Role of Electrical + Magnetic Phenomena

*Electrical: LIGHTNING
→ fundamental parameter of matter: CHARGE
- charged matter exerts a force on other charged matter

electronics

*Magnetic: AURORAE
→ another aspect of matter
→ physics inherently tied to charge

ELECTROMAGNETISM

*Optical: RAINBOW
→ study of light

Electro-magnetic waves

General Relativity — Special Relativity

Modern Physics

Classical Physics

Quantum Field Theory — *Quantum Mechanics (QM)

(11-12 decimal place precision: like measuring Earth's diameter to 1/10 human hair)

World of the Atom

@ fundamental level, matter consists of atoms
→ 'electrons' in clouds or shells of probability around nucleus

→ protons (p) and neutrons (n) in nucleus

	Q	m
e	$-e$	9.1×10^{-31} kg
p	$+e$	1.7×10^{-27} kg
n	0	"

⇒ much lighter

electron is smallest isolatable charge (quark charge $\pm\frac{e}{3}, \pm\frac{2e}{3}$ but cannot be observed in isolation.)

$|Q| = N|e|$ ↳ electron charge
↓ total charge.

→ so charge is quantized (not "quantum" of QM)

→ also $q_{\text{proton}} = -q_e$ (experimentally confirmed)

$q_e = "e" = 1.6\times10^{-19}$ C (very tiny) "coulomb"

100W bulb has 10^{19} e in 1 sec!

"amount of charge flowing thru any cross-section of a wire in 1s if there's a steady current of 1 Amp."

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E+M — world of atom
→ foundation for most of modern science + technology
→ electronics
→ optics
→ semiconductors
→ ~~nuclear~~

*Chemistry
→ complex systems of atoms interacting via E+M

*Biology
→ DNA, genetic material
→ ions thru cell membranes
→ neural signals ~~in brain~~

*Engineering
→ friction → electron interactions for nearby materials
→ tensile strength
→ computer storage
→ ~~motor~~ generators

L1p4

Electricity

Originally, thought of as a fluid.
→ two kinds observed: positive and negative (B. Franklin)

→ electricity made of electrons since lightness makes easy to move

Conductors — copper, silver
→ free electrons occur when many metal atoms together
- not bound to atoms and move easily in material

insulators
→ all electrons bound to atoms

semiconductors
→ conductivity limited and sensitive to (intentional) additional other types of atoms in material

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Demo: Electrification by Induction

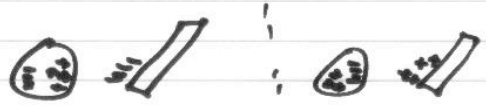
can attracted to electrified rod

→ what charge is can?

rubber rod → attracts

glass rod → " "

what's going on?



electron pushed from or pulled to rod side of can

L1 pp 6

Charge Conservation

historically: When rub glass rod with silk
- positive charge transferred onto rod
- negative charge on silk (e^- stripped from atoms)

Demo

→ total charge conserved

"in a closed system, one can never make or destroy net charge."

At fundamental particle level

charge 0 0

$\not{\gamma} \rightarrow e^+ e^-$

↳ positive electron = "positron"

- No cases of change in net electric charge have ever been observed (+ we're looking!)

↳ charge a scalar quantity

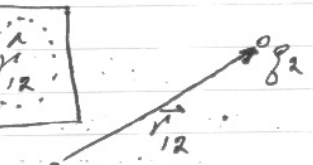
Coulomb's Law

→ use a "torsion balance"
  → rotating rod under tension.
    → indicates strength of force
    → repulsion causes twisting which can be adjusted

if q_1 & q_2 same sign: repel
opposite: attract

$$\vec{F}_{12} = k \frac{q_1 q_2}{r_{12}^2} \hat{r}_{12}$$

unit vector in direction of $\vec{r}_{12}$

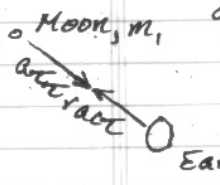


→ for point charges
→ r^n → n known to 1 part in 10^{16}!

$$k = 9 \times 10^9 \, Nm^2/C^2 = \frac{1}{4\pi\epsilon_0}$$ where $\epsilon_0 = 8.85 \times 10^{-12} \, C^2/Nm^2$

"permittivity constant"

NOTE similarity to Newton's Law of Gravity

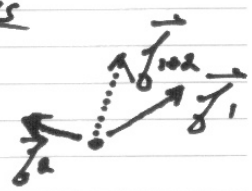


$$\vec{F}_{12} = -G \frac{m_1 m_2}{r_{12}^2} \hat{r}_{12}$$

(a force between masses)

Vector Addition & Angles & Force Diagrams

a) Adding 2 vectors:

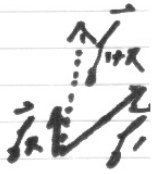


$\vec{f}_1 = 4\hat{i} + 3\hat{j}$
$\vec{f}_2 = -3\hat{i} + 1\hat{j}$

→ add in each ⊥ direction

$\vec{f}_1 + \vec{f}_2 = (4-3)\hat{i} + (3+1)\hat{j}$
$= \boxed{1\hat{i} + 4\hat{j}}$

b) Considering Angles



$\vec{f}_1 = 30N \text{ @ } \theta = 45°$
$\vec{f}_2 = 10N \text{ @ } \theta = 90°$

$\vec{f}_1 = f_{1x}\hat{i} + f_{1y}\hat{j} = |f_1|\cos\theta\,\hat{i} + |f_1|\sin\theta\,\hat{i}$
$= 21.2\hat{i} + 21.2\hat{j}$

$\vec{f}_2 = \cancel{f_{2x}\hat{i}} + f_{2y}\hat{j} = |f_2|\sin 90°\,\hat{j}$
$= 10\hat{j}$

$\therefore \vec{f}_1 + \vec{f}_2 = \boxed{21.2\hat{i} + 31.2\hat{j}}$

Multiple Charges

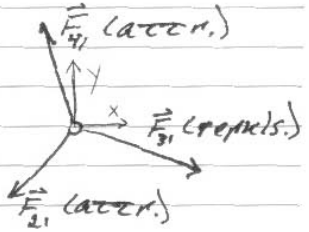
If > 2 charges, use superposition

$$\vec{F}_1 = \vec{F}_{21} + \vec{F}_{31} + \vec{F}_{41} + \cdots$$

- resultant force is vector sum of all forces from all particles

Force Diagrams

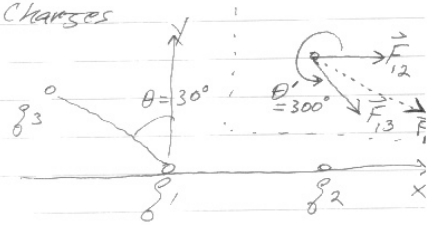
when multiple forces act on a point charge, it's useful to draw magnitude & direction



$$|F_{1x}| = |F_{31x}|\hat{i} - |F_{41x}|\hat{i} - |F_{31x}|\hat{i}$$

$$|F_{1y}| = |F_{41y}|\hat{j} - |F_{21y}|\hat{j} - |F_{31y}|\hat{j}$$

Example: Multiple Point Charges



$q_1 = -1.0\times10^{-6}$ C
$q_2 = +3.0\times10^{-6}$ C
$q_3 = -2.0\times10^{-6}$ C

$r_{12} = 15$ cm; $r_{13} = 10$ cm

What is resultant force + direction?

$$|F_{12}| = k q_1 q_2 / r_{12}^2$$
$$= 9\times10^9 \text{ N m}^2/\text{C}^2 \; \frac{(+1.0\times10^{-6}\text{C})(+3.0\times10^{-6}\text{C})}{(0.15\text{m})^2}$$
$$= 1.2\text{N}$$

$$|F_{13}| = k q_1 q_3 / r_{13}^2$$
$$= 9\times10^9 \text{ N m}^2/\text{C}^2 \; \frac{(-1.0\times10^{-6}\text{C})(-2.0\times10^{-6}\text{C})}{(0.1\text{m})^2}$$
$$= 1.8\text{N}$$

Adding vectors

$$F_{1x} = F_{12x} + F_{13x} = |F_{12}| + |F_{13}|\cos\theta'$$
$$= 2.1\text{N}$$

$$F_{1y} = F_{12y} + F_{13y} = |F_{13}|\sin\theta'$$
$$= 1.6\text{N}$$

$$|F_1| = \sqrt{(2.1\text{N})^2 + (1.6\text{N})^2}$$
$$= \boxed{2.6\text{N}}$$

$$\phi = \tan^{-1}\left(\frac{-1.6}{2.1}\right)$$
$$= \boxed{-37°}$$