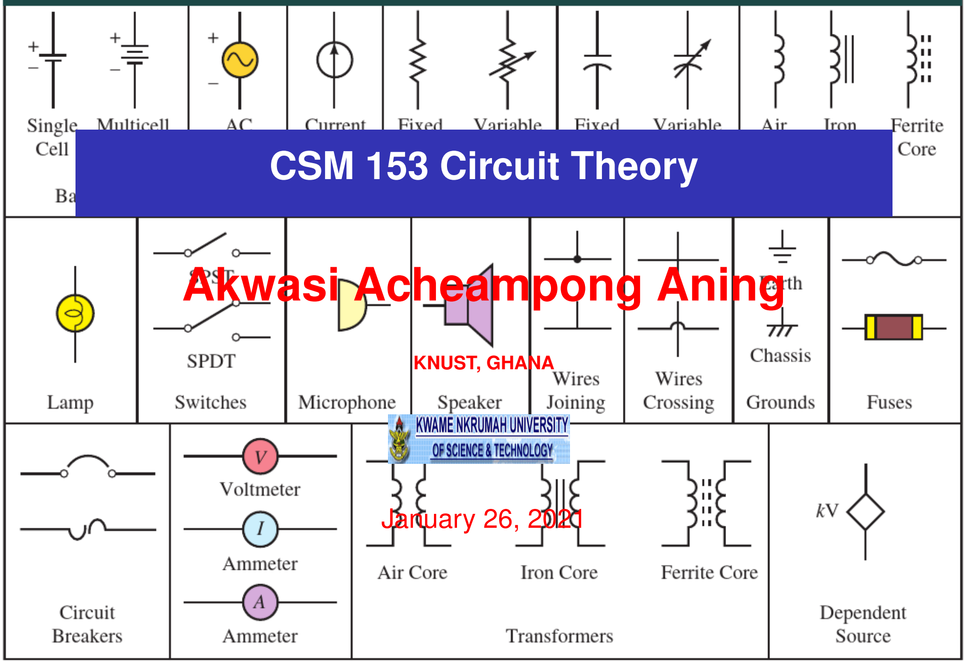

CSM 153 Circuit Theory

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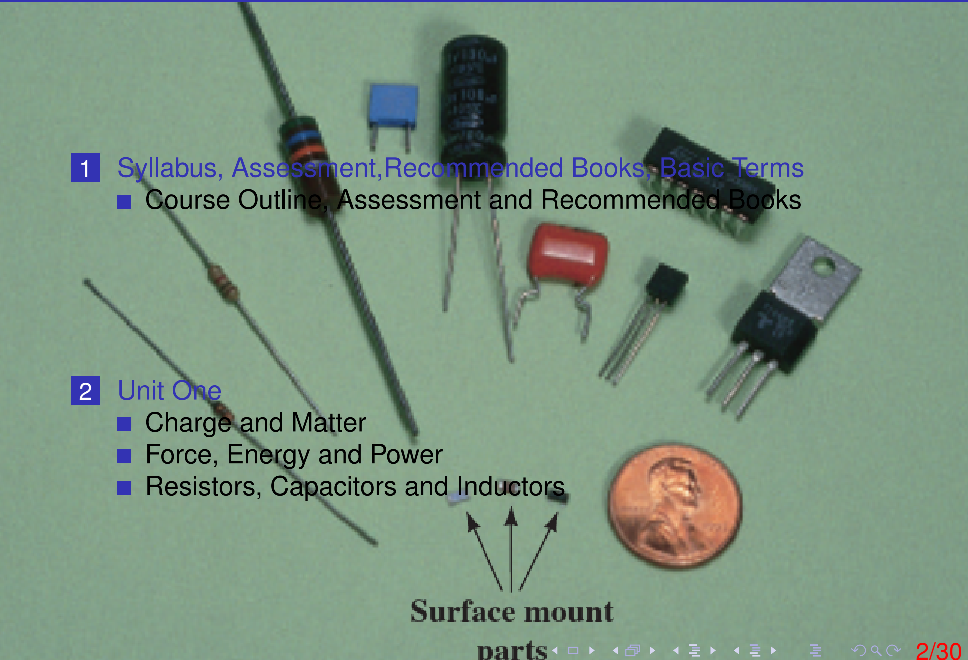
Outline I

1. Syllabus, Assessment,Recommended Books, Basic Terms
   - Course Outline, Assessment and Recommended Books
2. Unit One
   - Charge and Matter
   - Force, Energy and Power
   - Resistors, Capacitors and Inductors



KNUST COVID-19 AWARENESS

COVID-19

- COVID-19: Caused by a virus known as Severe Acute Respiratory Syndrome Coronavirus-2 (SARS-CoV-2). Spreads very easily from person to person.
- **Signs and symptoms**
  - Fever or chills
  - cough, difficulty in breathing, cold
  - headache, diarrhoea, loss of taste/smell and
  - several non-specific symptoms
- **Transmission**
  - Respiratory droplets
  - airborne
  - contaminated surfaces
- **Prevention**
  - Adhere to the KNUST COVID-19 safety protocols
  - Respiratory hygiene: Wear a nose mask, cough etiquettes
  - Hand hygiene: Frequent hand washing, hand sanitizing
  - Maintain ‘safe’ physical distancing
  - Avoid crowds and confined/poorly ventilated spaces

Virus is changing itself with even more serious ramifications, so it is important we all adhere to the safety protocols

Course Outline

- Unit 1: Basic Concepts and Elements
  - Charge and Matter
  - Force, Energy and Power
  - Resistors, Capacitors and Inductors
- Unit 2: Direct Circuit Analysis
  - Ohm's law
  - Series Circuit
  - Parallel Circuit
  - Methods of Analysis
- Unit 3: Networks Theorems
  - Superposition Theorem
  - Thevenin's Theorem
  - Norton's Theorem
  - Delta and Wye Networks

Course Outline

- Unit 4: Magnetism
  - Field and Force
  - Electromagnetics
  - Ampere's Law
  - Biot-Savart Law
- Unit 5: AC Circuits
  - Alternating Currents and Voltages
  - R, L and C Elements
  - Power in AC Circuits

Assessment

- Exam = 70%
- Quiz, home works, attendance and Mid-semester Exam = 30%

Recommended Books

- Giancoli, D. C. Physics: Principles with Applications 7th Edition. 2014.
- Randall D. Knight, Physics for Scientists and Engineers a Strategic Approach with Modern Physics 4/e, 2017
- Raymond A. Serway and John W. Jewett Jr., Physics for Scientists and Engineers with Modern Physics, 10th Edition, 2019
- Allan H. Robbins and Wilhelm C. Miller, Circuit Analysis: Theory and Practice, Fifth Edition, 2013
- William H. Hayt, Jr., Jack E. Kemmerly and Steven M. Durbin Engineering Circuit Analysis, 8th Edition, 2012
- John Bird, Electrical Circuit Theory and Technology Sixth edition, 2017
- Any University Physics Book

Course Objectives

- To introduce electric circuits and its analysis
- To impart knowledge on solving circuit equations using network theorems
- To develop a clear understanding of the important parameters of a magnetic circuit
- To introduce the phenomenon of resonance in coupled circuits.

Learning Outcomes

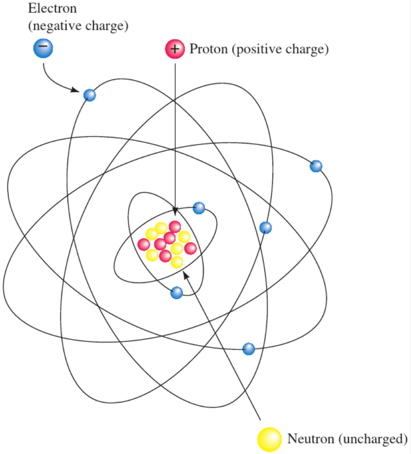
- To be able to understand basic electrical properties
- Use node and mesh analyses methods for the analysis of linear circuits
- Analyze circuits by utilizing Superposition, Thevenin's and Norton's theorems.
- To be able to understand basic magnetic properties

UNIT ONE
Basic Concepts and Elements

Charge and Matter

- Sub-atomic particles make up atoms, which make up ordinary matter
- Thus, matter is made up of several sub-atomic particles (protons, electrons and neutrons)
- The protons and neutrons (nucleons) are closely packed to form the nucleus
- If the nucleus is considered a sphere, its diameter is of the order of 10^{-14}
- The total charge of electrons balance the total charge of protons
- The atom as a whole is electrically neutral (no charge)

The Structure of the Atom



Charge and Matter

The Structure of the Atom: The Neutron

- It has no electrical charge so it is electrically neutral
- It cannot be deflected by electric and magnetic fields because it has no charge
- They are more penetrating than the electron or the proton

The Structure of the Atom: The Electron

- The electron has negative charge of $1.6x10^{-19}C$
- It can be deflected by electric and magnetic fields
- It is always deflected towards the positive plate in an electric field

The Structure of the Atom: The Proton

- It has a positive charge equal in magnitude to the charge on the electron
- It can be deflected by electric and magnetic fields
- It is always deflected towards the negative plate in an electric field

Charge and Matter

The Structure of the Atom

- The protons and neutrons of an atom share a very small volume of space called the nucleus of the atom
- The electrons are attracted to the nucleus by a force called the electrostatic force or Coulomb force
- This force exists because the electrons and nuclei have electric charges of opposite sign
- The electron is negatively charged and the nucleus is positively charged
- The positive charge of the nucleus is entirely due to the charges of protons, since the neutrons do not have any net electric charge
- The charge of an object can be regarded as the algebraic sum of all the elementary atomic charges which make up the object
- The electric charge is an intrinsic property of the elementary particles, such as electron or proton, just as mass is an intrinsic property of matter

Charge and Matter

The Structure of the Atom

- Thus, electric charge is a property (characteristic) associated with fundamental particles wherever they exist
- Mass can create a gravitational field g, which in turn can exert a force mg on a body of mass m
- Thus, mass m can create gravitational force $F_g = mg$
- Electric charge, like mass, is an important inherent property of matter which can be present in both large and small bodies
- Electric charge q can create electric field E in space, which can also exert a force qE on another body of charge q
- Thus, electric charge q can create electric or electrostatic force $F_E = qE$
- These fields in turn transmit forces to other charged bodies and thereby affect their motion
- Therefore, the region in space around the charged body, where electric forces can be experienced defines electric field

Charge and Matter

The Structure of the Atom

- Another important feature of charge is that electric charge is always conserved
- In any interaction or reaction, the initial and final values of the total electric charge must be the same. Thus, total electric charge is neither created nor is it destroyed
- Matter or solid state materials may be classified into insulators, semiconductors and conductors

Insulators

- From atomic point of view electrons in insulators are firmly (tightly) bound to the nucleus
- Thus unable to move under applied potential difference for electrical conduction
- Therefore, electrical conduction in insulators is by the mechanism of dielectric conduction

Charge and Matter

Semiconductors

- Electrons in semiconductors are relatively not firmly (tightly) bound to the nucleus
- Thus only few electrons are able to move under applied potential difference for electrical conduction
- However, electrons can be generated to take part in electronic semi-conduction

Conductors

- In metallic conducting materials some of the electrons are very loosely bound to the nucleus
- Thus electrons can move about freely within the crystal structure
- Such electrons are called free electrons or conduction electrons
- Therefore, electric current through metals is by electronic conduction

Force, Energy and Power

Force

- The electrical force between two stationary charged particles is given by Coulomb's Law
- The force is directly proportional to the product of the charges, q_1 and q_2, on the two particles and inversely proportional to the square of the separation, r between the particles and directed along the line joining them
- The force is attractive if the charges are of opposite sign
- The force is repulsive if the charges are of like sign
- The force is a conservative force

Mathematically the Coulomb's law is:

$$F_e = k_e \frac{q_1 q_2}{r^2} \tag{1}$$

The SI unit of charge is the coulomb (C) k_e is called the Coulomb constant $ke = \dfrac{1}{4\pi\varepsilon_0} = 8.9875x10^9 \ N.m^2/C^2$ ε_0 is the permittivity of free space $\varepsilon_0 = 8.8542x10^{-12} \ C^2/N.m^2$

Force, Energy and Power

Force

The electrical force between the electron and proton is found from Coulomb's law $F_e = k_e \frac{q_1 q_2}{r^2} = 8.2x10^8\ N$

This can be compared with the gravitational force between the electron and the proton given by

$F_g = G\frac{m_e m_p}{r^2} = 3.6x10^{-47}\ N$

Potential

Electric potential V at a point in an electric field is defined as the potential energy per unit charge. i.e.

$$V = \frac{U}{q} \tag{2}$$

Similarly, electric potential can be defined as the work done per unit charge in moving the charge from infinity to the point

$$V = -\frac{W_\infty}{q} \tag{3}$$

Force, Energy and Power

Potential

- Potential is a scalar quantity, and not a vector with SI unit Joule per Coulomb $[JC^{-1}$ or $Volt(V)]$
- The potential can be positive, negative or zero depending on the signs and magnitude of q
- The potential energy per unit charge (potential) is independent of the charge q of the particle we use
- The potential is characteristic only of the electric field we are investigating
- The electric potential difference $\triangle V$ between any two points i and f in an electric field is equal to the difference in potential energy per unit charge between the two points

$$\triangle V = V_f - V_i = \frac{\triangle U}{q} = -\frac{W}{q} \tag{4}$$

- Therefore, potential difference between two points is the negative of the work done by the electrostatic force to move a unit charge from one point to the other in the field

Force, Energy and Power

Potential

- For a potential energy to exist, we must have a system of two or more charges
- Potential energy belongs to the system and changes only if a charge is moved relative to the rest of the system
- The electric field is a measure of the rate of change of the electric potential with respect to position
- The work done $\triangle W$ in moving the unit charge through a small distance $\triangle x$ toward the charge is given by

$$\triangle W = F(-\triangle x) \tag{5}$$

Thus

$$dW = -Fdx = Edx$$
$$W = V = -\int_{\infty}^{r} \frac{q}{4\pi\varepsilon_0 x^2} = -\frac{q}{4\pi\varepsilon_0}\left[-\frac{1}{x}\right]_{\infty}^{r} = \frac{q}{4\pi\varepsilon_0 r} \tag{6}$$

- the potential, V is equal to the work done per unit test charge,
- A positively charged particle produces a positive electric potential and a negatively charged particle produces a negative electric potential

Force, Energy and Power

Potential

- When dealing with energies of electrons, molecules or atoms, the joule appears to be a very large unit of energy
- For this reason alternative unit of energy called the Electronvolt (eV) is used
- Electronvolt is defined as the energy gained by an electron accelerated through a potential difference of one volt (1V)
- The electronvolt is the energy that can be acquired by a particle, which carries a charge of the magnitude of the charge on the electron $(q = e)$ and moved through a potential difference of 1V

Current

- The charge is related to the current

$$Q = It \tag{7}$$

- Electrical conduction in a wire (metal) is due to the movement of free electrons
- Emf set up an electric field in the metal and the electron are then accelerated by the field and they gain velocity and energy

Force, Energy and Power

Current

- The moving electrons collide with atoms of the metal vibrating about their fixed mean position and give up some of their energy to the atoms
- The amplitude of vibrations of the atoms increases and the temperature of the metal rises
- On the average the electrons drift in the opposite direction to the electric field with a mean speed. Therefore the drift constitute electric current

Power

- Power is the rate of doing work or, equivalently, as the rate of transfer of energy. The symbol for power is P
- The charge is related to the current

$$P = \frac{W}{t} = VI = I^2R = \frac{V^2}{R} \tag{8}$$

Circuit Elements: Resistors

- Resistors are specifically designed to possess resistance and are used in almost all electronic and electrical circuit
- Resistors are the simplest components in any circuit but their effect is very important in determining the operation of a circuit
- Resistance is represented by the symbol R and is measured in units of ohms (after Georg Simon Ohm). The symbol for ohms is the capital Greek letter omega (Ω)
- The resistance of a material is dependent upon several factors
  - Type of material
  - Length of the conductor l
  - Cross-sectional area A and
  - Temperature T
- The resistance R and the resistivity ρ are related by the equation

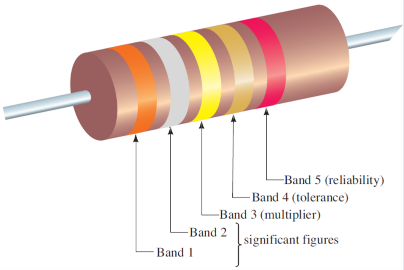
$$R = \frac{\rho l}{A} \tag{9}$$

Circuit Elements: Resistors

- There are two main types of resistors:
  - Fixed Resistors are resistors with constant resistance values and
  - Variable resistors are three terminal resistors are used to adjust the volume of our radios, set the level of lighting in our homes, and adjust the heat of our stoves and furnaces
- Large resistors have their resistor values and tolerances printed on their cases
- Smaller resistors are too small to have their values printed on the component
- They are usually covered by an epoxy or similar insulating coating over which several coloured bands are printed radially
- The coloured bands provide a quickly recognizable code for determining the value of resistance, the tolerance (in percentage), and occasionally the expected reliability of the resistor

Circuit Elements: Resistors

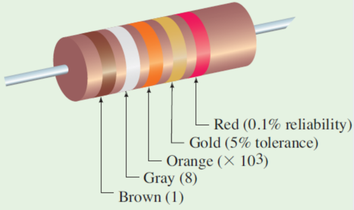
- The coloured bands are always read from left to right, left being defined as the side of the resistor with the band nearest to it
- The first two bands represent the first and second digits of the resistance value
- The third band is called the multiplier band and represents the number of zeros following the first two digits; it is usually given as a power of ten
- The fourth band indicates the tolerance of the resistor, and the fifth band (if present) is an indication of the expected reliability of the component
- The reliability is a statistical indication of the expected number of components that will no longer have the indicated resistance value after 1000 hours of use



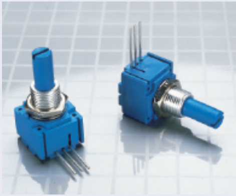
Circuit Elements: Resistors

Color	Band 1 Sig. Fig.	Band 2 Sig. Fig.	Band 3 Multiplier	Band 4 Tolerance	Band 5 Reliability
Black		0	$10^0 = 1$		
Brown	1	1	$10^1 = 10$		1%
Red	2	2	$10^2 = 100$		0.1%
Orange	3	3	$10^3 = 1\ 000$		0.01%
Yellow	4	4	$10^4 = 10\ 000$		0.001%
Green	5	5	$10^5 = 100\ 000$		
Blue	6	6	$10^6 = 1\ 000\ 000$		
Violet	7	7	$10^7 = 10\ 000\ 000$		
Gray	8	8			
White	9	9			
Gold			0.1	5%	
Silver			0.01	10%	
No color				20%	

Fixed Resistor



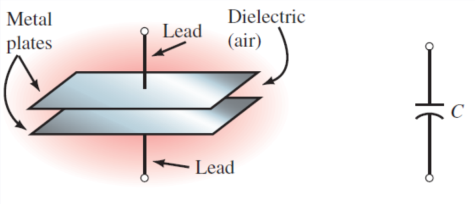
Variable Resistor



Circuit Elements: Capacitors

- A capacitor is an electrical device that is used to store electrical energy
- Next to the resistor, the capacitor is the most commonly encountered component in electrical circuits
- Capacitors are used extensively in electrical and electronic circuits
  - To smooth rectified ac outputs
  - In telecommunication equipment – such as radio receivers - for tuning to the required frequency
  - In time delay circuits
  - In electrical filters
  - In oscillator circuits and
  - In magnetic resonance imaging (MRI) in medical body scanners
- Capacitance is the electrical property of capacitors: it is a measure of how much charge a capacitor can hold
- A capacitor consists of two conductors separated by an insulator. One of its basic forms is the parallel-plate capacitor
- It consists of two metal plates separated by a non-conducting material (i.e., an insulator) called a dielectric
- The dielectric may be air, oil, mica, plastic, ceramic, or other suitable insulating material

Circuit Elements: Resistors



(a) Basic construction (b) Symbol

- The amount of charge Q that a capacitor can store depends on the applied voltage V
- For a conductor of any geometrical shape the capacitance, C is defined as the ratio of charge on the conductor to the potential it is raised. Thus

$$C = \frac{Q}{V} \tag{10}$$

- The unit of capacitance C is the farad, F

Circuit Elements: Capacitors

- For a parallel-plate capacitor, capacitance C is defined as the ratio of charge on each (either) plate to the potential difference between the plates
- The capacitance of a parallel plate capacitor is:

$$C = \frac{\varepsilon_0 A}{d} \tag{11}$$

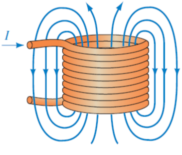
- C increases as we increase the area A or decrease separation d of the plates
- For a Parallel Plate Capacitor, the capacitance depends only on the following factors:
  - Area (Geometry) of the plates A
  - Separation (distance) between the plates d
  - The nature of material (dielectric material) between the plates
- For an isolated sphere, the capacitance is:

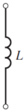
$$C = \frac{Q}{V} = 4\pi\varepsilon_0 R \tag{12}$$

- C is independent of the charge on the spherical conductor but depends only on the radius R

Circuit Elements: Inductors

- Inductance is due entirely to the magnetic field created by the current, and its effect is to slow the build-up and collapse of the current and in general oppose its change
- A component called an inductor is used when the property of inductance is required in a circuit
- The basic form of an inductor is simply a coil of wire
- Factors which affect the inductance of an inductor include:
  - the number of turns of wire - the more the turns the higher the inductance
  - the cross-sectional area of the coil of wire - the greater the cross-sectional area the higher the inductance
  - the presence of a magnetic core - when the coil is wound on an iron core the same current sets up a more concentrated magnetic field and the inductance is increased
  - the way the turns are arranged a short, thick coil of wire has a higher inductance than a long, thin one





(b) Ideal inductor

Circuit Elements