INTRODUCTION TO ELECTRICAL SYSTEMS + RESISTORS

EE 306 – SS2016

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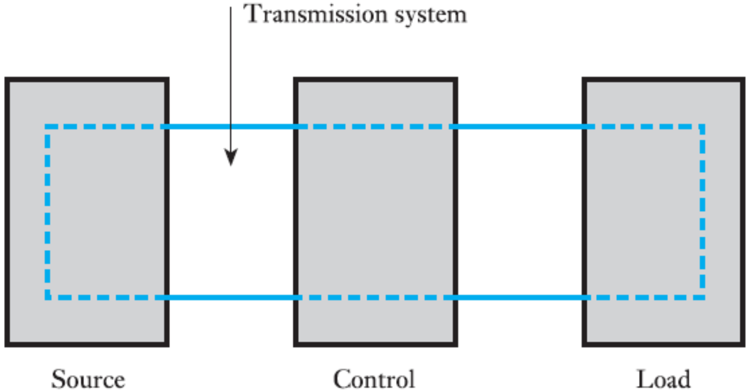
Motivation

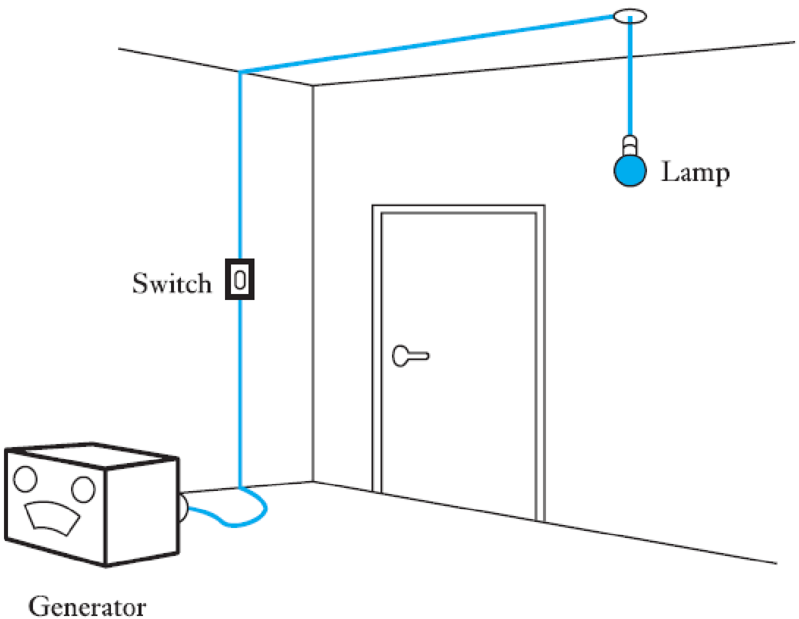
- Electricity can be considered from two points of view:
  - Scientist: concerned with what happens in an electric system and seeks to explain its mysteries.
  - Engineer accepts that electricity is there and seeks to make use of its properties without the need to fully understand them
- As engineers, we concentrate on most signigicant features of electricity : Electrical system permits transmitting energy from source of supply to point of application
- Electrical engineering fields:
  - Production of electrical energy
  - Transmission of electrical energy
  - Application of electrical energy
  - Control of electrical energy

Electrical System Components

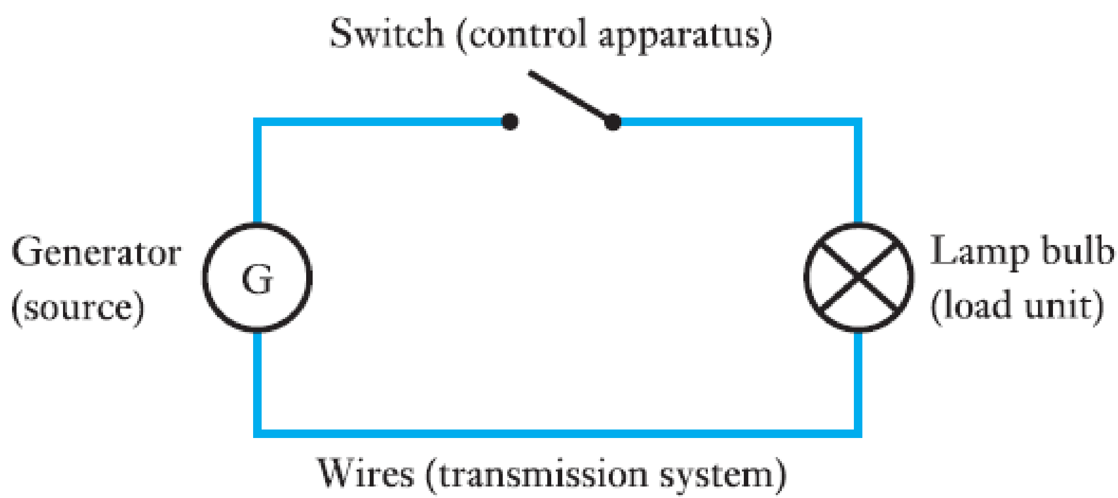
- Source
  - Provides energy for electrical system (e.g., battery or generator)
- Load
  - Absorbs electrical energy supplied by source (e.g., lamp)
- Transmission system
  - Conducts energy from source to load – Typically use insulated wire
- Control apparatus
  - Control delivery of energy from source to load (e.g., switch)



Electrical System: Example



Symbol	Representing
	Wires (conductors)
G	Generator
	Lamp bulb
	Switch

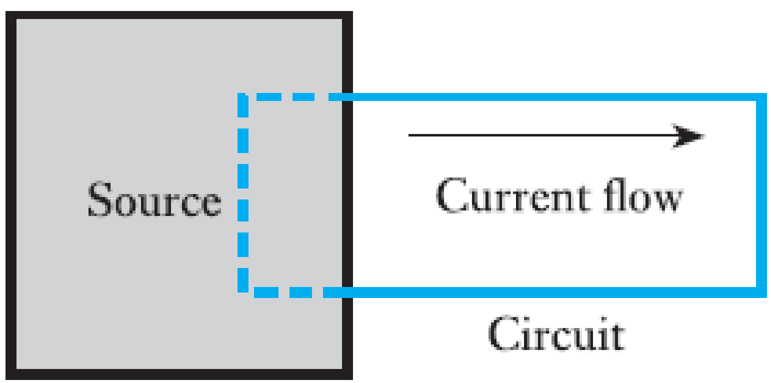


Electric Charge and its Movement

- Electrical system transmits energy due to movement of electric charge
- Electricity appears in one of two forms: negative and positive electricity
  - Negative: electron is elementary particle charged with negative electricity.
  - Positive: Proton is similarly defined but charged with positive electricity
- In conductors, free electrons are available and can easily move
  - All electrons have a certain potential energy
  - They move freely from one energy level to another and this movement is termed *electric current flow*

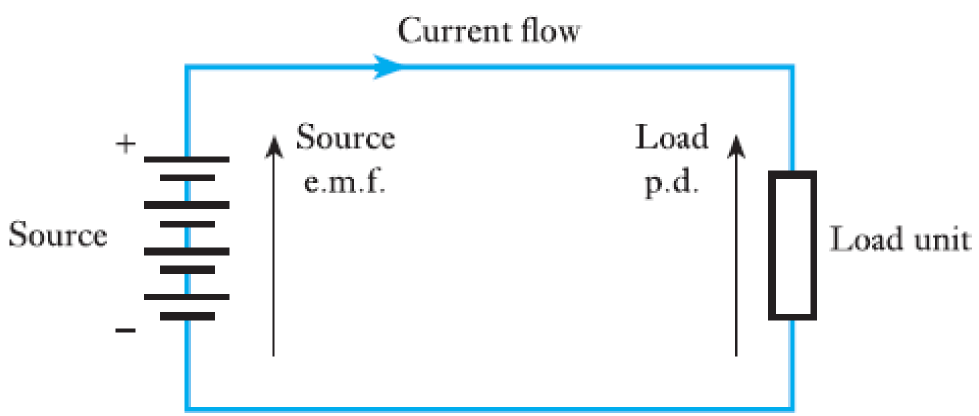
Current Flow in a Circuit

- For current flow to continue in a circuit, following conditions should be fulfilled:
  1. There must be a complete circuit around which the electrons may move.
  2. There must be a driving influence to cause the continuous flow
- Driving influence is termed electromotive force (e.m.f.)
  - Each time charge passes through source, more energy is provided by source to permit it to continue round once more



Electromotive Force and Potential Difference

- e.m.f. represents driving influence that causes current to flow
- Energy transferred due to passage of unit charge between two points in a circuit is termed potential difference (p.d.)
  - If all energy transferred to load, p.d. across load unit = source e.m.f.
- Both e.m.f. and p.d. are similar quantities but e.m.f. is always active in that it tends to produce electric current in a circuit whereas p.d. may be either passive or active
  - p.d. is passive whenever it has no tendency to create current in a circuit



Electrical Units

Current Symbol: I Unit: ampere (A)

$$Q \text{ [coulombs]} = I \text{ [amperes]} \times t \text{ [seconds]}$$

$$\therefore \quad Q = It$$

Charge Symbol: Q Unit: coulomb (C)

Electric potential Symbol: V Unit: volt (V)

Electric resistance Symbol: R Unit: ohm (Ω)

$$P = VI$$

$$V = \frac{W}{Q}$$

$$V = IR$$

$$P = IV = I^2R$$

$$W = Pt = I^2Rt = IVt$$

Electrical Units

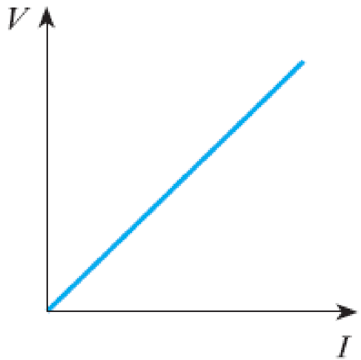
Electromotive force Symbol: E Unit: volt (V)

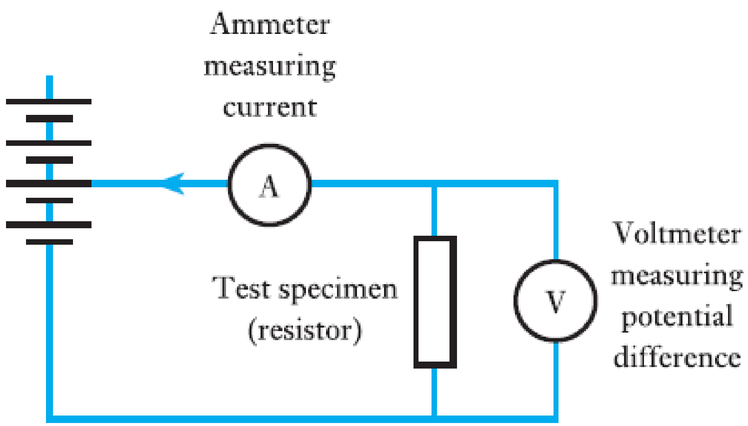
- The principal sources of e.m.f. are as follows:
  - The electrodes of dissimilar materials immersed in an electrolyte, as in primary and secondary cells, i.e. batteries
  - The relative movement of a conductor and a magnetic flux, as in electric generators; this source can, alternatively, be expressed as the variation of magnetic flux linked with a coil
  - The difference of temperature between junctions of dissimilar metals, as in thermo-junctions

Ohm's Law

- p.d. across ends of many conductors is proportional to current flowing between them
  - Direct proportionality, provided that temperature remained constant
  - Proportionality constant termed Resistance R

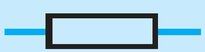
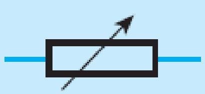
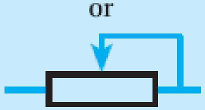
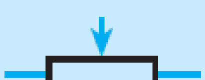
$$V \propto I \quad \Rightarrow \quad V = IR$$

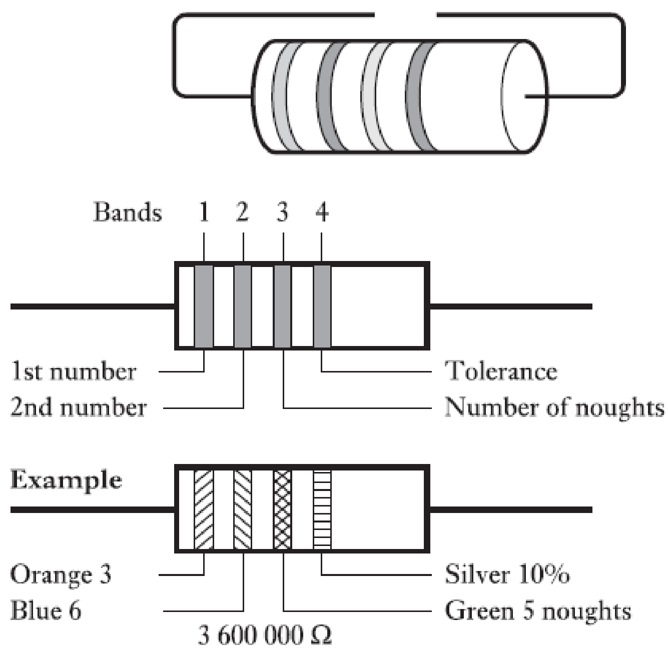




Resistors

- Resistor is device which provides resistance in electrical circuit
- Resistance is said to be linear if current through resistor is proportional to p.d. across its terminals
  - Otherwise, called non-linear (e.g., resistors made from semiconductors)

Symbol	Representing
	Fixed resistor
	Resistor symbol found in old diagrams, no longer used
 or 	Variable resistor (or rheostat)
	Potentiometer



Digit	Colour
0	Black
1	Brown
2	Red
3	Orange
4	Yellow
5	Green
6	Blue
7	Violet
8	Grey
9	White
Tolerance	**Colour**
5%	Gold
10%	Silver
20%	No colour band

Resistors: Standard Values and Marking

5% Tolerance Values
(10% Bold)

Ohms (Ω)					Kilohms (kΩ)		Megohms (MΩ)	
0.10	**1.0**	**10**	**100**	**1000**	**10**	**100**	**1.0**	**10.0**
0.11	1.1	11	110	1100	11	110	1.1	11.0
0.12	**1.2**	**12**	**120**	**1200**	**12**	**120**	**1.2**	**12.0**
0.13	1.3	13	130	1300	13	130	1.3	13.0
0.15	**1.5**	**15**	**150**	**1500**	**15**	**150**	**1.5**	**15.0**
0.16	1.6	16	160	1600	16	160	1.6	16.0
0.18	**1.8**	**18**	**180**	**1800**	**18**	**180**	**1.8**	**18.0**
0.20	2.0	20	200	2000	20	200	2.0	20.0
0.22	**2.2**	**22**	**220**	**2200**	**22**	**220**	**2.2**	**22.0**
0.24	2.4	24	240	2400	24	240	2.4	
0.27	**2.7**	**27**	**270**	**2700**	**27**	**270**	**2.7**	
0.30	3.0	30	300	3000	30	300	3.0	
0.33	**3.3**	**33**	**330**	**3300**	**33**	**330**	**3.3**	
0.36	3.6	36	360	3600	36	360	3.6	
0.39	**3.9**	**39**	**390**	**3900**	**39**	**390**	**3.9**	
0.43	4.3	43	430	4300	43	430	4.3	
0.47	**4.7**	**47**	**470**	**4700**	**47**	**470**	**4.7**	
0.51	5.1	51	510	5100	51	510	5.1	
0.56	**5.6**	**56**	**560**	**5600**	**56**	**560**	**5.6**	
0.62	6.2	62	620	6200	62	620	6.2	
0.68	**6.8**	**68**	**680**	**6800**	**68**	**680**	**6.8**	
0.75	7.5	75	750	7500	75	750	7.5	
0.82	**8.2**	**82**	**820**	**8200**	**82**	**820**	**8.2**	
0.91	9.1	91	910	9100	91	910	9.1	

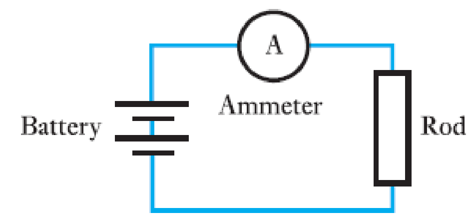
Band 5 (Optional)

1	Brown
0.1	Red
0.01	Orange
0.001	Yellow

Resistance	Marking
0.47 Ω	R47
4.7 Ω	4R7
47 Ω	47R
470 Ω	470R
4.7 kΩ	4K7
47 kΩ	47K
4.7 MΩ	4M7

Conductors and Insulators

- Experiment: Measure resistance of rods made of different materials
  - Rods made from metals permit reasonable currents to flow
  - Rods made from non-metallic materials permit virtually no current
- Classification is rather oversimplified
  - No material completely stops flow of current
  - No material freely permits passage of current
- Not all metals conduct the same
  - Ex. Copper conducts better than steel



Conductors	Insulators
Copper	Glass
Aluminium	Rubber
Silver	Plastic
Platinum	Air
Bronze	Varnish
Gold	Paper
	Wood
	Mica
	Ceramic
	Certain oils

Resistivity

- Certain materials permit the reasonably free passage of electric charge and are termed conductors, while others oppose such a free passage and are termed insulators
  - These abilities are simply taken relative to one another and depend on material considered but other factors also have to be taken into account

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

Material	ρ (Ω m) at 0 °C
Aluminium	2.7×10^{-8}
Brass	7.2×10^{-8}
Copper	1.59×10^{-8}
Eureka	49.00×10^{-8}
Manganin	42.00×10^{-8}
Carbon	6500.00×10^{-8}
Tungsten	5.35×10^{-8}
Zinc	5.37×10^{-8}

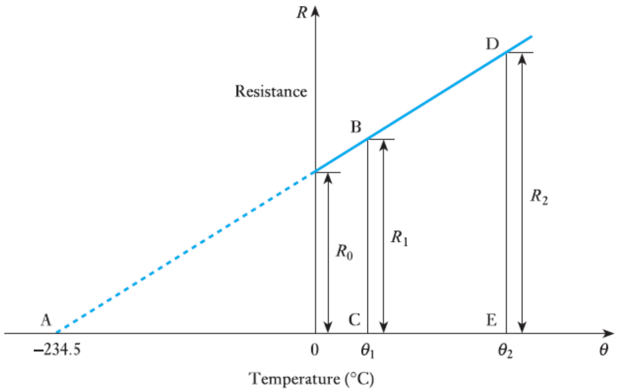
Resistivity   Symbol: ρ Unit: ohm metre (Ω m)

Temperature Coefficient of Resistance

- Resistance of all pure metals increases with increase of temperature, whereas the resistance of carbon, electrolytes and insulating materials decreases with increase of temperature
- Ratio of change of resistance per degree change of temperature to resistance at some definite temperature is termed *temperature coefficient of resistance* and is represented by α

Temperature coefficient of resistance

Symbol: α Unit: reciprocal degree centigrade (/°C)



Temperature Coefficient of Resistance

- In general, if a material having a resistance R_0 at 0°C, taken as standard temperature, has a resistance R_1 at θ_1 and R_2 at θ_2, and if α_0 is temperature coefficient of resistance at 0 °C,

$$R_1 = R_0(1 + \alpha_0\theta_1)$$

$$\frac{R_1}{R_2} = \frac{1 + \alpha_0\theta_1}{1 + \alpha_0\theta_2}$$

- If standard temperature is taken as 20°C

$$R_t = R_{20}\{1 + \alpha_{20}(\theta - 20)\}$$

Material	α_0(/°C) at 0 °C
Aluminium	0.003 81
Copper	0.004 28
Silver	0.004 08
Nickel	0.006 18
Tin	0.004 4
Zinc	0.003 85
Carbon	–0.000 48
Manganin	0.000 02
Constantan	0
Eureka	0.000 01
Brass	0.001

Temperature Rise

- The maximum power which can be dissipated as heat in an electrical circuit is limited by the maximum permissible temperature, and the latter depends upon the nature of the insulating material employed.
  - Materials such as paper and cotton become brittle if their temperature exceed about 100 °C, whereas materials such as mica and glass can withstand much higher temperature without any effect on their insulating and mechanical properties
- When an electrical device is loaded, temperature rise of device is largely due to I^2R loss in conductors
  - The greater the load, the greater is the loss and therefore the higher the temperature rise
  - Full load or rated output of the device is maximum output obtainable under specified conditions, e.g. for specified temperature rise after device has been loaded continuously for period of minutes or hours
- Temperature rise can damage insulation and hence is the basis of rating electrical equipment

Summary

Current is the rate of flow of electric charge in a circuit. The term is often used to describe the flow of electric charge, e.g. ‘a current is flowing in a circuit’; this is ambiguous but is so common that we have to accept it.

A **source** supplies energy to a system.

A **load** accepts energy from a system.

Electric charge may be either positive or negative. Negative electrons are free to move around a circuit thus transporting energy from source to load.

To maintain a current, the source must provide a driving force called the **electromotive force** (e.m.f.).

The **potential difference** across a load indicates in volts the energy lost per coulomb of charge passing through the load.

Summary

Since the current is the rate of flow, its product with the voltage gives the rate of energy transmission, i.e. the **power**.

Resistance is a measure of the opposition to the flow of charge through a load.

Ohm's law states that the ratio of voltage to current is constant, provided other physical factors such as temperature remain unchanged.

The resistances of resistors can be identified by a code system.

Electric charge $Q = It$ (coulombs)

Voltage $V = P/I$ (volts)

$V = W/Q$

$V = IR$

Power $P = IV = I^2R = V^2/R$ (watts)

Resistance $R = \rho l/A$

Using the temperature coefficient of resistance:

$$\frac{R_1}{R_2} = \frac{1 + \alpha_0\theta_1}{1 + \alpha_0\theta_2}$$

Suggested Readings and Exercises

- Hughes textbook – Chapters 2 and 3
- Exercise 2 (Hughes)
  - Problems 7, 12, 16, 18, 19, 22
- Exercise 3 (Hughes)
  - Problems 18, 19, 20, 21, 22, 23