Chapter 21: Charge and Coulomb's Law

If you don't yet have syllabus and homework schedules please pick them up now.

Chapter 21 Homework

- **Find 2140 homepage (physics.utoledo.edu)**
- **Read Chapter 21**
  - **Note Checkpoints 3,4**
  - **Do Questions 1,2**
  - **Do Problems 2, 7, 13, 65**
- **Log onto WileyPlus system**
- **Do online homework assignment**

I. Electric Charge

- **Two kinds: positive and negative**
- **Matter is made of charged particles: protons, electrons, atoms, molecules**
- **Charge is *conserved* and *quantized***
- **The elementary charge: $e = 1.6 \times 10^{-19}$ C.**
- **Electric current -- the rate of flow of charge**
- **Conducting and insulating materials**

II. Coulomb's Law

$$F = k\frac{Q_1 Q_2}{r^2}$$

- **Inverse square law, attraction and repulsion**
- **SI units: Coulomb and Ampere**
- **The Coulomb constant: $k = 9 \times 10^9$ SI units.**

III. Vector Notation

$$\vec{F} = k\frac{Q_1 Q_2 \vec{r}}{r^3} = k\frac{Q_1 Q_2 \hat{r}}{r^2}$$

If two forces act on a body, then the net force is the **vector sum:**

$$\vec{F} = \vec{F}_1 + \vec{F}_2$$

BUT remember that the **magnitudes** may **NOT** add:

$\vec{A} = \vec{B} + \vec{C}$ does **not** mean that A = B + C

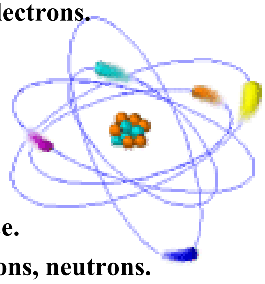
Notes about quizzes and exams

- **Do the powers of 10 in your head.**
- **Use only one or two significant figures – that's enough to show you have the basic principles right.**

For example $k = 9 \times 10^9$ **SI units**

The quantum of charge

The world is made of atoms, which are made of protons, neutrons and electrons.



- Proton has charge +e.
- Electron has charge –e.
- Neutron has charge 0.

Atom is mostly empty space.

Tiny nucleus contains protons, neutrons.

Fundamental quantum of charge: $\mathbf{e = 1.60 \times 10^{-19}\ C}$

Moving Charge

- I can charge an object by adding or removing electrons.
- When I comb my cat, I move electrons from the fur to the rubber comb, leaving the cat with a net *positive* charge, and the comb with a *negative* charge.
- *Charge conservation* means that, if both cat and comb were originally neutral, then

$$Q_{cat} + Q_{comb} = 0$$

Atomic number and mass number

- Z = *atomic number* = no. of e's = no. of p's (so Q=0 for a neutral atom)
- A = *mass number* = no. of protons + no. of neutrons ($m_p = m_n >> m_e$)
- N_A = Avagadro's number = 6×10^{23} (number of atoms in one *mole*)

N_A is defined so that the mass of N_A atoms is A grams

Example

Two isotopes of uranium:

U_{235} ($^{235}U_{92}$) has Z=92, A=235 (92p's, 92e's, 143n's)

U_{238} ($^{238}U_{92}$) has Z=92, A=238 (92p's, 92e's, 146n's)

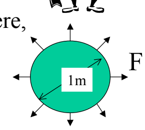
Question: How many atoms in 1 kg of U_{235}?

Answer: One mole is 235 grams, so 1 kg is 1000/235 = 4.26 moles. The number of atoms in a mole is $N_A = 6 \times 10^{23}$ so the answer is

$$4.26 \times 6 \times 10^{23} = 2.6 \times 10^{24} \quad \text{atoms}$$

Another example

- Estimate the force on a person who lost electrons from 1 gram of his/her body?



- Model body with a ~1 m^3 water sphere,
- 1 mole of H_20 is 18g.
- 1 g has $n=N_A/18 \sim 10^{22}$ atoms
- Electric charge $Q=ne \sim 10^3$ C
- Force $F=kQ^2/r^2 \sim 10^{10} \times (10^3)^2 / 1^2 = 10^{16}$ N

Huge! Electrostatic forces are strong.

Coulomb's Law: Action at a Distance?

- One charged object exerts a force on another.
- Like charges repel, unlike charges attract.
- How can a force be exerted at a distance?
- Next chapter: the electric field.

The inverse square law

- True for both electricity and gravity! **Why?**
- Because space is three-dimensional.
- $F \propto 1/r^2$
- If $r \to 2r$ then $F \to F/4$
- The force is inversely proportional to the square of the distance

The Coulomb Law Constants

Coulomb's experiment gives $F = kQ_1Q_2/R^2$

and determines the ***electrostatic constant***

$$k = 8.99\times10^9 \approx 9\times10^9 \quad \text{SI units}$$

This is often written as $k = \dfrac{1}{(4\pi\varepsilon_0)}$

with the ***permittivity constant*** having the value

$$\varepsilon_0 = 8.85\times10^{-12} \qquad \text{SI units}$$

Example 1

Two charges are separated by 3 meters. If each charge is 2 microcoulombs, what is the force by one charge on the other?

Solution

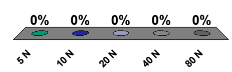
$$Q = 2\mu C = 2\times10^{-6}C$$

$$F = k\frac{Q^2}{r^2} = \frac{9\times10^9\times(2\times10^{-6})^2}{3^2}$$

$$F = \frac{9\times4\times10^{-3}}{9} = 4\times10^{-3}N$$

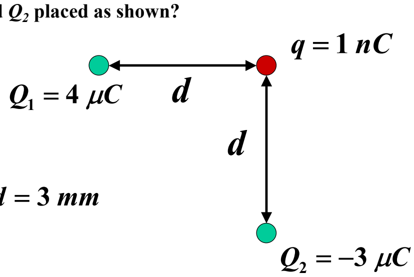
Two charges are separated by 2 m and repel each other with a force of 20 N. If they are moved to a separation of 4 m, what will be the repulsive force?

1. 5 N
2. 10 N
3. 20 N
4. 40 N
5. 80 N



Example 2

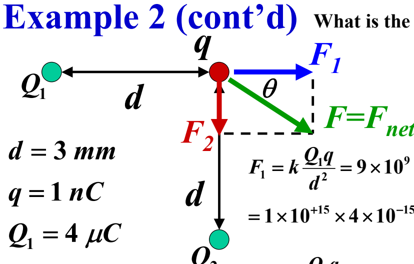
What is the net force on the charge q due to the charges Q_1 and Q_2 placed as shown?



$d = 3\ mm$

Example 2 (cont'd)

What is the net force on q?



$d = 3\ mm$

$q = 1\ nC$

$Q_1 = 4\ \mu C$

$Q_2 = -3\ \mu C$

$$F_1 = k\frac{Q_1 q}{d^2} = 9\times10^9\frac{(4\times10^{-6})(1\times10^{-9})}{(3\times10^{-3})^2}$$

$$= 1\times10^{+15}\times4\times10^{-15}N = 4\ N$$

$$F_2 = k\frac{Q_2 q}{d^2} = 9\times10^9\frac{(3\times10^{-6})(1\times10^{-9})}{(3\times10^{-3})^2}$$

$$= 1\times10^{+15}\times3\times10^{-15}N = 3\ N$$

$$\vec{F} = \vec{F}_1 + \vec{F}_2$$

$$F = \sqrt{F_1^2 + F_2^2} = \sqrt{3^2+4^2} = 5\ N$$

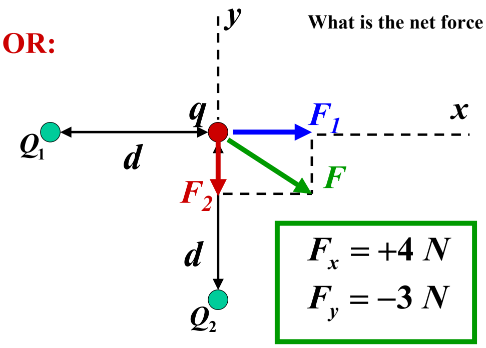
$$\tan\theta = 3/4$$

$$\theta = 37^\circ$$

Example 2 (cont'd)

OR:

What is the net force on *q*?



$$F_x = +4\ N$$
$$F_y = -3\ N$$

No test tomorrow in DC 1019!

- For future tests:
- Bring PRS unit
- No formula sheet
- Multiple-choice questions