PHYS 1410 L2 (reading ch. 17.2-4) 1/9/13

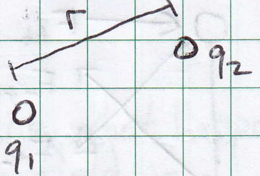
☐ Charge is a fundamental property and has its own units (C, or Coulombs)

- 1 C comes from the force required to hold two charges apart
- 1 C = 1 A·s (ampere per s)
- electron has a charge of -1.60×10^{-19} C ($\equiv -e$) negative!
- proton charge has same magnitude ~~charge~~ but opposite sign ($+1.60 \times 10^{-19}$ C)

☐ Coulomb's Law

- Consider two point charges (q_1 and q_2)
- Coulomb established these two exert a force upon one another as:

$$\boxed{\begin{aligned}|\bar{F}| &= k\frac{q_1 q_2}{r^2}\\ &= \frac{q_1 q_2}{4\pi\epsilon_0 r^2}\end{aligned}}$$



Where $k = 9.0 \times 10^{9}\ \mathrm{Nm^2/C^2} = \frac{1}{4\pi\epsilon_0}$

($\epsilon_0 = 8.85 \times 10^{-12}\ \frac{C^2}{N \cdot m^2}$, the permitivity of free space)

- depending upon the sign of q_1 and q_2, the force $\bar{F}$ can be attractive or repulsive
- Just like gravity, superposition of forces applies ($\bar{F}_{net} = \sum \bar{F}_i$)
- No force if an object is 'neutral' (i.e. $q = 0$), UNLESS the charge is not uniformly distributed!

$\boxed{\text{ex1}}$ A penny has a mass of 3.1 g. $(\equiv m)$
its is electrically neutral (i.e. same # of positive and negative charges. What is the mag. of these charges?

[a copper atom has a positive nuclear charge of 4.6×10^{-18} C]

N = # of copper atoms in a penny

$$\frac{N}{N_0} = \frac{m}{M} \quad \left(\begin{array}{l} N_0 \text{ - Avogardo's \#} \\ M \text{ - atomic weight of copper} \end{array} \right)$$

$$\rightarrow N = \frac{(6.0 \times 10^{23} \text{ atoms/mol})(3.1 \text{ g})}{64 \text{ g/mol}}$$

$$= 2.9 \times 10^{22} \text{ atoms}$$

Q = (charge of all those atoms)

$$= (2.9 \times 10^{22} \text{ atoms})\left(4.6 \times 10^{-18} \frac{C}{\text{atom}}\right)$$

$$= 1.3 \times 10^{5} \text{ C}$$

→ this is enough charge to run a 100W lightbulb for 40+ hours!

∴

$\boxed{\text{ex2}}$ Two protons in an iron atom are separated by 4.0×10^{-15} m. What is the repulsive force?

$$F = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$$

$$= \left(9.0 \times 10^{9} \frac{Nm^2}{C^2}\right) \frac{(1.6 \times 10^{-19} \text{ C})^2}{(4.0 \times 10^{-15} \text{ m})^2}$$

$$= 14 \text{ N}$$

→ This large repulsive force is counter-acted by the strong nuclear force (another of the four fundamental forces). This force does create a degree of instability though, leading towards radioactive decay.

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ex.4

The distance r between a proton and electron in a hydrogen atom is ~5.3×10^{-11} m. What is the magnitude of a) the electrical force and b) the gravitational force?

a) $F_e = \frac{1}{4\pi\epsilon_0} \frac{q_1 q_2}{r^2}$

$= (9.0 \times 10^{9} \frac{N \cdot m^2}{C^2}) \frac{(1.6 \times 10^{-19} C)^2}{(5.3 \times 10^{-11} m)^2}$

$= 8.1 \times 10^{-8}$ N

b) $F_G = G \frac{m_1 m_2}{r^2}$

$= (6.7 \times 10^{-11} \frac{N \cdot m^2}{kg^2}) \frac{(9.1 \times 10^{-31} kg)(1.7 \times 10^{-27} kg)}{(5.3 \times 10^{-11} m)^2}$

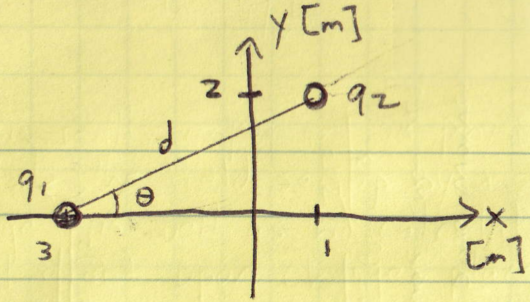
$\simeq 3.7 \times 10^{-47}$ N

→ Though both forces are attractive, the electrical force is ~10^{39} times stronger!

ex3

[illegible]

17.14



$q_1 = 2.5C$

$q_2 = 4.0C$

a) Force exerted by q_1 on q_2?

$d = \sqrt{4^2 + 2^2} = 4.47$ m

$\cos\theta = \frac{4}{4.47} = 0.9 \rightarrow \theta = 0.46$ rads

(= 26.5°)

$\bar{F}_{12} = \underbrace{F_{12x}\hat{x}}_{\text{positive}} + \underbrace{F_{12y}\hat{y}}_{\text{positive}}$ (both due to repulsion)

$|\bar{F}_{12}| = k \frac{q_1 q_2}{d^2} = 4.5 \times 10^{9}$ N

$F_{12y} = |F_{12}| \sin\theta = 4.03 \times 10^{9}$ N

$F_{12x} = |F_{12}| \cos\theta = 2.0 \times 10^{9}$ N

$\rightarrow \bar{F}_{12} = [4.03\hat{y} + 2.0\hat{x}] \times 10^{9}$ N

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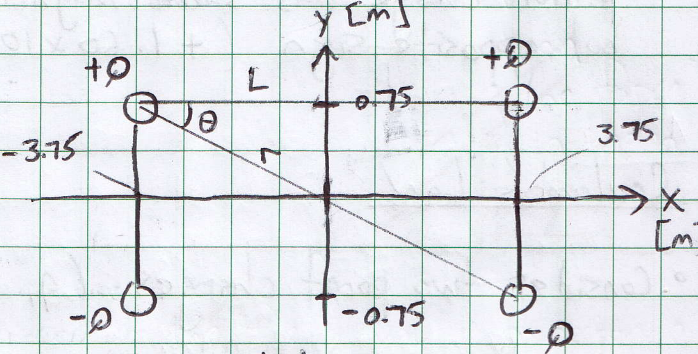
Electric dipole

- Suppose you have two charges, one positive and one negative, of equal magnitude separated by a distance d
- total net charge is zero
- However, put another charge nearby and it will most likely move (see Fig. 17.7)
- Water molecules act like dipoles → hydrogen bonding

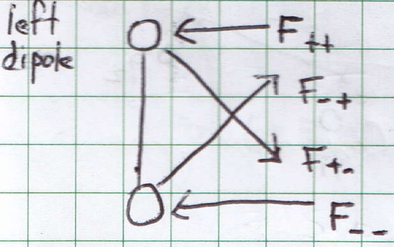
exs

(prob. 17.24)

Two dipoles (fixed inter-separation) where $|Q| = 5\ C$. Find the total force between them.



ANS Free-body diagram (for one dipole)



NOTE: Due to rigid separation, the net force between the two charges shown is zer

$$\bar{F}_{++} = -|F_{++}|\hat{x}$$

$$\bar{F}_{--} = -|F_{--}|\hat{x}$$

$$\underbrace{|F_{++}| = |F_{--}|}_{\text{due to symmetry}} = k\frac{Q^2}{L^2} = 8.99\times10^9 \cdot \frac{5^2}{7.5^2} = 4.00\times10^9\ N$$

(check your units!)

$$r = \sqrt{7.5^2 + 1.5^2} = 7.65\ m$$ (diagonal dist. between charges)

$$|F_{+-}| = |F_{-+}| = k\frac{Q^2}{r^2} = 3.84\times10^9\ N$$

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Note that the y-components of $\bar{F}_{+-}$ and $\bar{F}_{-+}$ cancel and only an x-component is left when summing them (and it points toward +x)

$$\bar{F}_{+-} + \bar{F}_{-+} = 2|F_{+-}|\cos\theta\,\hat{x} \qquad \text{where } \cos\theta = \frac{7.5}{7.65} = 0.98$$

$$= 7.53\text{ N}\,\hat{x} \qquad (= 3.76 + 3.76)$$

So $\bar{F}_{++} + \bar{F}_{--} + \bar{F}_{+-} + \bar{F}_{-+} = -$ [illegible]

$$= \hat{x}\left[-4 - 4 + 3.76 + 3.76\right]^{\times 10^{9}}\text{ N}$$

$$= -4.7\times 10^{8}\text{ N}\,\hat{x}$$

→ Negative sign here means the left dipole will get pushed to the left (i.e. the two repel each other)

☐ Electric Field

- Just like the notion of a gravitational field (i.e. what happens if we put a mass m here?), an electric field is a useful concept for determining the force a charge is subjected to when put close to other charges)
- Like forces, the electric field is a **vector** quantity
- To define, we consider a point charge Q. Now suppose we put a 'test charge' q nearby (at distance r). Coulomb's Law has the resulting force as

$$|F| = k\frac{Qq}{r^2} \equiv q|E| \rightarrow |E| = \frac{kQ}{r^2}$$

- So we define the electric field E in terms of F through the notion of a 'test charge'

- Analogous to the gravitational force near the earth's surface:

$$\underset{\text{(gravity)}}{\bar{F} = m\bar{g}} \quad \longleftrightarrow \quad \underset{\text{(electricity)}}{\bar{F} = q\bar{E}}$$

- The notion of a field is really important in physics as it allows us to a) calculate the field set up by a given distribution of charge as well as b) calculate the forc that given fields will exert upon changes placed in them

$\boxed{\text{ex}}$ What is the magnitude of the electric field strength such that an electron placed in the field would experienc a force equal to its own weight?

$$|E| = \frac{|F|}{q_0} = \frac{mg}{e} = \frac{(9.1 \times 10^{-31}\ \text{kg})(9.8\ \text{m/s}^2)}{1.6 \times 10^{-19}\ \text{C}}$$

$$= 5.6 \times 10^{-11}\ \text{N/C}$$ → small field; points downwa (towards earth

⊡ Lines of force

- Provides a graphical means to get a handle on what the field looks like; some rules

1) tangent to any line of force gives the direction of $\bar{E}$ at that point

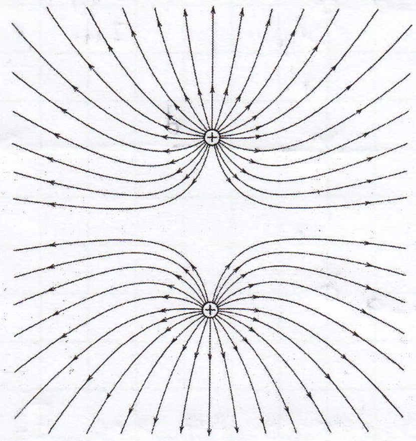

Fig. 27-4 Lines of force for two equal positive charges.

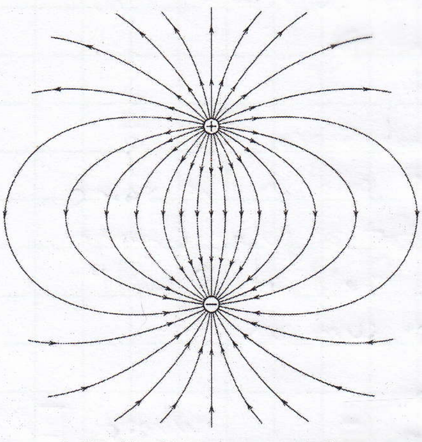

Fig. 27-5 Lines of force for equal but opposite charges.

2) The lines of force are drawn such that the # of lines per unit area is proportional to $\bar{E}$ (i.e. lines close together means E is large)

☐ To find $\bar{E}$ for a group of point charges, you calculate E_n from each charge at a given point as if it were the only one present, then you add them altogether (as vectors!) to find the total field

$$\bar{E} = \bar{E}_1 + \bar{E}_2 + \bar{E}_3 + \cdots = \sum E_n$$

[Calculus Aside] If the charge distribution is a continuous one, you can consider an infitesimal charge (dq) and its associated field (dE) as

$$|dE| = \frac{1}{4\pi\epsilon_0}\frac{dq}{r^2}$$

(where r is the dist. between dq and some point P). Then the resulting field at P is given as

$$\bar{E} = \int d\bar{E}$$