Chapter 21 - Electric Charge

Physics of electromagnetism → Combination of electric and magnetic phenomena

Begin with electrical phenomena; first step is to discuss the nature of electric charge and electric force.

Every object contains a vast amount of $\underbrace{\text{electric charge}}_{\text{intrinsic characteristic}}$

Two kinds of charge } positive, negative ⇒ electrically neutral } charge balance → ~~equality of~~ amounts of charge

Charged object → charge imbalance, net charge ⇒ charged object interacts } by exerting forces on one another

Electric Force : Charges with the **same** electrical sign **repel** each other, and charges with **opposite** electrical sign **attract** each other
Coulomb's law of electrostatic force

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Conductors & Insulators

Ability of charge to move through! Conductance

- Conductors : charge can move rather freely ; metals, body, water, ..
- Nonconductors (Insulators): charge can not move freely; rubber, plastic, glass
- Semiconductors : intermediate btw conductors and insulators; (silicon, germanium)
- Superconductors : perfect conductors

We can neutralize (discharge) the object (charge balance) by grounding (creating a pathway btw. object and Earth's surface) the object.

Earth is a huge conductor

See Lecture notes

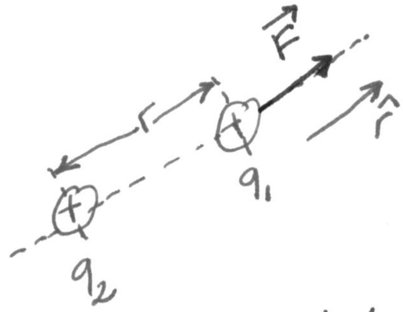
Coulomb's Law

Two charged particles are brought near each other → each exert force on the other

The force of repulsion or attraction : $\vec{F}$, electrostatic force
The equation giving the force for charged particles is called Coulomb's law.

$$\boxed{\vec{F} = k\,\frac{q_1 q_2}{r^2}\,\hat{r}}$$ Coulomb's law

charge q_1
charge q_2
r: distance btw two charged particles
$\hat{r}$: unit vector along an axis
k; ~~k~~constant
See lecture notes



$\vec{F}$, force on particle 1

$$\vec{F} = G\,\frac{m_1 m_2}{r^2}\,\hat{r}$$: Newton's law

Both eqns describe inverse square laws
→ always attractive
→ either attractive or repulsive

Unit of charge : Coulomb (C). Derived from $\underbrace{\text{electric current}}_{i\ \text{(Ampere, A)}}$, $\frac{dq}{dt}$ at which charge moves past a point or through a region
→ $1\ C = (1\ A)(1\ s)$

Electrostatic constant : k

$k = \frac{1}{4\pi\varepsilon_0}$. ε_0: permittivity constant, $8.85\times10^{-12}\ N\ m^2/C^2$ in vacuum

The magnitude of the force in Coulomb's law

$$F = \frac{1}{4\pi\varepsilon_0}\,\frac{|q_1||q_2|}{r^2}$$

Superposition principle for $\vec{F}$: $\boxed{\vec{F}_{1,net} = \underbrace{\vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14} + \cdots + \vec{F}_{1n}}}$ Here, on particle 1
- n particles
- interacting independently in pairs

} Then, net force on any of them

Shell theorem of electrostatics:

- A shell of uniform charge attracts or repels a charged particle that is outside the shell as if the shell's charge were concentrated at its center.
- If a charged particle is located inside a shell of uniform charge there is no net electrostatic force on the particle from the shell.

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Spherical Conductors: if excess charge is placed on a sphericall shell (metal), the excess charge spreads uniformly over the surface.

- place exces electrons
- they repel each other
- spreading over the surface
- uniformly distributed
- Now, first shell theorem works!

Charge is quantized

"Electrical fluid" is made up of multiples of a certain elementary charge.

Charge is one of property of particles like mass.

multiples: $q = ne$ e: elementary charge (electron) 1.602×10^{-19} C

$n: \mp 1, \mp 2, \mp 3, \ldots$: quantized, it has discrete values. not continuous

Charge is conserved! In any kind of interaction, charge is transferred. Conservation!

i.e.

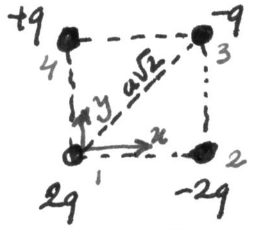
Radioactive decay of nuclei

Transformation of ^{238}U to ^{234}Th by emitting apha particle (^{4}He)

$$^{238}U \rightarrow {}^{234}Th + {}^{4}He$$ } charge is conserved

^{238}U	^{234}Th	^{4}He
92e	90e	2e
238 p,n	234 p,n	4 p,n

Example: In figure shown, what are i) horizontal components of the net electrostatic force on the charged particle in the lower left corner of the square ii) vertical components of that



$q = 1.0 \times 10^{-7}$ C

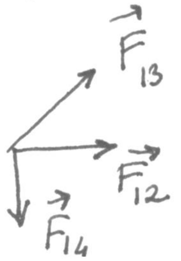
$a = 5.0$ cm

asked

$\vec{F}_{1,net} = \vec{F}_{12} + \vec{F}_{13} + \vec{F}_{14}$

$F_{1,net,x} = ?$

$F_{1,net,y} = ?$



$F_{12}: |\vec{F}_{12}| = k\dfrac{|2q||-2q|}{a^2} = k\dfrac{4q^2}{a^2}, \quad \vec{F}_{12} = k\dfrac{4q^2}{a^2}(\hat{i})$

$\longrightarrow \vec{F}_{12}$

$F_{14}: |\vec{F}_{14}| = \dfrac{k|2q||q|}{a^2} = k\dfrac{2q^2}{a^2}, \quad \vec{F}_{14} = k\dfrac{2q^2}{a^2}(-\hat{j})$

$\downarrow$

$F_{13}: |\vec{F}_{13,x}| = \dfrac{k|2q||-q|}{(a\sqrt{2})^2}\underbrace{\cos 45^\circ}_{\sqrt{2}/2}, \quad F_{13,x} = k\dfrac{2q^2}{a^2 2}\dfrac{\sqrt{2}}{2}$

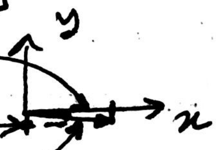
$|\vec{F}_{13,y}| = \dfrac{k|2q||-q|}{(a\sqrt{2})^2}\underbrace{\sin 45^\circ}_{\sqrt{2}/2}, \quad F_{13,y} = k\dfrac{2q^2}{a^2 2}\dfrac{\sqrt{2}}{2}$

i) $F_{1,net,x} = F_{12,x} + F_{13,x} + F_{14,x} = k\frac{q^2}{a^2}\left(4+\frac{\sqrt{2}}{2}\right) = 8.99\times10^{9}\,\frac{(1.0\times10^{-7})^2}{0.050^2}\left(4+\frac{\sqrt{2}}{2}\right) = \boxed{0.17\,N}$

ii) $F_{1,net,y} = F_{12,y} + F_{13,y} + F_{14,y} = k\frac{q^2}{a^2}\left(-2+\frac{\sqrt{2}}{2}\right) = \boxed{-0.046\,N}$

$$\vec{F}_{1,net} = k\frac{q^2}{a^2}\left[\left(4+\frac{\sqrt{2}}{2}\right)\hat{i} + \left(-2+\frac{\sqrt{2}}{2}\right)\hat{j}\right]$$

$$\vec{F}_{1,net} = 0.17\,N\,\hat{i} + 0.046\,(-\hat{j})$$



$$\tan\theta = \frac{-0.046}{0.17}$$