Course: PHYSICS 102 - PHY 102

Textbook: College Physics by Serway/Vuille

These notes were written by Professor HMDimas.

The purpose of these notes is to facilitate to the student the reading of the textbook, as well as the understanding of the concepts.

The open spaces are for notes, drawings, and student's additional information received in class.

The Gravitational Field: Review **The Electric Field - Electric Charges**

A body of mass m_1 generates a **gravitational field** around it, the field manifest itself when another body of mass m_2 comes into its proximity. The body of mass m_2 also generates a gravitational field around itself, and both masses experience a **gravitational force, F_G**, of attraction to one another.

$$F_G = G\frac{m_1 m_2}{{r_{12}}^2}$$

r_{12} = distance between the center of mass of the two bodies.

The **electric charge** is found on the elementary particles that make up all known matter (all bodies).

Atoms

An electric charge can be stationary or in motion. We are to study first the stationary (**static**) electric charges and then we will study the one that are in motion.

The electric charge can be either **positive** (+) or **negative** (-).

The **electric charge** generates an **electric field** around it. The **direction of the electric field** can either be inward (towards the charge itself) when the charge is negative or outward when the electric charge is positive.

We draw **electric field lines** which allow us to **visualize** the direction of the **electric field** as well as the type and location of the electric charge (positive or negative) generating the electric field.

draw

The existence of the electric field is observed when two charges are located within their interaction region.
Two positive charges repel one another.
Two negative charges repel one another.
A positive charge and a negative charge attract each other.

draw force

A drawing of the electric field lines for these three cases provides a significant amount of information about the electric field and the direction of the electric force.

Repulsion and attractive effects are measured by the **Electric Field Force, F_e**, experienced by each charge.

$$F_e = k_e \frac{q_1 q_2}{{r_{12}}^2}$$

This is known as the "Coulomb's Law".

r_{12} = distance between the center of mass of the two charges.

q_1 and q_2 are the amount of charge on each electric charge. The Coulomb (C) in the SI system is the unit of the electric charge.

k_e = is called the Coulomb constant; its value and units depend on the choice of units system used.

$$k_e = 8.9875x10^9 \frac{Nm^2}{C^2}$$

Observe that F_G and F_e vary as the inverse square of their separation.
The corresponding units of force in the MKS system are the Newtons (N).
The electric force is directed along the line joining the two particles. See the electric field lines diagram. Because of Newton's third law, the magnitude of the force on each of the two charges is the same regardless of the magnitude of the values of q_1 and q_2.

In cases where there are more than two charges present, the resultant force on any one charge, is the **vector sum of the forces** exerted on that charge by the remaining individual charges present.

three charges

The **Electric Field, E**, produced by a given **charge q** at any point in space, that is, located at a **distance r** from the charge q is defined as follows:

$$E = k_e \frac{q}{r^2}$$

When a charge q_o is located in the electric field produced by q and at the location r then the electric field can be defined as:

$$E = \frac{|F|}{|q_o|} = k_e \frac{q q_o}{r^2 q_o}$$

The magnitude and units of the electric charge of a proton is: represented by: $e=+1.6x10^{-19}$ C

Question: **How many protons do we have in 1 C** ? (1 Coulomb)

Number of protons = $(\frac{1C}{e}) = (\frac{1C}{1.6x10^{-19}C}) = 6.3x10^{18}\ protons$

The magnitude & units of the electric charge of an electron is: represented by $\mathbf{e^- = -}\ 1.6x10^{-19}$ C

The magnitude and units of the electric charge of a neutron is: 0 C

See the textbook table 15.1 to see the masses of the electron, proton, and neutron.

Note: 1 Coulomb is a rather large amount of charge.

When rubbing a glass rod or a rubber rod with wool and other materials that by induction are able to and that by friction an amount of charge is moved into the surface of these objects, the net charge induced is usually of the order of $\mathbf{10^{-6}\ C}$ = 1 micro C = $1\mu C$

The electric field lines begin at the positive charges and terminate at the negative charges. The electric force is a vector and the direction of the Electric field E at any point is defined to be the direction of the electric force that would be exerted on a small positive charge if placed at the point in question.

No two field lines can cross.

There are materials in which electric charges can move freely, but this occurs under the influence of an electric field. These materials are called **Conductors**.
Other materials do not have the characteristic of transporting charges. These materials are called **Insulators**.

An electric field can be generated by a stationary electric charged material (a conductor); these electric fields are known as electrostatic fields.

A conductor in electrostatic equilibrium has the excess charges entirely on its surface, while inside the conductor the electric field is zero " 0 ".
The electric field is always perpendicular to the conductor's surface.

The direction of the electric field is always radially outward from the positive point charge and radially inward on a negative point charge.

Electric field lines are used for the graphical representation of electric field patterns.

Note: The electric field vector, E, is tangent to the electric field lines at each point.

Looking at the point charge from a three dimensional perspective we observe the surface of a sphere with its center located at the center of the charge, hence we can observe that the number of lines per unit area through a surface perpendicular to the lines is proportional to the strength or magnitude of the electric field over the region. The furthest from the charge, the smaller the number of lines density per unit area.

The number of lines approaching or leaving a charge is proportional to the magnitude of the charge.

No two field lines can cross.

The electric flux provides in formation on the electric field vectors crossing a closed surface.

$$\Phi_E = ElectricFlux$$

The **E** vectors may or may not be perpendicular to the surface, we define the electric flux as follows:

$$\boxed{\Phi_E = E \bullet A = EA\cos\theta}$$

Vector notation: reads: **E** dot **A**

$\boxed{\theta =}$ is the angle between electric field vector and the area unit vector which is perpendicular to the area. When the **E** and **A** vectors are parallel then

$\boxed{\theta = 0^o}$ Cos 0^o = 1

Note: "For a closed surface, the flux lines passing into the interior of the volume contained by the closed surface, are negative, while those passing out of the interior of the volume are positive".
Observe that the normal unit vector of the surface area points outward.

We can imagine a closed surface which contains the charge(s) producing the electric field. This surface is known as the **Gaussian Surface**. The close surface can have any shape, the objective is to select a closed surface that will minimize the calculation of the electric field.

(1) If the charge is located on a spherical surface, one could select the imaginary (Gaussian surface) surface to be a sphere of radius larger than the sphere where the charges are located.

Lets review textbook page 519, Gauss Law Figure 15.27 (a)
Consider a **positive point charge** q surrounded by the Gaussian spherical surface of radius **r**. That is, the electric field vector is perpendicular everywhere of the surface, and the surface unit vector is also perpendicular outwards. Hence the angle between the vectors is 0^{o}.

Since we know: $\boxed{E = k_e \frac{q}{r^2}}$ and $\boxed{A = 4\pi r^2}$ then $\boxed{\Phi_E = EA = k_e \frac{q}{r^2}(4\pi r^2) = 4\pi k_e q}$

Where k_e = Coulomb's constant
We define the **permittivity of free space** = $\varepsilon_0 = \frac{1}{4\pi k_e} = 8.85x10^{-12} \frac{C^2}{Nm^2}$

Hence $\boxed{\Phi_E = \frac{q}{\varepsilon_o}}$

(2) Likewise, if we know the electric field at the Gaussian surface, we can then calculate the charge contained inside the surface. $EA\cos\theta = \Phi_E = \frac{Q_{inside}}{\varepsilon_o}$

Study example 15.7 page 520

$$\boxed{Work = W = F * S = FS\cos\theta}$$

dot product

Scos(theta) = is the displacement in the direction of the action of the force F.

Gravitational Field

The work done on a body by the force of gravity is express in terms of the initial and final values of body's y-coordinates

$$\boxed{W_g = PE_i - PE_f = -\Delta PE}$$

The work done by the force of gravity is then equal to the negative change in the gravitational potential energy.

```
y_i -  O                  A
       | mg \
       .      \
       .       \
y_f -          O          B
               | mg
```

Electric field

$W_e = F_eD$

$W_e = qED$

```
                 A
 - - - - - - - - - - - - - - - - - - ->
 - - -  o (charge)   - - - - - ->
 - - - - - - - - - - - - - - - - - - ->
electric field - - - - -
- - - -              - - - - - - - - - - - ->
 - - - - - - - =-    - - - - - -o(charge)
 - - - - - - - - - - - - - - - - - - ->
                                        B
         | < -----D----> |
```

$$\boxed{\Delta PE_e = -W_e = -qED}$$

The negative work done by the electric force is equal to the **change** in **Electrical Potential energy** of an electric charge when moving between two points in an electric field E

D = distance moved parallel to the direction of the electric field.

Definition: The vicinity at each point of a charge distribution is characterized by a scalar quantity called "**Electric Potential**", symbol " V " with units: volts.

$\boxed{\Delta V = V_B - V_A}$ = **Electric Potential Difference$_{AB}$** This is a change in **potential energy** per unit charge as a positive charge is moved from point A to point B.

$$\Delta V = \frac{\Delta PE}{q} ==> SI \quad \text{units:} \quad 1volt = \frac{1Joule}{1Coulomb}$$

One "volt" = the work that requires 1 Joule to move the charge of 1 Coulomb from point A to point B

Since we know that the **units of the electric field E** is in newtons per coulomb, using the previous units one finds:

$$1\frac{N}{C} = (1\frac{N}{C})(\frac{1\circ V\circ C}{1J})(\frac{1J}{1N\circ m}) = 1\frac{V}{m}$$

Therefore the **volts per meter** are also **units** of the **electric field**.

We now define the energy unit more appropriate for the energy measurements in the atomic and subatomic domain: The energy unit is the **electron-volt (eV)**. 1 eV is the work required to move to move a single elementary particle of charge e through a potential difference of one volt.

$$\boxed{1eV = e(1V) = (1.60x10^{-19}C)(1\frac{J}{C}) = 1.60x10^{-19}J}$$

Note: The electric force is a conservative force hence the work done is independent of the path followed when moving from point A to point B.

Note to remember: There are two sets of charges. (1) the one originating the electric field (2) the charge(s) placed inside the electric field.

Since q_1 is a charge distribution originating an electric field in its vicinity we defined: " The **Electric Potential** of a point charge at a point P in space is inversely proportional to the distance from the charge " $V_1 = k_e \frac{q_1}{r_1}$

|< ------ r_1 ------->|

(q_1) o P

Note: **(1)** as $r_1 \to \infty$ then $V_1 = 0$

(2) if q_1 = - negative charge, then V_1 = - negative at a distance r_1

if q_1 = + positive charge, then V_1 = + positive at a distance r_1

(3) V= is a scalar quantity

The **electric potential** due to a group of point charges and with the help of the superposition principle and keeping the charge sign for each charge is given by:

Assume " n " point charges:

$$V = \sum_{i=1}^{n} V_i = \frac{1}{4\pi\varepsilon_o} \sum_{i=1}^{n} \frac{q_i}{r_i}$$

Where: $k_e = \frac{1}{4\pi\varepsilon_o}$

PE = Potential energy. The PE of two point charges q_1 and q_2 separated by distance r_{12} is given by: $PE = k_e \frac{q_1 q_2}{r_{12}}$ the units: (Joules)

Hence if q_1 and q_2 are both (+) or both (-) then PE = + quantity; if the 2 charges are of opposite charge, the PE = - quantity.

This PE represents the minimum amount of work needed to move these charges from an infinite separation to the separation of r_{12}

Since: $\Delta V = V_B - V_A = \frac{\Delta PE}{q}$ and $W = -\Delta PE$ then $W = -q(V_B - V_A)$

When the charge located at point A is pushed to move to point B from the work-energy theorem we have:

$$W = \Delta KE + \Delta PE_e = (KE_f - KE_i) + (PE_f - PE_i)$$

One will consider again the initial and final conditions of the problem. If the charge is at rest prior to motion, then the initial velocity and consequently the KE are " 0 ", at the end you would have velocity and KE as well as the initial potential energy (|q|Ed) which can also be written $q\Delta V$

When applying conservation of energy W=0 and the change of KE = the change in PE

The parallel plate capacitor are two conductor plates set up in parallel to one another, each plate is charged with the **same amount of charge** but with opposite charge. One plate is charged positive (+) the other is charged negative (-). Hence, charged capacitors are able to store energy that can be used when needed.

The charge Q of the capacitor and the potential difference of the plates are proportional to one another, but with the limitation of the material for a maximum amount of charge stored in a unit. The ratio (Q / ΔV) is called the Capacitance (C) of the capacitor. $\boxed{C = \frac{Q}{\Delta V}}$

The units of capacitance: $1 Farad = 1\frac{Coulomb}{Volt}$ Therefore Q = C ΔV

Since (1) the electric field between 2 plates has been given by: $E = \frac{\sigma}{\varepsilon_o}$

(2) The potential difference between two plates: $\Delta V = Ed$

(3) The charge of one is given by: $q = \sigma A$

Then: $$C = \frac{q}{\Delta V} = \frac{\sigma A}{Ed} = \frac{\sigma A}{(\frac{\sigma}{\varepsilon_o})d} = \varepsilon_o \frac{A}{d}$$

$\sigma =$ charge density =amount of charge per unit area on each plate
A = Area of the plate.

Symbol of a plate capacitor: -| |-

Capacitors can be connected to one another and also to a battery to form an electric circuit. The electric circuit can be open or it can also be closed in the proximity of the battery.

The capacitors can be connected in parallel or in series.

When the capacitors are connected in **parallel** they all have the same potential difference given by the battery. Hence the total charge provided by the battery is accumulated among all the capacitors in the circuit. Since the capacitors can have different capacitance, each capacitor can accumulate different amount of charge. $Q_{total} = Q_1 + Q_2 + \ldots + Q_n$

If there are only 2 capacitors present then $Q_{total} = Q_1 + Q_2$

If there are only 3 capacitors present then $Q_{total} = Q_1 + Q_2 + Q_3$

So we define the Equivalent Capacitance as C_{eq} $\boxed{C_{eq} = C_1 + C_2 + C_3}$

Where the potential difference ΔV is given by: $\Delta V = \Delta V_1 = \Delta V_2 = \Delta V_3$

$$\Delta V = \frac{Q_1}{C_1} = \frac{Q_2}{C_2} = \frac{Q_3}{C_3} = \frac{Q_{total}}{C_{eq}}$$

When the Capacitors are connected in Series: The right plate of the furthest capacitor to the right when connected to the (-) negative of the battery, then upon closing the circuit, the right plates of all the capacitors will be negatively charge (- Q) with the amount of charge equal to the negative charge (- Q) provided by the battery. All the left sides of the capacitors will gain + charge (+ Q)

Where the potential difference ΔV is given by: $\Delta V = \Delta V_1 + \Delta V_2 + \Delta V_3$

$$\Delta V = \frac{Q}{C_1} + \frac{Q}{C_2} + \frac{Q}{C_3} = \frac{Q}{C_{eq}} \qquad \frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Energy stored in a charged capacitor

/\ W = is the amount of work required to move the charge /\ Q the potential difference /\ V.

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

W = Energy stored in the capacitor $W = \frac{1}{2}Q\Delta V = Energy\_stored$

Since Q = C /\V and /\V = Q / C then the energy stored is given by:

$$Energy\_stored = \frac{1}{2}Q\Delta V = \frac{1}{2}(C\Delta V)(\Delta V) = \frac{1}{2}C\Delta V^2 = \frac{1}{2}Q(\frac{Q}{C}) = \frac{1}{2}Q^2/C$$

Dielectrics: Are substances that can be placed in the space between the two plates of the capacitor. These are insulating materials.

Based on the type of substance, the presence of the dielectric improves the capacitance of the capacitor.

No dielectric present: $C = \varepsilon_o \frac{A}{d}$	Dielectric present: $C = \kappa\varepsilon_o \frac{A}{d}$

A = Area of the plates
d = Separation of the plates

$\kappa > 1 =$ Dielectric constant of the material

Polarization effects of the molecules of the material are the drivers to the dielectric effects.
A dielectric is an insulating material.

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When charges enter an electric field, the charges, if they are electrons, they move in the opposite direction of the electric field, if they are protons, they will move in the direction of the field.

When a potential difference is set up at the ends of a wire, and the presence of an electric field is established, the free charges of the wire find themselves inside an electric field, consequently the charges are in motion through the wire, and their motion generate what is known as the Electric Current. The current is the rate at which charge flows through the surface of the wire (conductor).

Note: The electric potential is continuously decreasing in a conductor, however, this is not usually the case in the superconductors.

An amount of charge **/\Q** flows through the cross sectional area of the wire in a **/\t** amount of time. The ratio of these two quantities represent the average current I_{avg} flow through the wire. While the instantaneous current I, corresponds to the limit of the flow measured as /\t --> 0.

$$I_{avg} = \frac{\Delta Q}{\Delta t} \qquad I = \lim_{\Delta t \to 0} \frac{\Delta Q}{\Delta t} \quad \text{the SI units: } \boxed{\frac{Coulomb}{Second} = Ampere = A}$$

The charges flowing through the cross sectional area can be positive or negative or both.
The direction of the conventional current used in several textbooks is the direction of flow of the positive charges, that is, the direction of the electric field,

When the established electric field in the wire remains constant, we then have direct current.
When the established electric field changes direction continuously, then the direction of motion of the charges is changing 180^o with respect to the original direction. This type of current is called alternating currents which we are study at a later time.

Since /\Q = /\t * I_{avg} then **Nq** = /**Q** where **N = Number of electrons of charge q** (example: electrons passing through the cross sectional area during this time /\t).

$$Nq = I_{avg}\Delta t$$

Definitions: n = Number of mobile charge carriers per unit volume = number density

v_d = drift speed of the charges

/\ **x** = **the distance traveled by the charges during time /\t**, then /\x=v_d /\t

Consequently **N = n A v_d /\t**

Hence the current: $$I = \lim_{\Delta t \to 0} \frac{\Delta Q}{\Delta t} = \lim_{\Delta t \to 0} \frac{(nAv_d \Delta t)q}{\Delta t} = nqv_d A$$ **I = nqv_dA**

When the substance is a gas inside a container of volume V where there is the presence of an electric field and knowing the volume mass and density of the substance in the gas state, and with information of the volume per mole of the substance, one can calculate the **number density (n)** of the substance. The drift velocity v_d can be calculated and compare to the v_{rms} calculated from the Boltzman equation, as a function of temperature. The v_{rms} is much larger than the drift velocity.

$$I = \frac{dQ}{dt}$$ = is the time rate of change (of transfer) of the charges crossing the cross sectional area A (units: A for ampere)

When the current is uniform at the crossing of the area surface, we can defin a vector **J** as the current density vector which direction is the direction of the moving charges. In a uniform current the direction of the current density is the same direction as the direction of the area unit vector.

The magnitude of the current density is: $J = \frac{I}{A}$ then I = **J * A** = J A

Since I = nqv_dA then J = (nq) v_d

(n q) = is the carrier charge density and its units are C / m^3

When q is a positive charge, then J and $\mathbf{v_d}$ are in the same direction, but when the carrier is negative then **J** and $\mathbf{v_d}$ have opposite directions.

Experiments performed and studied by Georg Simon Ohm relating the effects of the current flow and the difference in potential at the end of the wires, Ohm was able to show and conclude that: $I \alpha \Delta V$

The constant of proportionality became the **resistance R** of the conductor. The unit of R is the ohm

$$\boxed{Ohm = \Omega}$$

Hence Ohm's Law is expressed as: $\Delta V = IR$

Ohm was able to observe that **<u>the resistance R is a property of an object</u>**.

Consider a wire of length L and cross sectional area A. When setting a potential difference between the ends of the wire, then we have the presence of an electric field and current density flow through the wire. /\ V = E L and I = J A

Then E L = (J A) R and $R = \frac{E}{J}\frac{L}{A}$

Then he was able to conclude that the property of the material given by the ratio E / J can be defined as the **<u>resistively of the of the material of the object</u>** $\rho = \frac{E}{J}$ hence: $R = \rho \frac{L}{A}$

Note: Remember that the area of a circle = πr^2

The resistively of the material is affected by the temperature, hence a **<u>reference resistively quantity</u>** at the temperature of 20^o C is established and its label is**:** ρ_o

Consequently the resistively values at other temperatures is given by: $\rho = \rho_o[1 + \alpha(T - T_o)]$

$\alpha =$ is defined as the **<u>temperature coefficient of resistively.</u>** This coefficient can be positive for all conductors, and negative for semiconductors where weakly charge carriers are present.

Then: $\boxed{R = \rho_o[1 + \alpha(T - T_o)]\frac{L}{A}}$ $\boxed{R = \rho_o \frac{L}{A}[1 + \alpha(T - T_o)]}$ $\boxed{R = R_o[1 + \alpha(T - T_o)]}$

Energy & Power

There are metals and compounds that at a temperature below the **critical temperature, T_c,** their their resistance fall to zero. These resistors are called **superconductors.**

When considering a circuit made of a switch, a battery, and a resistor, as the current flows through the circuit, the charge ΔQ loses energy as it passes through the resistor which is at the potential difference ΔV. The instantaneous rate at which it losses electric potential energy is given by:

$$\lim_{\Delta t \to 0} \frac{\Delta Q}{\Delta t} \Delta V = I \Delta V$$

Note: **(1)** The charge ΔQ regains the energy lost as it passes through the battery where a chemical energy exchange occurs.

(2) The **energy lost** by the charge ΔQ is **gained by the internal energy** of the resistor. Hence, this energy is delivered to the resistor in a given amount of time. This is the definition of the power **P** that is delivered to the resistor.

$$\mathbf{P} = I \Delta V \quad \text{since } \Delta V = IR \text{ then} \quad \mathbf{P} = I^2 R \quad \text{or} \quad \mathbf{P} = \Delta V^2 / R$$

The unit of Power is the watt. The kilowatt-hour is the unit used to show the consumption of electrical power per hour. Customers of the power plants pay their received services based on $ / kilowatt-hour

1 kilowatt-hour = 1 kWh = $(1 \times 10^3\ W)(3600\ s) = 3.6 \times 10^6\ J$