<u>Chapter 8: E & M (Electricity & Magnetism or Electromagnetism)</u>

Electric charge & electric force – Coulomb’s Law
Electrons & basic facts about atoms (mainly review)
- Charge conservation
- Electric current & circuits
- Resistance & Ohm’s Law
- Concept of ***<u>FIELD</u>*** (electric/magnetic/gravitational)
- Magnetism – only a few examples

Electric charge – need two types, positive & negative (arbitrary nomenclature!), and electric force – a new fundamental force. Demos on *electrostatics*…..

Coulomb's Law of the Electric Force

Between any two small charged objects there is a force that is repulsive if both objects have positive charge or if both have negative charge, and is attractive if one has positive and the other has negative charge. This force is proportional to the amount of charge on each object, and proportional to the inverse of the square of the distance between them:

$$\text{electric force} \propto \frac{(\text{charge on 1st object}) \times (\text{charge on 2nd object})}{\text{square of the distance between them}}$$

Using abbreviated symbols,

$$F \propto \frac{q_1 \times q_2}{d^2}$$

Similar to gravitational force, except attractive OR repulsive!

If electric charge is measured in "coulombs" (see below), distance in meters, and force in newtons, then this proportionality becomes[1]

$$F = 9 \times 10^9 \frac{q_1 \times q_2}{d^2}$$

Looks like a strong force. But 1 C(oulomb) is huge!

Note the (mathematical) similarity between Newton's law of gravity and Coulomb's law, especially the 1/distance^2 dependence – coincidence?

Perhaps not …. (a single, small) electric charge (or mass) sets up an electric or (gravitational) ***field*** around itself. Field is spherically symmetric. And the surface area of a sphere goes like (4πradius^2)!

Note: $q_{electron} = -1.6 \times 10^{-19}$ C (the − sign is convention!)
and $q_{proton} = +1.6 \times 10^{-19}$ C, so that $q_{electron} + q_{proton} = 0$ ("neutral")
to the highest measured precision! Why is a great mystery!
(Also a mystery is what sets the mass scales & mass ratios of these particles, for instance $m_p \approx 2000 \times m_e$)

Electric charge is "quantized", i.e. charges of other particles come only in integer (except the "quarks" that make up protons & neutrons) multiples of this "elementary charge", and every e^- appears to carry exactly the same amount of charge.

Source of $F_{gravity}$: masses   Source of $F_{electric}$: electric charges
→ Two of the four fundamental forces in nature!

But *remarkable* difference in strength:
In an H-atom $F_{electric} > F_{gravity}$ by about 10^{39} !!

Good question: C.E. 2 Because matter tends to be electrically neutral, i.e. + and − charges balance each other out.

C.E. 8: Forces on both are reversed in direction.

Quiz # 57: Ping pong ball A has an electric charge that is 10 times larger than the charge on ball B. When placed sufficiently close together that they exert a measurable force on each other, how does the force by A on B compare with the force by B on A?

(a) Need to tell us whether the charges are + or −.
(b) Equal in strength and in direction.
(c) Same direction, but A on B is 10 times the one by B on A.
(d) Opposite direction, otherwise as in (c).
(e) Equal in strength and opposite in direction.

Charges within atoms and other simple facts about atoms (see also chapter 2):

electrons (−), protons (+), and neutrons (0, i.e. electrically neutral)

Overall size of atoms: ~ 10^{-10}m; of nucleus: ~ 10^{-14}m

→ Atoms are mostly "empty" space! (Not really empty at all!)

$m_{p(roton)} \cong m_{n(eutron)}$ m_p or $m_n \approx 2000 \times m_e$

Atomic nuclei consist of protons & neutrons, and there are plenty of stable nuclei (and even more unstable ones, different story).

OK, so put that last statement (stable nuclei and $F_{Coulomb}$ together – what conclusion do you draw?

A *very strong* nuclear force must exist! Nevertheless, for your daily life the electric (or really electromagnetic) force is crucial, often the most important force.

"Ion": an atom with an excess or deficiency of electrons, i.e. where # of electrons ≠ # of protons, and therefore **ions carry net charge**.

Quiz # 58: The electric (Coulomb) force between an H-atom (hydrogen) and an H^- ion (1 proton + 2 electrons) is
(a) attractive (b) repulsive (c) zero, i.e. there is no such force

Remember the Periodic Table of the Elements?
1 Hydrogen, 2 Helium, 3 Lithium,…. 6 Carbon, … 8 Oxygen,…..
What determines that #, called the **atomic number** ?

Simply the # of protons in the nucleus, which of course is normally equal to the # of electrons (unless the atom has been "ionized"), and the # of electrons in turn determines the chemical properties of an element.

Remember: Chemical reactions are due to the electromagnetic force!

Quiz # 59: An atom loses two of its electrons (becomes "ionized"). How does the resulting ion behave when it is near a proton?
(a) it is repelled (b) it is attracted (c) neither, i.e. feels no force

Another crucial conservation law:

Electric charge is conserved! – Charges can be moved, but no **net** charge (positive minus negative) is ever created or destroyed in a process.

Examples from high-energy/particle physics:

1) High energy “photons” (chunks of light, more in ch. 12) interact with matter: γ (“gamma”, the photon, charge 0) → e^- + e^+ (e^+ = “positron”, anti-particle of the electron, opposite charge)

2) p + p → anti-p + p + p + p (because of charge conservation a (p – anti-p) pair has to be produced, costing lots of energy!)

Quiz # 60: Suppose you had enough energy in the incident particles and can satisfy energy & momentum conservation, could the following reaction happen: e^- + e^+ → p(roton) + n(eutron) ?

(a) no (b) yes

What about e^- + e^+ → p + n + anti-p ? (Apart from charge conservation there is another, particle-physics problem above……)