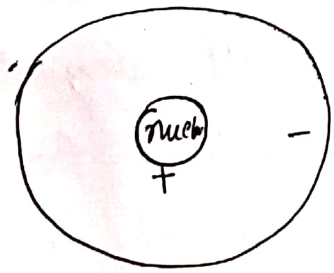
Electricity & Magnetism

Electricity and Magnetism are all around us. We have electric light, electric clocks, we have microphone, calculator, cell phones, TV, laptops. Light itself is an example of electro-magnetic phenomena. Cars, planes & trains run only because of electricity. When we run, we need electricity because muscle constraction requires electrity. Our nerve systems are driven by electricity. You could not see without electricity & your heart would not beat without electricity. However, some of you might get problem with electrity.

The modern picture of an atom is



nucleus → p^+ , n
proton, + charged ; neutron, chargeless

mass of $m_p \approx m_n \approx 1.7 \times 10^{-27}$ Kg

Then we have electrons in a cloud around it. [speed 2200 Km/s]

If the atom is neutral, then number of protons & electrons are same. Mass of the electrons is 1830 times smaller than the mass of proton. Hence, we can neglect that & say that the mass of the atom is concentrated at nucleus.

If I take 6 billions atoms lined up touching each others, then we will have only a length of 60 cm. This will give you an idea about the size of the atom. (10^{-8} cm) -

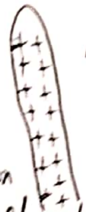
Already in 600 bc, (Thelis) ~~It~~ was found ~~known~~ that If you rub an amber, It attracts pieces of dry leaves. The greek word for amber is electron, It is also known, When people were bored at parties, They used to rub their jwelleries, touched frogs, those frogs started jumping of desperation. people used to consider this as fun.

In 1800 century, it was discovered that there are two types electricity. One, if you rub glass. other if you rub rubber or amber. Let call a & b. It was known that a repels a & b repels b. However, a attracts b. It was Benjamin Franklin, without any knowledge of atom electrons & protons, who introduced the idea of eletric fluid / fire. He stated, If you get too much of the fire, u get positively charged. & if you have lack of fire, u get negatively charged. This is also the idea behind the conservation of charge. So you can not create charge & can't destroy it. If you create plus, then you automatically create minus.

*** [muons & tau leptons are – charged
proton → 2 quarks up/ 1 down
+/- charged π mesons or pion]

What is electric charge?

Electric charge is an intrinsic characteristic of the fundamental particles making up those objects. It is a property that comes automatically with those particles wherever they exist.

If we rub a glass rod, then it gets these positive charges.  What would happen if we take a con-ductors close to this rod? In conductors, there are some fraction of electrons which are not bound to atoms & they can freely move within the atom.

[In nonconductors, electrons are fixed & not allowed to move freely within atom]

If we take the rod close to conductor, some electrons (1 in 13^{th}) will come here,

And this is called induction. You get a sort of polarization/ charge division.

Franklin already noticed, shorter the distance, the stronger the force. ~~Therefore~~. Example: ballon & glass rod
(ballon: conductor)

① Ballon will try to come closer to Glass.

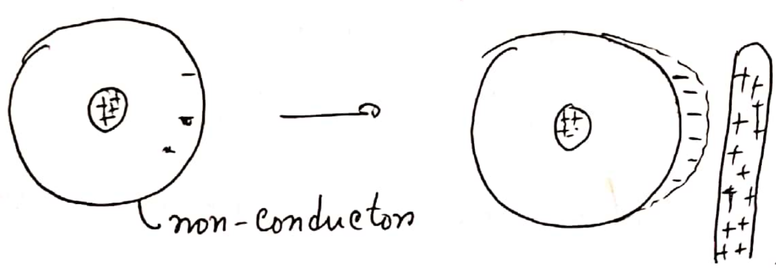
If we now touch the ballon with glass rod, couple of times, & rub the glass, see what happens.

They will repel each other, but why?
Because ~~the~~ positively charged rod touched the ballon couple of times, so the ballon gets + charged.
Rubbing the glass again makes it positively charged.
+ & + repels each other.

Show some other example.

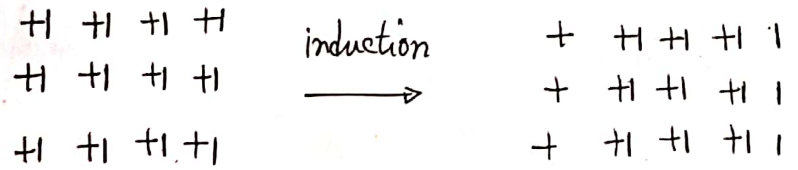
How about taking a non conducting plastic ballon?

(I)



[Note: The amount of charge produced by rubbing plastic on glass rods is typically in the range of 1nC to 100nC. This corresponds to an excess or dificit of 10^{10} to 10^{12} electrons]

(II)



There fore the plastic ballon will also behave like conducting ballon. [Show the small ballons sticking with wall, board].

Talk about US experience with Car!

The take home massage:
" Charges with the same electrical sign repel each other, and charges with opposite electrical signs attract each other "

We should discuss these phenomena in a quantitative way through Coulomb's law of electro-static force between charges.

According to the ability of charge to move through, we can classify materials,

Conductors are materials through which charge can move rather. Examples: Metals, Human body, tap water.

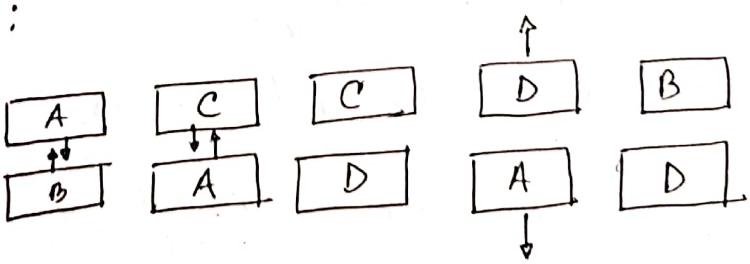
Nonconductors/ inslulators are materials through which charge can not move freely. Examples: Rubber, plastic, glass

Semiconductor are materials that are intermediate between conductors & insulators. Examples: Silicon/Germanium

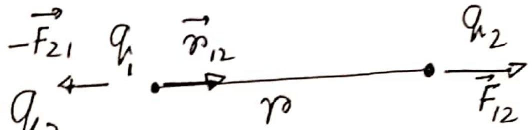
Super conductors are materials that are perfect conduc-tors, allowing charge to move without any hinderance.

Checkpoint 1:

A, B & D are charged plastic plates & C is neutral copper plate. Do C&D or D&B repel each other.



Coulomb's law:



If we take two charges q_1 & q_2 & they are seperated by distance r. The unit vector directed from q_1 to q_2 is $\vec{r}_{12}$. If these charges are equal (both + or -), the force $\vec{F}_{12}$ is on q_2 due to q_1 & $\vec{F}_{21}$ is force in opposite direction due to q_2.

Coulomb, Charles Augustin de Coulomb French Physicist, did alot of research on this & found the force

$$\vec{F}_{12} = K \frac{q_1 q_2}{r^2} \hat{r}_{1,2}$$

unit vector from 1 to 2

Force on q_2 due to q_1, K is Coulomb constant

The SI unit of charge is coulomb, C.

1 C is horrendous amount of charges, One could've never seen in his/her life time. We normally work with micro coulomb.

Charge of Proton / electron

$$q_{p+} = q_{e-} \approx 1.6 \times 10^{-19} C.$$

The constant has a value $K = 9 \times 10^{9}\ Nm^2/C^2$

For historical reason $K = \frac{1}{4\pi \varepsilon_0}$, there is no magic about it. ε_0 is called permitivity of free space. value : $\varepsilon_0 = 8.85 \times 10^{-12}\, C^2/N{\cdot}m^2$

Notice, Coulomb law is ~~similar~~ parallel with ~~like~~ Newton's Gravitational law, $F = \frac{G m_1 m_2}{d^2}$ [Attraction force only]

* If we add a third charge q_3 here, & want to know the force on q_2, we will use the superposition principle. Calculate the force between 2 & 1, 2 & 3 ; the net force would be vectorial sum of these two.

$\vec{F}_{21} \leftarrow q_1 \xrightarrow{\hat{r}_{12}} - - - r - - - q_2 \rightarrow \vec{F}_{12}$

$\vec{F}_{32}\ \cdot q_3$ $\quad \vec{F}_{2net} = \vec{F}_{21} + \vec{F}_{23}$

* If we compare Gravitational force from PHY 107 with coulomb force, you will realize that coulomb force is way more powerful than gravitational force. But why? Assignment?

* Let's say two proton

p ⊙ - - - d - - - ⊙ p

$$F_{coul} = \frac{(1.6 \times 10^{-19})^2\ 9 \times 10^9}{d^2}$$

$$F_g = \frac{(1.7 \times 10^{-27})^2 \times 6.7 \times 10^{-11}}{d^2}$$

$$\frac{F_{coul}}{F_g} \approx 10^{36}$$

That means Electric force F_{coul} is 36 times ~~higher~~ order of magnitude higher than F_g.

That teaches you some respect for PHY 108.

* If this is the only force acting on proton & you bring them to the nucleus ($\sim 10^{-12}$ cm), then the acceleration $a_p = \frac{F_{el}}{m_p}$, based on Phy 107, newtons law.

Then the acceleration, the proton will experience

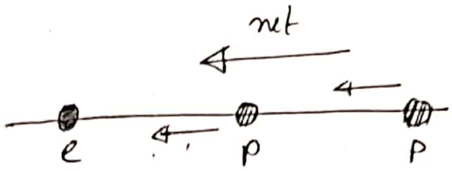
a_p would be 10^{26} orders of magnitude higher than the gravitation acceleration on earth.

* What the hell holds the protons together inside nucleus?

Its because of Nuclear force, which is not fully understood. & its not part of PHY 108. So we will leave it here.

* So what holds the world/universe together? is it nuclear electric force? nuclear electric force works on nuclear scale/ranges ($\sim 10^{-12}$ cm). In atomic scale to thousands of kilometers is really electric force. For much larger scale, example: planets/stars/galaxy, It is gravity that holds together.

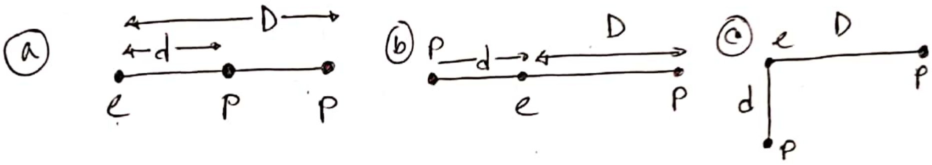
Checkpoint 2, Page 615



On the central proton, what is the direction of ⓐ The force due to the electron ⓑ The force due to the other proton ⓒ The net force.

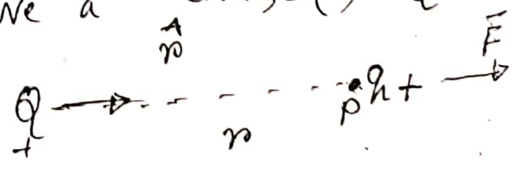
Sample problem 21·01, Page 616, *** problem 21·2, - Page 618

Check point 3



The figure shows three arrangements of an electron e, & two protons.
ⓐ Rank the arrangements according the magnitude of the net electrostatic force on the electron due to protons, largest first ⓑ In situation c, is the angle between the net force on the electron and the line d less or more than 45°. [* charge is quantized.] $q = ne$ $n = \pm 1, \pm 2, \pm 3 \ldots$
$e = 1.6 \times 10^{-19} C$.
[* check point 4]

Electric Field: Lets say we have a charge (+) Q & at distance, r, there is another charge q (+) (we will call it test charge. $\hat{r}$ is the unit vector from Q to q. So from the Coulomb's law, We can say that they will repel



each other. However, the question is, how does particle Q know the presence of particle q at the first place? They also don't touch each other, right?

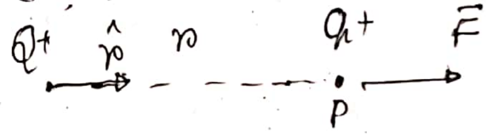
The explanation would be, particle Q sets up an electric field at all points in the surrounding space, even if the space is a vacuum. Therefore, if we place particle q at any point in that space, particle q knows the presence of particle Q since it is affected by the electric field particle Q has already set up at that point.

From Coulomb's law

$$\vec{F} = \frac{qQK\hat{r}}{r^2}$$

Now we introduce the electric field, E

$$\vec{E}_p = \frac{\vec{F}}{q}, \quad \text{unit } \frac{N}{C}$$



So we eliminated the test charge q.

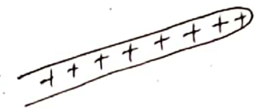
$$\vec{E}_p = \frac{Qk\hat{r}}{r^2}$$

by convention we choose the force that if q is positive test charge, then $\vec{E}_p$ is away from Q (if it is +). We choose force on a positive test charge.

Notice that in electric field, $\vec{E}$, there is no test charge q. However, The electrostatic $\vec{F}$ is dependent on q.

* Electric field is a representation of what happens around the charge Q configuration.

Electric field is a vector field as it is responsible for conveying the information for a force, that involves both magnitude & direction. $\vec{E}_P$ – electric field at point P.

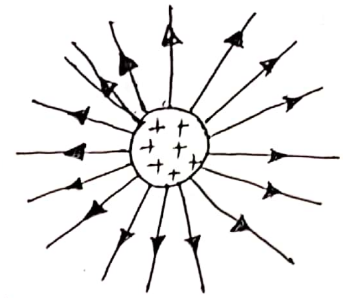


If the test charge is positive then $\vec{E} = \frac{\vec{F}}{q}$, $\vec{E}$ & $\vec{F}$ are in the same direction. Electric field is represented by an arrow & its tail is the point where the measurement is made. The SI unit for the electric field is Newton / coulomb. (N/C)

Electric Field lines

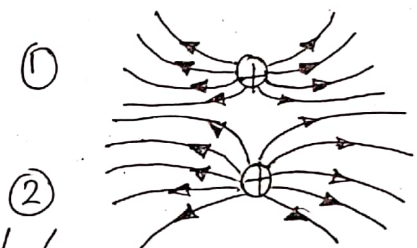
If we have a charge particle at in a space, can we visualize a field of vector throughout that space? As impossible as that seems, Michael Faraday, introduced the idea of electric field in the 19th century, found a way. He envisioned lines, now called electric field lines, in the space around any given charged particle or object.

We can represent the electric field with electric field lines as →

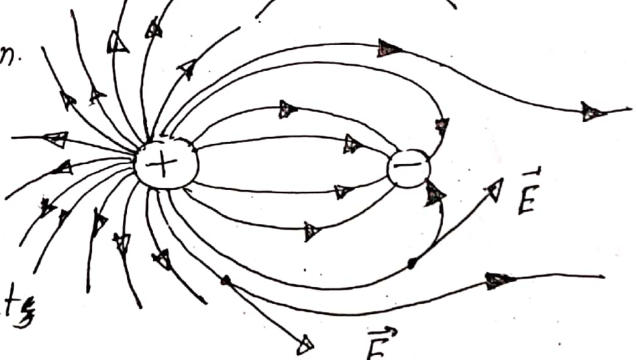


At any point, such as the one shown, the direction of field line through the point matches the direction of electric vector at that point. Now How do we draw electric field line?

The rules for drawing electric field lines are



① At any point, the electric field vector must be tangent to the electric field line through that point & in same direction.



② In a plane perpendicular to the field lines, the relative density of the lines represents the relative magnitude of the field there, with greater density for greater magnitude.

* Electric field lines extend away from positive charge (where they originate) and toward negative charge (where they terminate)

Check! Phet.colorado.edu/en/simulation/charges-and-fields

The electric Field due to a point charge:

To find the electric field due to a charged particle (a point charge) we place a positive test charge (q_0) at any point near the particle, at distance r. From coulomb's law

The force on the test charge due to the particle with charge q is

$$\vec{F} = 9\times10^9 \frac{q q_0}{r^2} \hat{r}$$

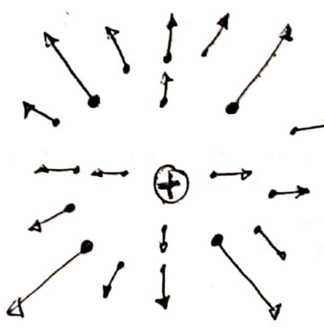
The direction of $\vec{F}$ is directly away from the particle if q is positive (as q_0 is +) and directly toward if q is negative. Now

$$\vec{E} = \frac{\vec{F}}{q_0} = 9\times10^9 \frac{q}{r^2} \hat{r}$$

Direction $\vec{E}$ & $\vec{F}$ would be similar if q_0 is positive & would be opposite if q_0 is negative.

In Magnitude form $E = 9\times10^9 \frac{|q|}{r^2}$.

Lets assume that we have number of electric field vectors at points around a positively charged particle, Each vector represents a vector quantity.



If several electric field are set up at a given point by several charged particle, To find the net field, we can place a positive test

1

particle at the point & calculate the force acting on it due to each particle, such as $\vec{F}_{01}$ due to particle 1. So

Net force, $\vec{F}_0 = \vec{F}_{01} + \vec{F}_{02} + \dots + \vec{F}_{0n}$

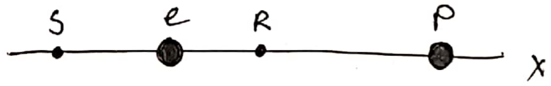
Net electric field, $\vec{E} = \dfrac{\vec{F}_0}{q_0} = \dfrac{\vec{F}_{01}}{q_0} + \dfrac{\vec{F}_{02}}{q_0} + \dots + \dfrac{\vec{F}_{0N}}{q_0}$

$= \vec{E}_1 + \vec{E}_2 + \dots + \vec{E}_n$

Thus electric field also obey the principle of superposition.

Checkpoint 1: $\boxed{\text{634 page}}$

Figure



shows a proton p & and electron e on X axis. What is the direction of the electric field due to the electron at a) point S b) point R? What is the direction of the net electric field at c) point R d) point S?

[Show phet.colorado.edu]

Sample problem 22.01