Electricity

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

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)

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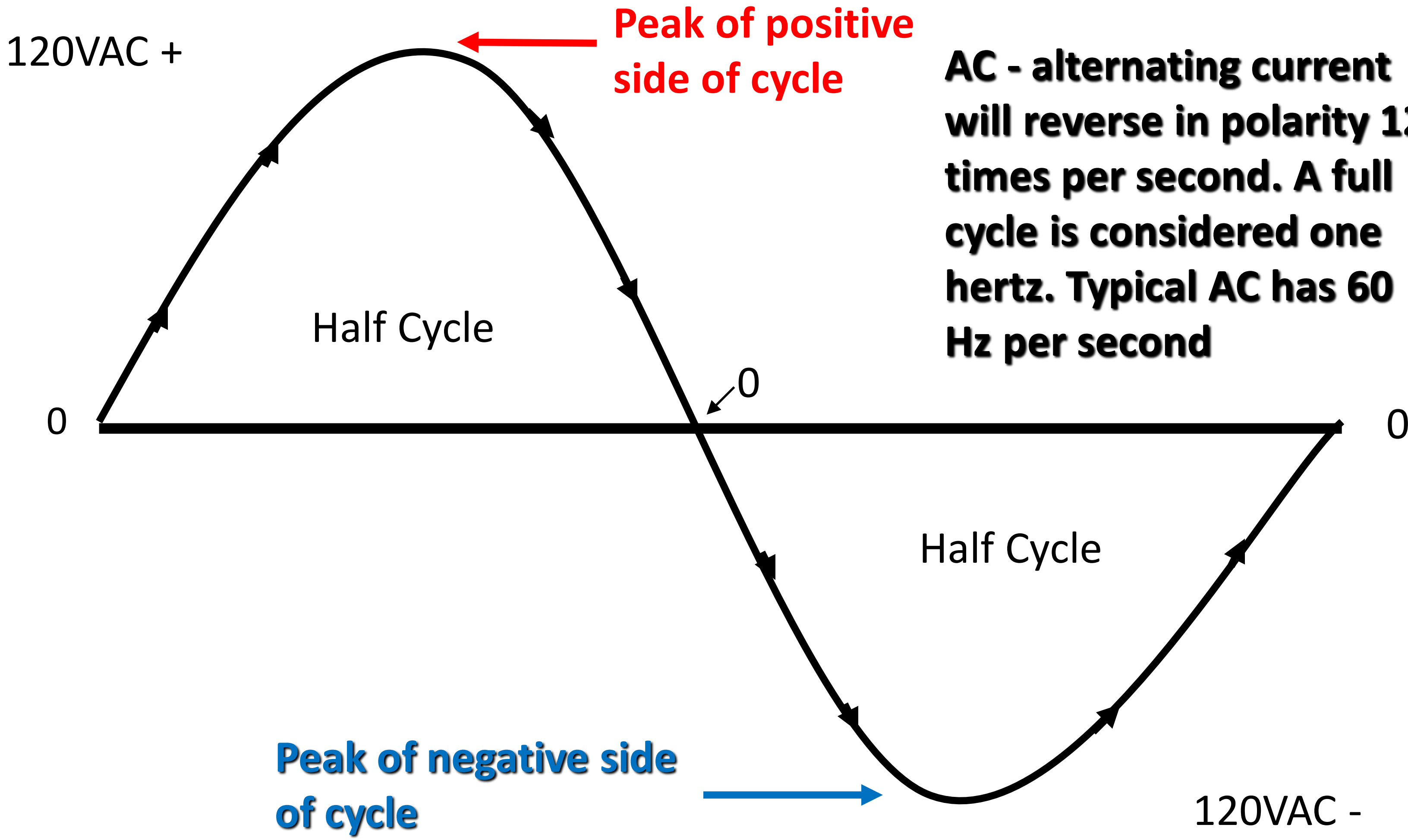
Alternating Current (AC)



AC - alternating current will reverse in polarity 120 times per second. A full cycle is considered one hertz. Typical AC has 60 Hz per second

SINE WAVE

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) *Discussed more in Chapter 3 - Corrosion Control Methods*

Direct Current (DC)

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

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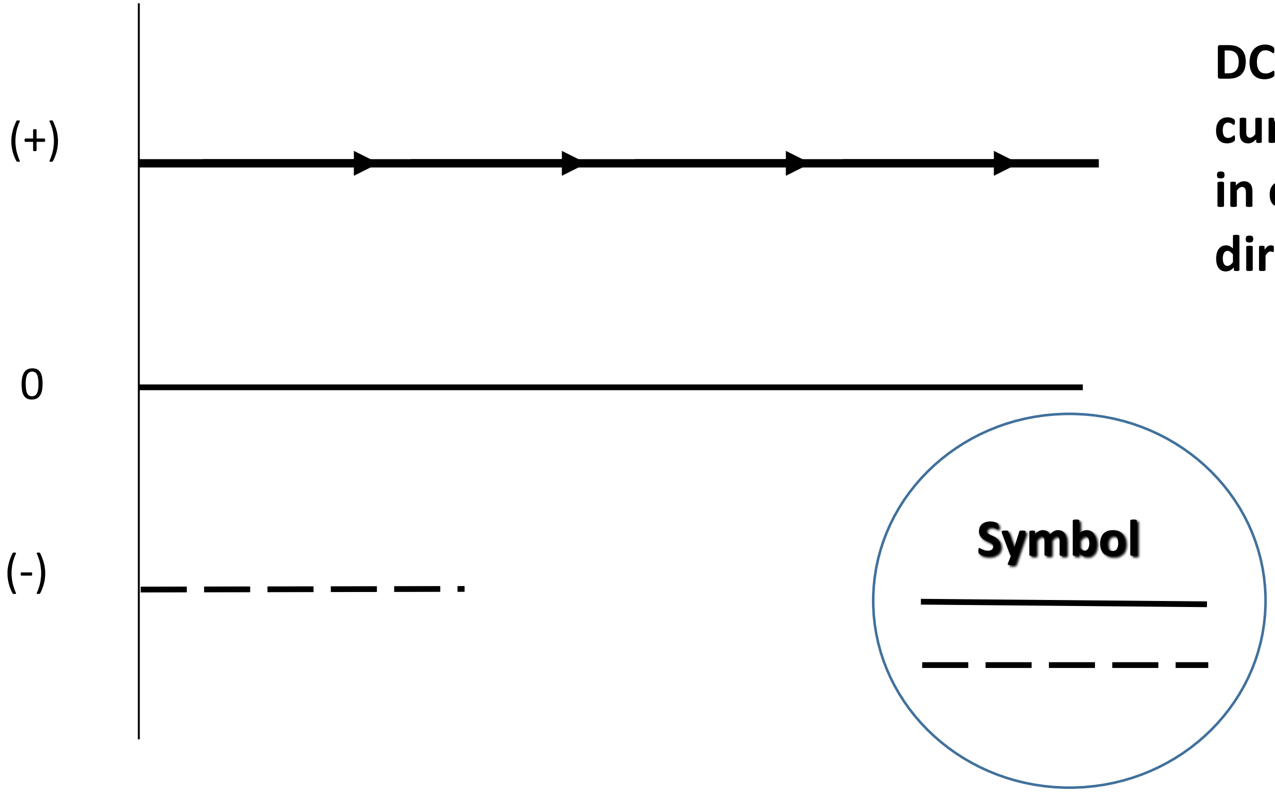
Direct Current (DC)



DC - direct current flows in one direction

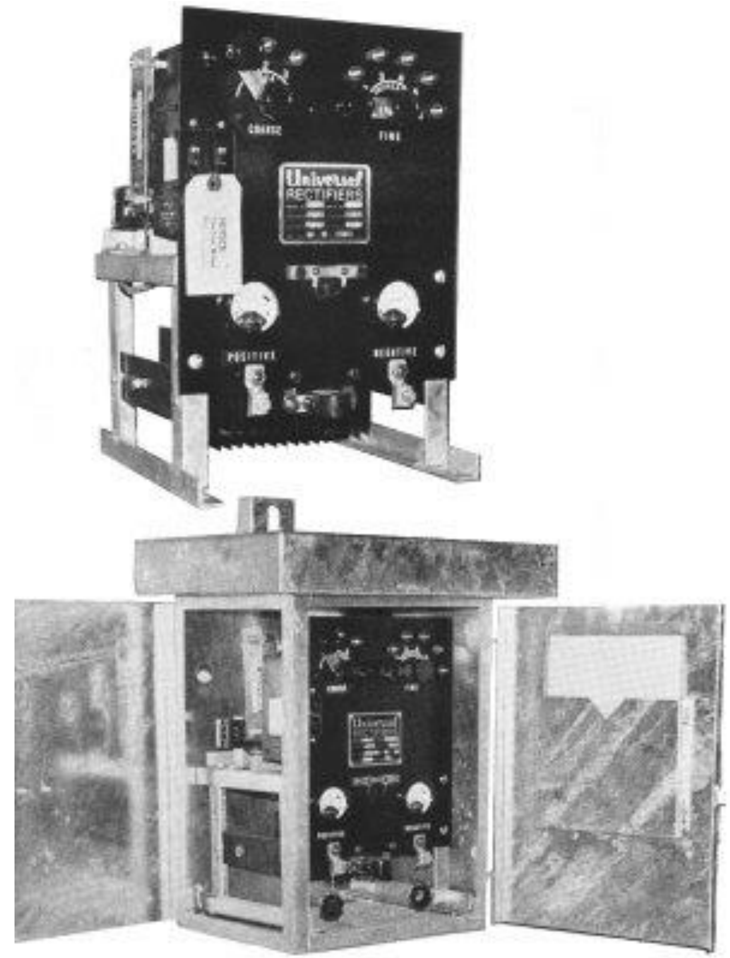
Significance of Direct Current

- **DC current is very important in the corrosion process**
  - **Involved in various types of corrosion cells (discussed in Chapter 2)**
  - **Involved in corrosion control – especially in cathodic protection (discussed in Chapter 3)**

Transformer Rectifier

Steps down AC voltage and

Converts AC to DC



Basic Terms

- Typical terms and units involved in electrical circuits
- Voltage - Volts (V)
- Current - Amps (A)
- Resistance – Ohms (R)

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Potential Difference, Volts (V)

- Basic unit of electrical potential difference that causes an electrical current (electrons) to flow through a metallic circuit

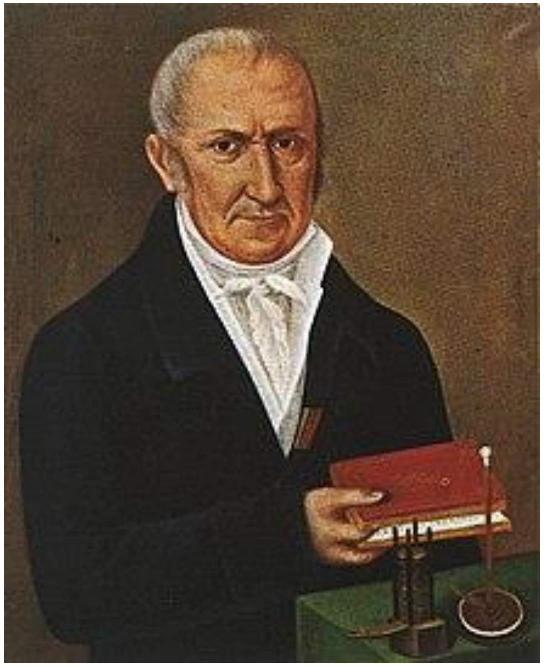
- Named after Italian

  Physicist, Alessandro Volta

- Potential difference

  also known as Electromotive Force,

  (EMF), abbreviated as E



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Volts

One volt (V) is the basic unit, there are instances where much smaller units are easier to use

One millivolt (mV) is one thousands of a volt

One microvolt (µV) is one millionth of a volt

–	1.000 volt	=	1000 millivolts
–	0.100 volt	=	100 millivolts
–	0.010 volt	=	10 millivolts
–	0.001 volt	=	1 millivolt
–	0.000001 volt	=	1 microvolt

Volts

- In corrosion prevention work, sources of DC voltage used to provide cathodic protection current include:
  - Galvanic anodes
    - Zinc
    - Aluminum
    - Magnesium
  - Driving voltage of anodes may be measured in tenths of a volt or in millivolts.

Volts - continued

- Other sources of DC voltage used to provide cathodic protection current include:
  - Higher capacity sources such as AC to DC rectifiers or DC generators of various types
    - Normally available in a wide range of voltages to match specific requirements
    - more fully discussed in chapter 3

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Current, Amperes (I)

- **Ampere is the basic unit of electrical current flow**

Named after French mathematician and physicist, Andre-Marie Ampere

- **Recall – Potential difference causes current flow in an electrical circuit**

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Ampere – often abbreviated as amp

One amp (A) is the basic current flow unit, there are instances where very small fractions of an ampere may be involved in corrosion work

One milliamp (mA) is one thousandth of an ampere

One microamp (µA) is one millionth of a ampere

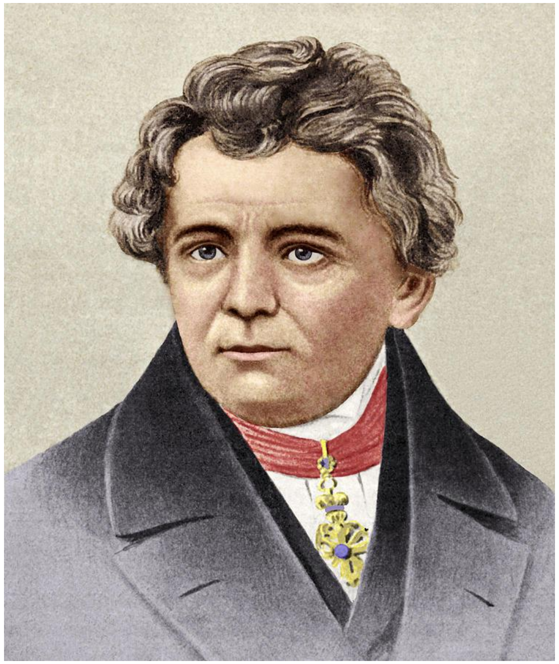
–	1.000 amp	=	1000 milliamps
–	0.100 amp	=	100 milliamps
–	0.010 amp	=	10 milliamps
–	0.001 amp	=	1 milliamp
–	0.000001 amp	=	1 microampere

Resistance (R)

- Ohm is the basic unit of resistance (R) to the flow of electrical current

- Named after German physicist and mathematician, Georg Simon Ohm

- Resistance (ohms) is the opposite of Conductance (mhos)



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Resistance (R) - Ohms

- Symbol Ω (omega) used commonly

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

R can have a wide range of values

- 10 megohms = 10,000,000 ohms
- 1 megohm = 1,000,000 ohms
- 10 kiloohms = 10,000 ohms
- 1 kiloohm = 1000 ohms
- 1 ohm = 1,000 milliohms
- 0.1 ohm = 100 milliohms
- 0.01 ohm = 10 milliohms

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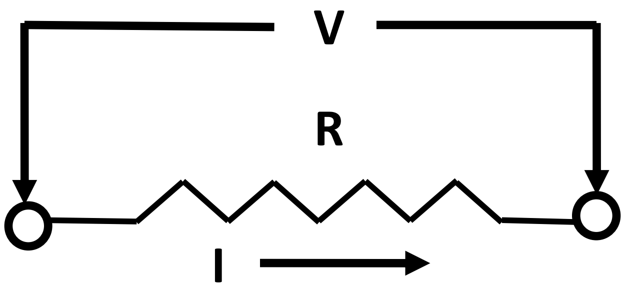
Ohm's Law

- Current flow through a conductor between two points is proportional to the voltage across the two points

- Current (I) = $\frac{\text{Voltage (V)}}{\text{Resistance (R)}}$



Can be written in 3 ways:

- $I = \frac{V}{R}$ or $R = \frac{V}{I}$ or $V = I \times R$

- If any 2 of these are known the 3rd can be calculated

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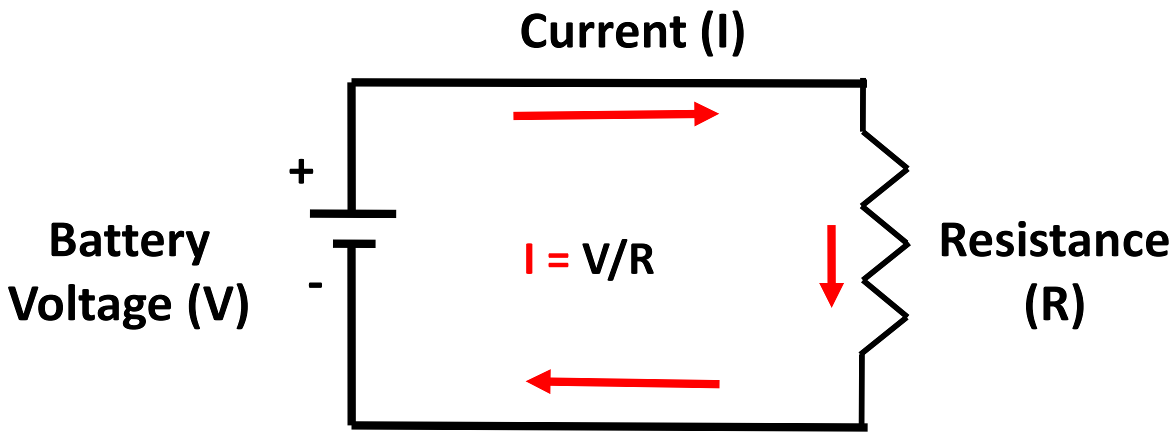
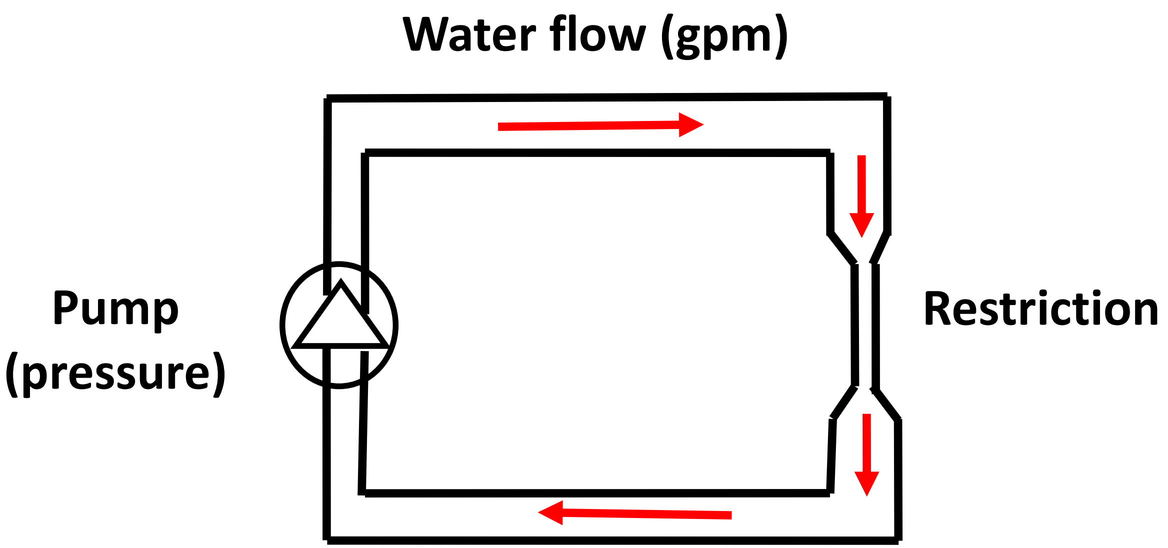
Ohm's Law - continued

- **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>**

Ohm's Law – Water Flow Analogy

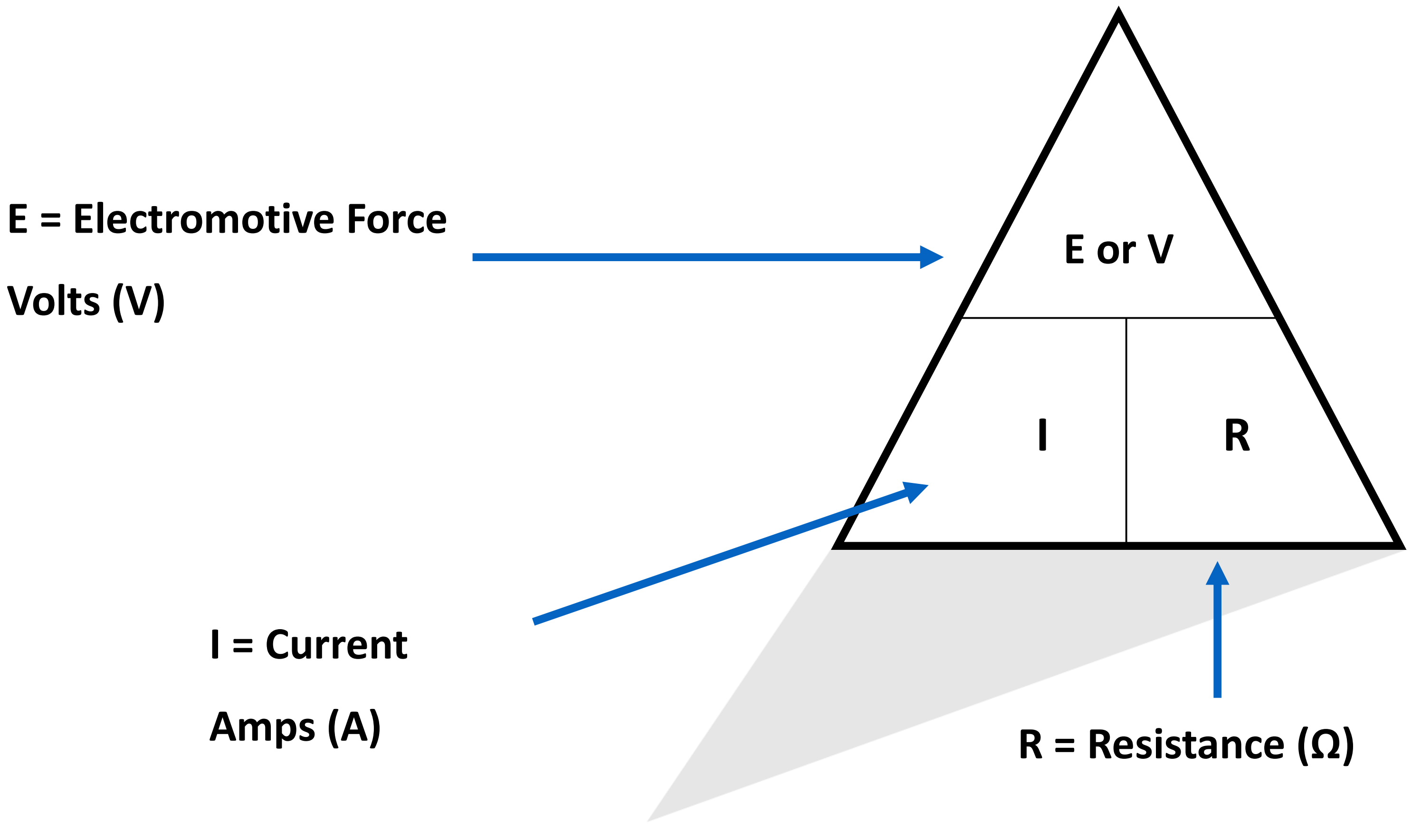




Resistance

- Importance of resistance in corrosion and its control
- For example,
    - Insulators
    - Coatings

Ohm's Law

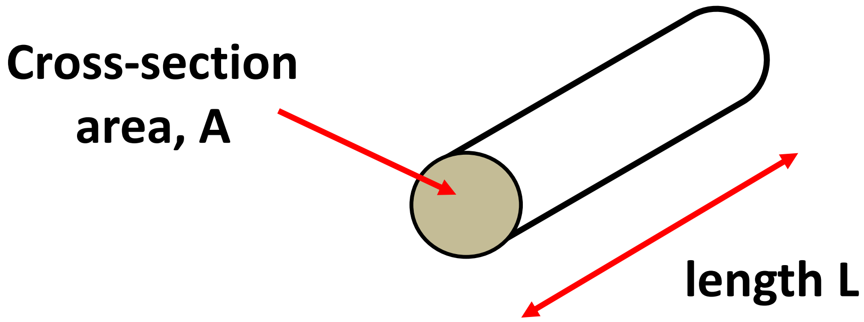

E = Electromotive Force
Volts (V)
E or V
I
R
I = Current
Amps (A)
R = Resistance (Ω)

Resistivity

- Resistivity is used to indicate the characteristic ability of a material to conduct electricity
- Can be applied to both metallic and non-metallic materials
- Commonly expressed as ohm-centimeters (ohm-cm); other units sometimes used are ohm-meters or ohm-ft
- Symbol used for resistivity - ρ (Greek letter rho)

Resistivity

- Resistivity is a material property



Resistance, $R = \frac{\rho \times L}{A}$ **or** **Resistivity,** $\rho = \frac{R \times A}{L}$

Resistivity vs. Corrosivity

- **Resistivity provides a general indication of corrosivity. Resistivity is opposite of conductivity**

- **Generally, <u>lower resistivity</u> (i.e. higher conductivity) of soil or water suggests more corrosion current can flow and hence <u>higher corrosion rate</u>**

- **Generally, <u>higher resistivity</u> (i.e. lower conductivity) of soil or water suggests less corrosion current can flow and hence <u>lower corrosion rate</u>**

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Resistivity vs. Corrosivity

Soil Resistivity (ohm-cm)	Corrosivity
< 2000	Severe
2000 - 5000	Moderately
5000 - 10,000	Low
> 10,000	Negligible

Resistivity

- Most common reason for measuring resistivity of soils and waters is in design of Cathodic Protection (CP) systems
  - Design
    - Galvanic anode-to-electrolyte resistance
    - Ground bed design for impressed current system

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Resistivity Measurements

- Tools used for measuring resistivity of soils
  - Collins rod
  - Wenner Four-pin method – most commonly used in
    the field
  - Soil box
- For water – typically conductivity cell used
  - Conductivity can be converted to resistivity

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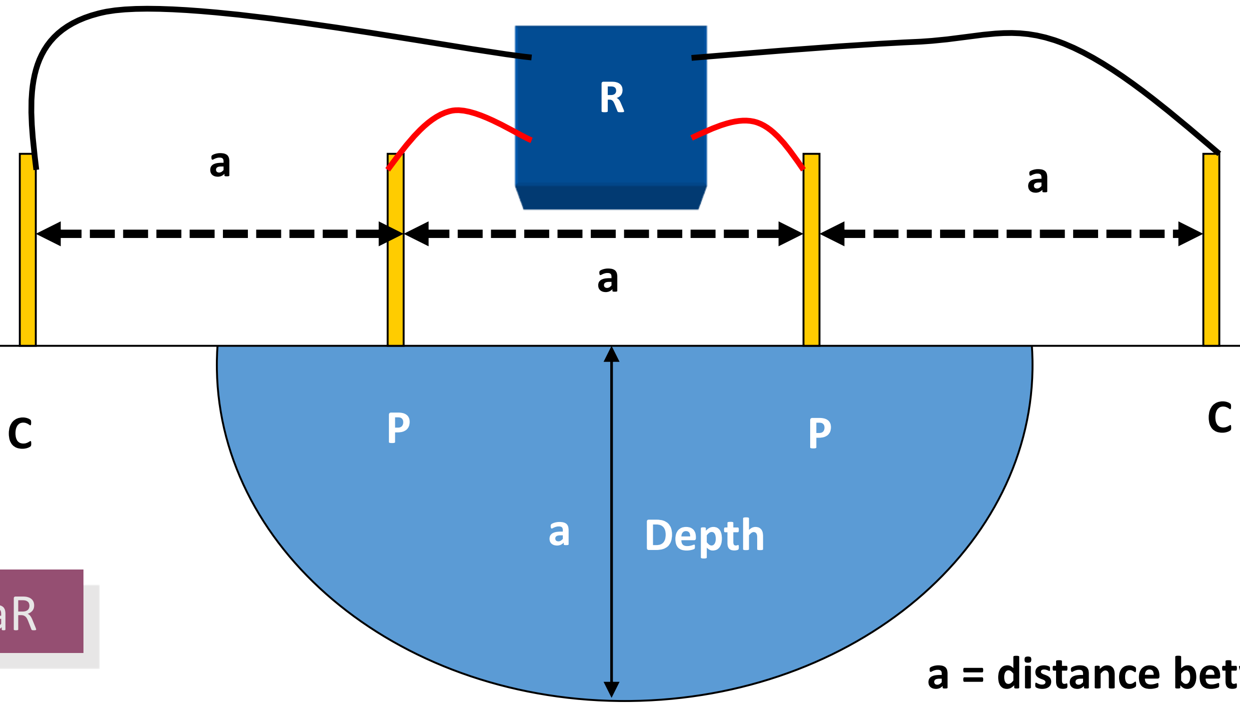
Wenner 4-Pin Method



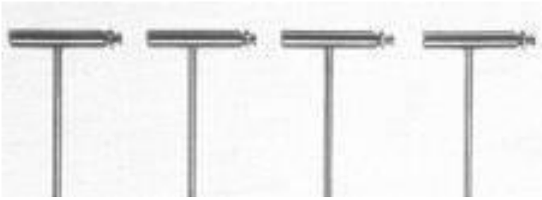
a = distance between pins

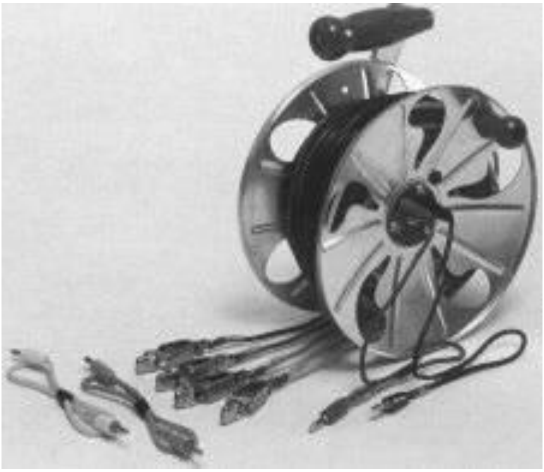
$\rho = 191.5aR$

Resistivity, ρ (ohm-cm)
Pin separation, a (ft)
Resistance, R (ohms)

Measured average resistivity to depth corresponding to distance between pins

4-Pin Soil Resistivity Tester





Soil Resistivity – Collins Rod

Resistivity - Soil Box

Conductivity

- Opposite of resistivity
- Units - millimhos/cm or

  Siemens per meter (S/m)
- The term <u>conductor</u> is used to designate a member of an electrical circuit that easily carries an electrical current

Conductance

- Examples of conductors in corrosion control –
  - Wire or Cable
  - Pipes or other metallic structures
- Different metallic materials have different capabilities for carrying electric current. Related to the characteristic resistivity of the material discussed earlier
- Can water or soil be considered a conductor?

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Conductance

- Different materials have different conductivities, e.g.
  - Copper - 100%
  - Aluminum - 60
  - Magnesium - 36.8
  - Zinc - 27.6
  - Brass - 24.6
  - Steel - 9.6
  - Lead - 8.0

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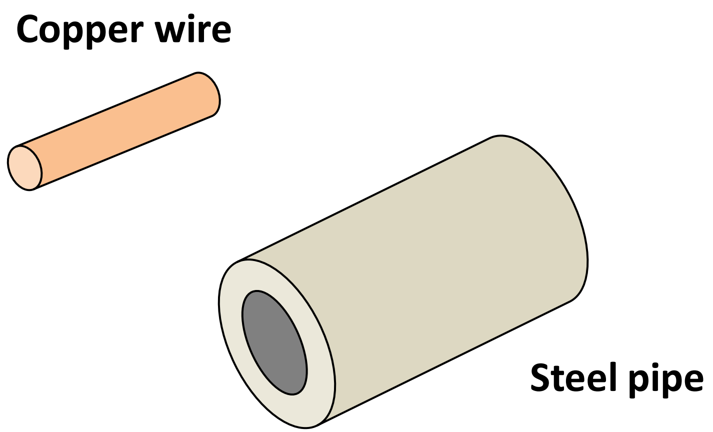
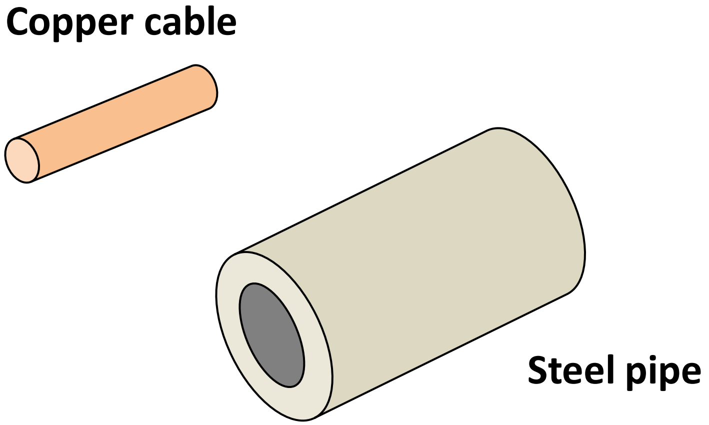
Conductance

- Although copper is the obviously the best conductor material, a steel pipe (even though a relatively poor conductor material) can be a very good practical conductor because, particularly in larger sizes, the amount of steel in the pipe is so much greater than the amount of copper in the usual copper wire or cable



Conductance

- Example,
  - Resistance of 1000 feet of 4/0 American Wire Gage (AWG) copper cable (approx 0.54 inch dia.) about 0.051 ohms
  - Resistance of 1000 feet of 12-inch steel pipe (0.375-inch wall thickness) about 0.0058 ohms i.e., approx one-tenth of the heavy copper cable



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Polarity

- The term polarity is important in determining the direction of conventional current flow in practical usage

- The direction of conventional current flow is "+" positive to "-" negative

- *In chapter 2,* flow of electrons is shown from minus (-) to plus (+) which is opposite to conventional current flow direction

Insulator

- Insulator or insulating material has very high resistance to the flow of electrical current and is used to confine or control the flow of current in electrical circuits

Examples:

- Wire or cable jackets of rubber
- Neoprene
- Plastics
- Fiberglass
- Coatings

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Ohm's Law

- Workers in the field of underground corrosion control must have thorough understanding of Ohm's Law as it applies to DC circuits

- Ohm's Law states that one volt will cause one ampere of current flow through a circuit whose resistance is one ohm

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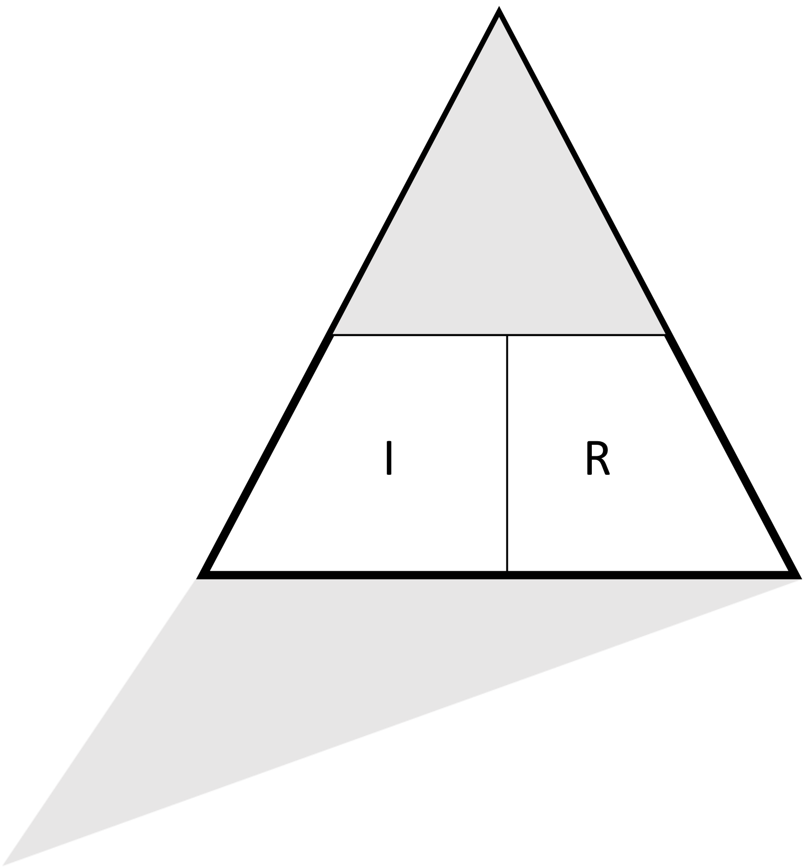
Ohm's Law

- E = I x R
- I = E / R
- R = E / I
  - E = Voltage
  - I = Current
  - R = Resistance
- Power (Watts)
- P = E x I
- $P = I^2 \times R$
  - P = Power in watts
  - R = Resistance in ohms
  - E = Voltage in volts
  - I = Current in amperes



Ohm's Law

- E = I x R
- I = E / R
- R = E / I
  - E = Voltage
  - I = Current
  - R = Resistance

- Power (Watts)
- P = E x I
- P = I^2 x R
  - P = Power in watts
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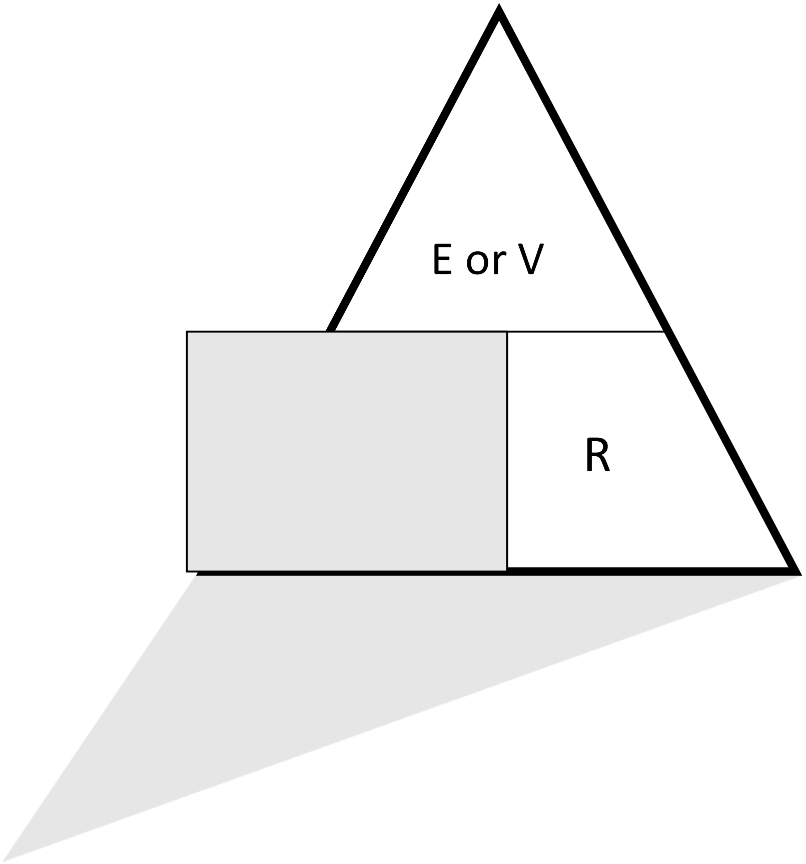
  - I = Current in amperes



Ohm's Law

- E = I x R
- I = E / R
- R = E / I
  - E = Voltage
  - I = Current
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- Power (Watts)
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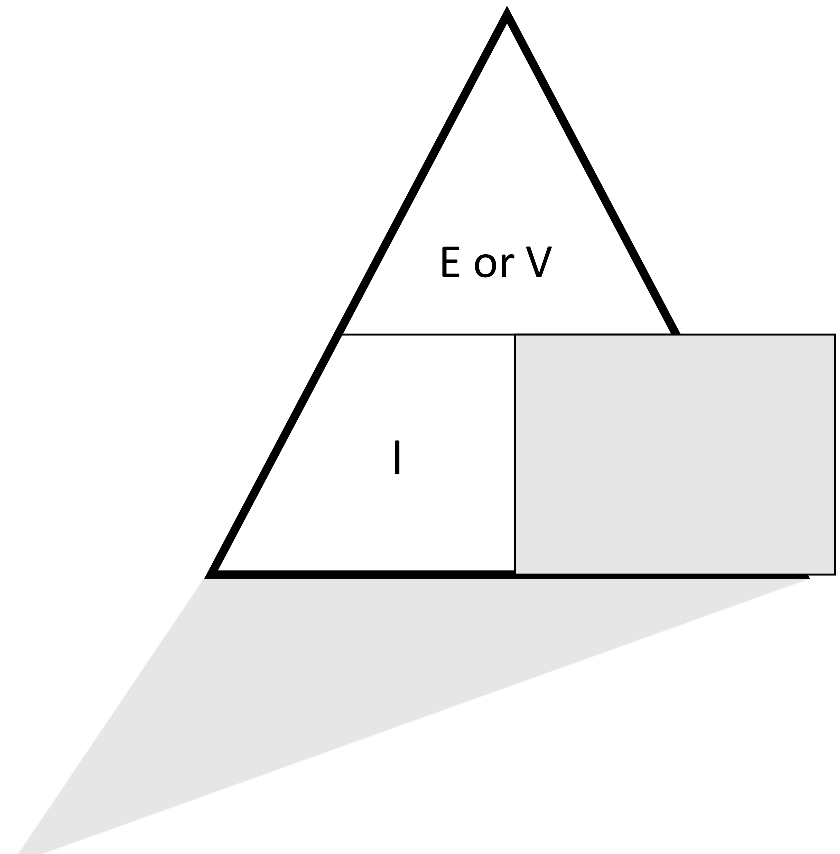
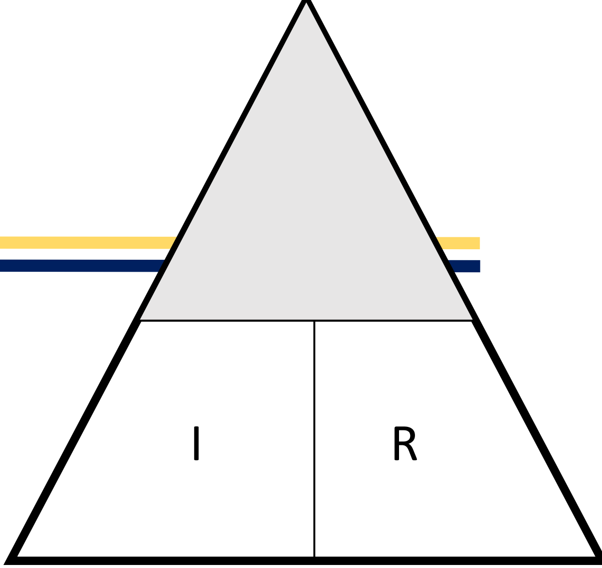


Ohm's Law



- **Assume,**
  - **Current, I, flowing through a circuit is 3.6 A**
  - **Circuit Resistance, R, is 1.7 Ω**
  - **What is the voltage = ?**
  - **E = I x R**
  -
  - **Volts = 3.6 A x 1.7 Ω = 6.12 V**
  - **If any two components are known, the other can be calculated**

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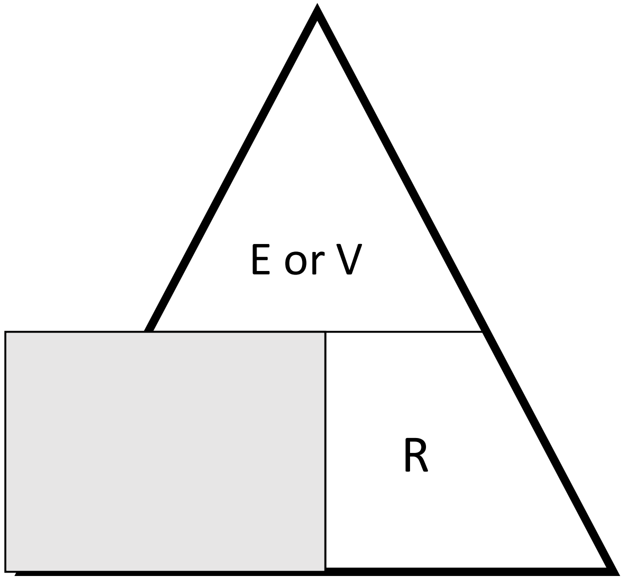
Ohm's Law

- If E = 12 V and R = 3.5 Ω
- What is the current, I ?
- $I = \frac{E}{R} = \frac{12\ V}{3.5\ A}$
- Current, I = 3.43 A



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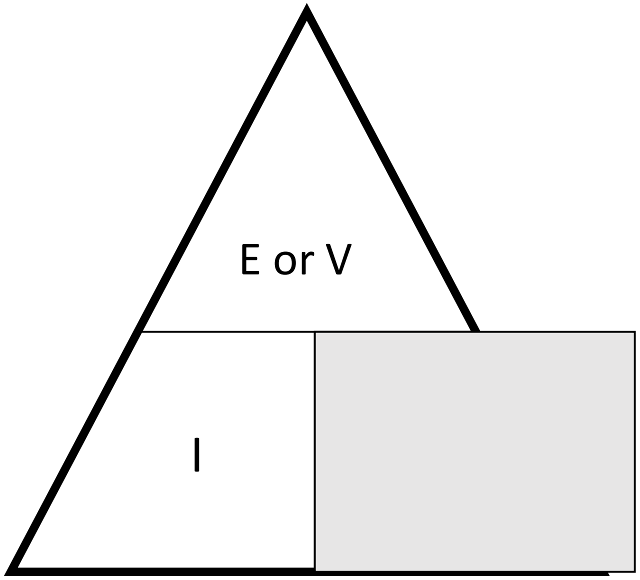
Ohm's Law

- If E = 6.0 V, I = 1.5 A,
- What is the Resistance, R ?
- $R = \frac{E}{I} = \frac{6.0\ V}{1.5}$
- Resistance, R = 4 Ω



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Ohm’s Law - Caution

- **<u>Values entered in the formula must be in appropriate units</u>**

- **For example,**
  - **Voltage circuit is 2.0 V and the current measured in the circuit is 1.0 mA**
  - **<u>Do not mix up units</u>**
  - **Resistance = $\frac{2.0\ V}{1.0\ mA}$ = 2 Ω is WRONG !**

Ohm's Law

- Either convert 1.0 mA to A

  i.e., $\frac{1.0\ \text{mA}}{1000\ \text{mA}} = 0.001\ \text{A}$

- The correct calculation would then be,
  - Resistance $= \frac{2\ \text{V}}{0.001\ \text{A}} = 2000\ \Omega$

- Alternatively, convert V to mV
  - Then, Resistance $= \frac{2000\ \text{mV}}{1.0\ \text{mA}} = 2000\ \Omega$

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Basic Electrical Circuit

- Figure 1-3 shows a simple circuit with a single resistor
- Assume that a DC power source providing current to a cathodic protection system for corrosion has instruments which indicate the following:
- Supply voltage (E) is 20 V
- Current flow (I) is 5 A
- Circuit resistance (R) can be calculated using Ohm's law, R = E/I
- Circuit Resistance = 20V/5A = 4 Ohms

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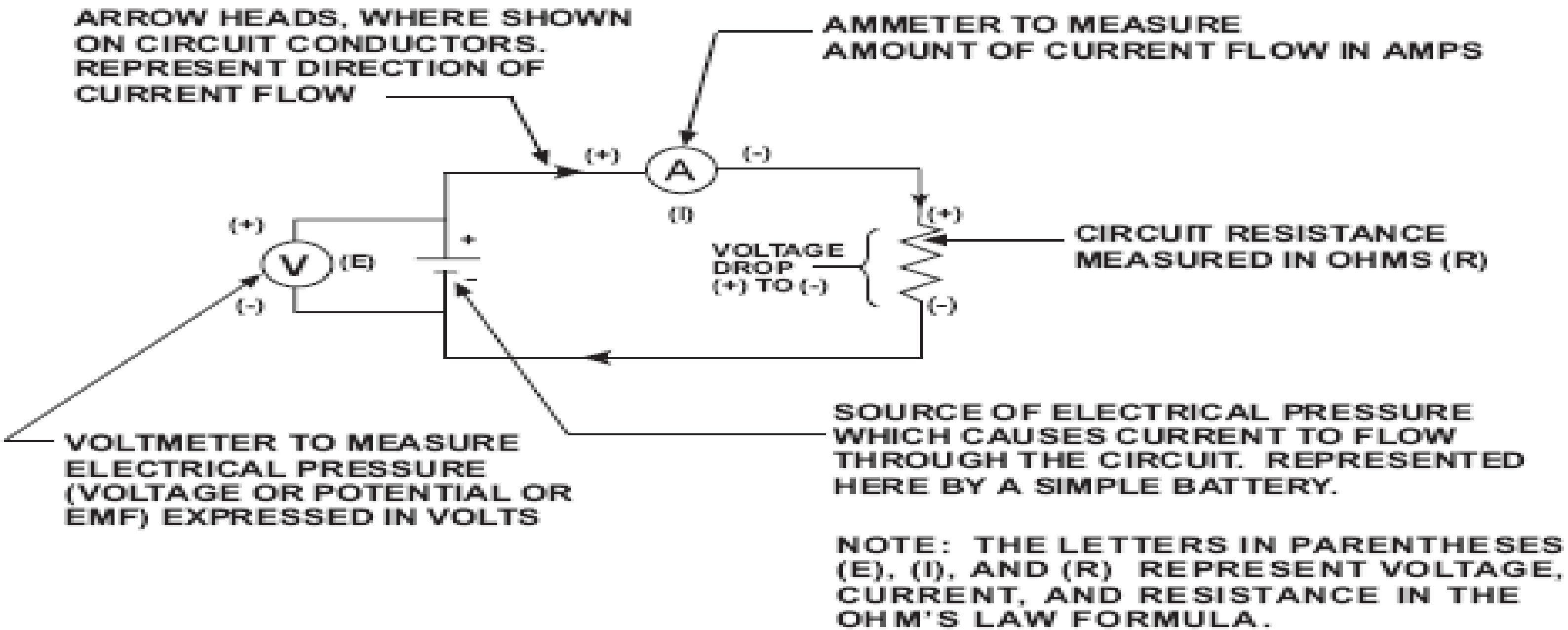

THE BASIC ELECTRICAL CIRCUIT
FIGURE 1-3

Basic Electrical Circuit

- 20 V DC power source is connected across a known resistance of 4 Ω
- What is the current flow ?
- Can be calculated by using I = E/R
- Current Flow (I) = 20 V / 4 Ω = 5 A

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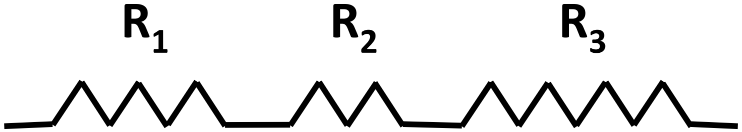
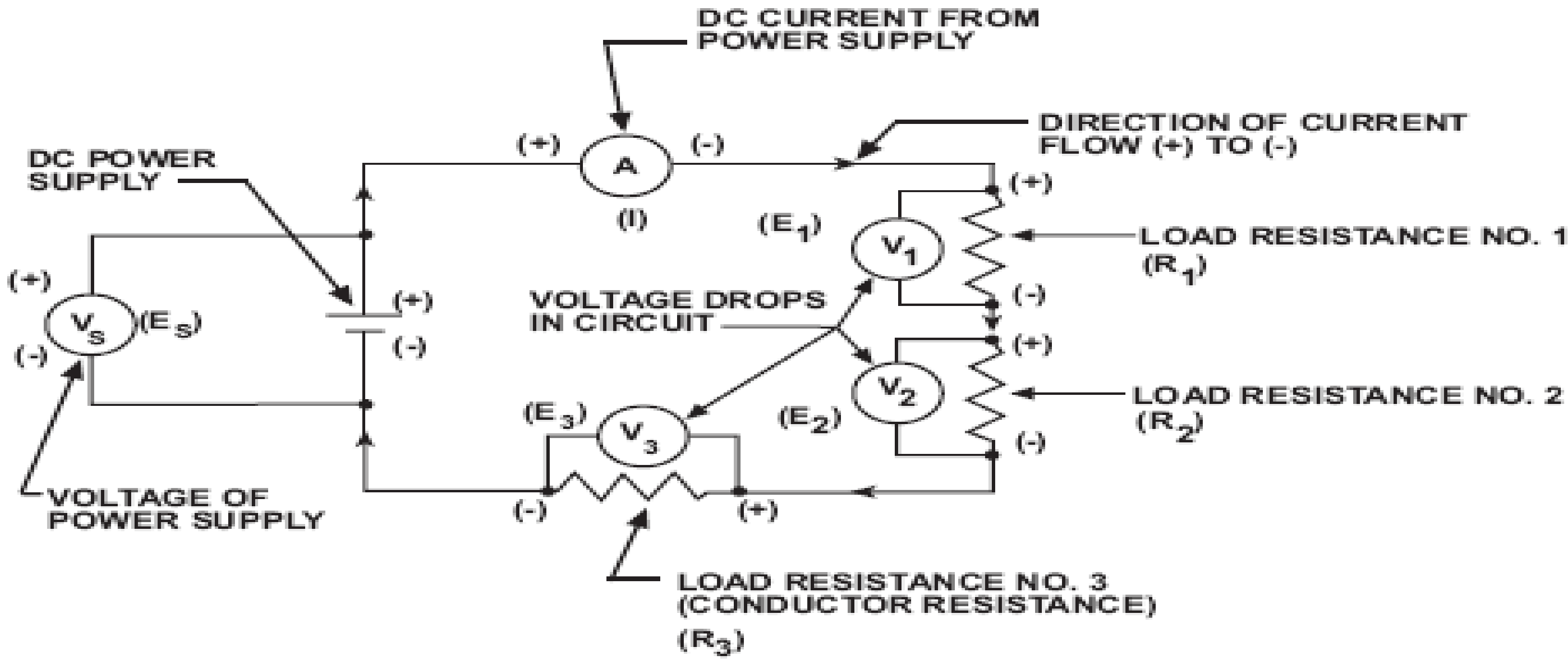
The Series Electrical Circuit

- Figure 1-4 represents an electrical circuit where the total circuit resistance comprises 3 load resistances connected in series
- "Series" means that the load resistances are connected end-to-end and that the same amount of current passes through each of the resistances
- Total resistance is sum of all resistances in series
- $R_{Total} = R_1 + R_2 + R_3 + \ldots\ldots$





SERIES ELECTRICAL CIRCUIT

FIGURE 1-4

The Series Electrical Circuit

- Assume the following values for the circuit in figure 1-4
- Power supply voltage (E_S) = 10 V
- Circuit current flow (I) = 2.0 A
- Load resistance No. 1 (R_1) = 3.0 Ω
- Load resistance No. 2 (R_2) = 1.87 Ω
- Load resistance No. 3 (R_3) = 0.13 ohms

(20 ft of No. 8 wire)

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Series Circuit

- Calculate the voltage drops across the three resistances
- Across R1: Voltage drop (V_1) = 2 A x 3.00 Ω = 6.0V
- Across R2: Voltage drop (V_2) = 2 A x 1.87 Ω = 3.74V
- Across R3: Voltage drop (V_3) = 2 A x 0.13 Ω = 0.26V

- Sum of these voltages is:
  6.0 V + 3.74 V + 0.26 V = 10 V
- Sum of the resistances is:
  3.0 + 1.87 + 0.13 = 5 Ω

- Check : E = I x R

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Series Electrical Circuit

- Assume the resistance values of R1, R2, and R3 are unknown
- Power source voltage, Es = 10 V and current, I, in the circuit is = 2 A
- Determine the value of each resistor

Series Electrical Circuit

- Measure the voltage drop across resistances R1 and R2 using a suitable DC voltmeter:
  - **Measured voltage drop across resistance R1 = 6 V**
  - **Measured voltage drop across resistance R2 = 3.74 V**
  - **Calculated resistance R1 = 6 V / 2 A = 3 Ω**
  - **Calculated resistance R2 = 3.74 V / 2 A = 1.87 Ω**

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Series Electrical Circuit

- Power source voltage (10V) and circuit current (2A) are known
- Using Ohm's law,
  - Total Circuit Resistance = 10 V / 2 A = 5 Ω
- Therefore, the value of resistance R3 is 5 Ω minus the sum of R_1 and R_2
  - Resistance R3 = 5 – (3 + 1.87) = 0.13 Ω

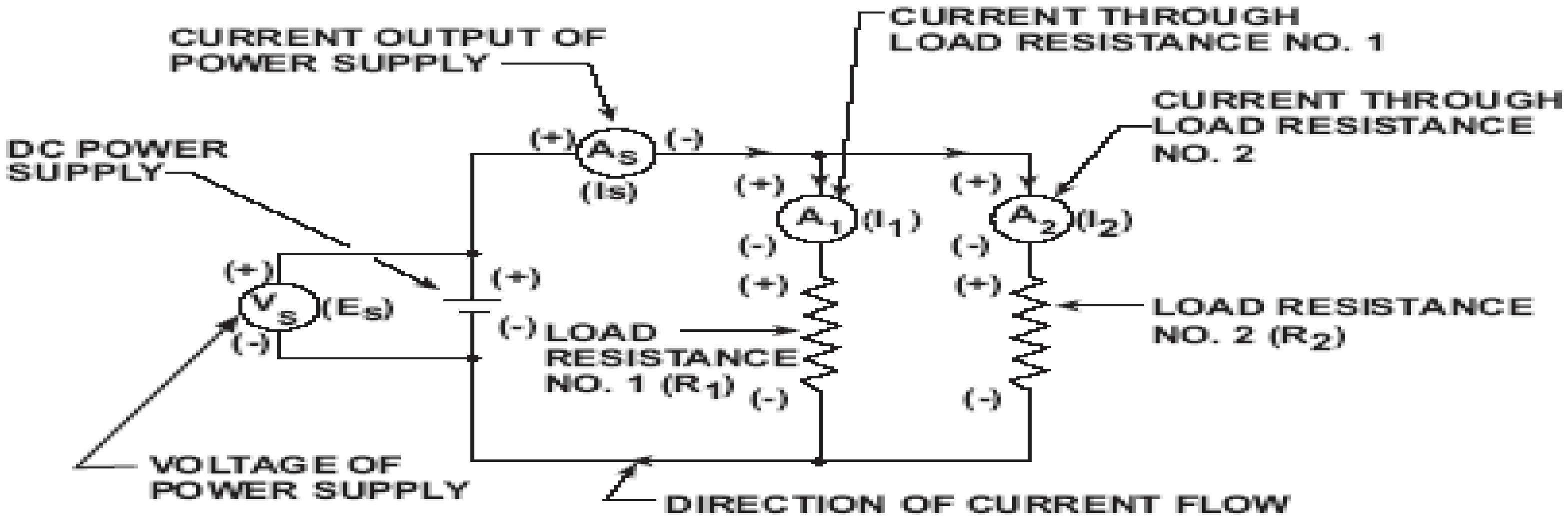
Series Electrical Circuit

- Things to remember:
- Same amount of current flows from the power source through each resistance element in the circuit
- Sum of the voltage drops across the resistance elements in the circuit must equal the voltage of the power source
- Sum of resistance elements in the circuit must equal the total circuit resistance:

  $RT = R1 + R2 + R3 ......$

Parallel Electrical Circuit

- Two or more load resistances are connected in parallel
- That is: + (current input) ends of all resistances are connected together instead of being connected end-to-end as is the case with a series circuit
- See Figure 1-5



PARALLEL ELECTRICAL CIRCUIT
FIGURE 1-5

Parallel Electrical Circuit

- Power source voltage is impressed on each resistance element instead of being distributed like in a series circuit

- Current is divided among the resistance branches

The Parallel Electrical Circuit

- Assume the following:
- Power supply voltage (E_S) = 20 volts
- Power supply current (I_S) = 16.67 amps
- Load Resistance R_1 = 3 ohms
- Load Resistance R_2 = 2 ohms

The Parallel Electrical Circuit

- First calculate the current flow (I_1 and I_2) through resistances R_1 and R_2
- Voltage drop across each branch equals the power supply voltage (ES) = <u>20 V</u>

- Current flow through R_1
  - $I_1 = 20\ V / 3\ \Omega = \underline{6.67\ A}$

- Current flow through R_2
  - $I_2 = 20\ V / 2\ \Omega = \underline{10\ A}$

- The sum of these two should equal the power source output current of 16.67 amps

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The Parallel Electrical Circuit

- Second, calculate the parallel resistance of R_1 and R_2
- Parallel Resistance Formula, $R_{Total} = \dfrac{R_1 \times R_2}{R_1 + R_2}$
- $R_{Total} = \dfrac{3\ \Omega \times 2\ \Omega}{3\ \Omega + 2\ \Omega} = \dfrac{6}{5} = \mathbf{1.2\ \Omega}$

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Parallel Electrical Circuit

- Note that the parallel resistance, R_{Total}, of any two resistors is always less than the resistance of the smaller one

- Perform check, $R_{Total} = E_S / I_S$

- R_T = 20 V / 16.67 A = **1.2 Ω**

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The Parallel Electrical Circuit

- Parallel circuit resistance with more than two branches, can be calculated as follows:

$$\frac{1}{R_{Total}} = \frac{1}{R_1} + \frac{1}{R_2} + \frac{1}{R_3} + \ldots..$$

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The Parallel Electrical Circuits

- Remember the following important points:
  - **Full power supply voltage is impressed across each parallel branch**
  - **Sum of the currents through the individual parallel branches must equal the total current output of the power source**
  - **Parallel resistance of two or more branches will always be less than that of the smallest branch resistance**

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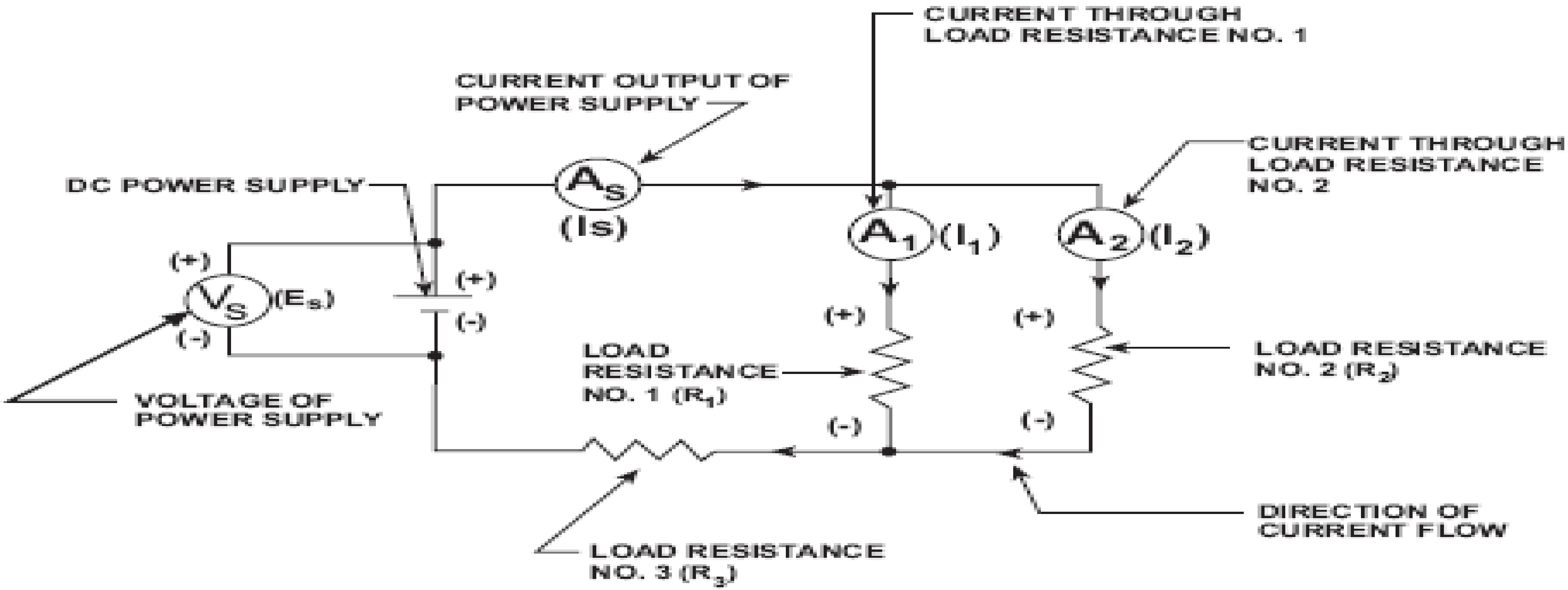
Combination Circuits

- Circuits can be a combination of series elements and parallel elements
- See Figure 1-6



COMBINATION ELECTRICAL CIRCUIT

FIGURE 1-6

Combination Circuit

- The power supply output current divides between the two parallel branches R_1 and R_2 and then combines again after passing through these resistances

- The full power supply current then passes through the resistance element R_3

- Step 1: Calculate the effective resistance (R_p) of the parallel resistance elements, $1/R_p = 1/R_1 + 1/R_2$

- Step 2: Add that resistance to the series resistance elements to obtain total resistance, $R_{Total} = R_3 + R_p$

Combination Circuit

- <u>Step 3</u>: Calculate current flow, $I = V_S / R_{Total}$

  This is the total current passing through R_1 and R_2 combined and also through R_3
- <u>Step 4</u>: Calculate voltage drop across R_3 , $V_3 = I \times R_3$
- <u>Step 5</u>: Calculate voltage drop across R_1 and R_2

  It will be will be the same across each, $V_S - V_3$
- <u>Step 6</u>: Calculate current passing through R_1 and R_2 ,

  $I_1 = (V_S - V_3) / R_1$ and $I_2 = (V_S - V_3) / R_2$

<u>Check</u>: I must equal $I_1 + I_2$

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