Phys123 – Electricity and Magnetism

- Lecturer
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- Lectures:
  - Monday 13:00?
  - Thursday 9:00 (Rotblat).
  - Thursday 11:00 (Gossage).
- Tutorials, for times and locations see first year notice board.
- Recommended text book:
  "University Physics", Young and Freedman, chapters 21 to 32.

Phys123 – Electricity and Magnetism

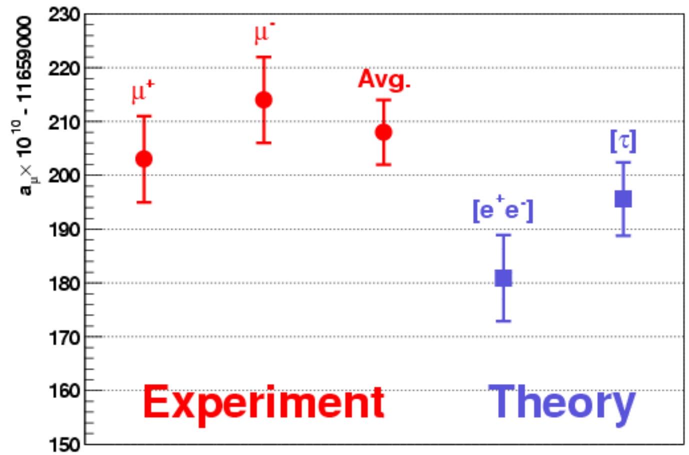
- Syllabus
  - Electric Charge, Coulomb's Law
  - Electric Fields and Gauss' Law
  - Electric Potential
  - Capacitance
  - Current, Resistance and Circuits
  - Magnetic Fields
  - Magnetic Fields and Currents
  - Induction and Inductance
  - Magnetic Materials
  - Maxwell's Equations
  - Electromagnetic Oscillations and Alternating Current
  - Electromagnetic Waves

Lecture 1

- This lecture we will cover:
  - Electricity and magnetism, from the Greeks to the present day
  - Coulomb's Law
  - Principle of superposition
  - Shell theorem
- Check your understanding: after this lecture, you should be able to answer the following questions.
- The surfaces of two table tennis balls are uniformly charged up by bombarding them with electrons. A total of 6.25×10^6 electrons stick to the first ball and 12.5×10^6 electrons to the second. What is the force between the balls if their centres are 0.08 m apart?
- What is the force on a third ball, carrying a uniformly distributed charge of + 2 pC, placed symmetrically between balls one and two. In what direction does it act?

Electricity and Magnetism

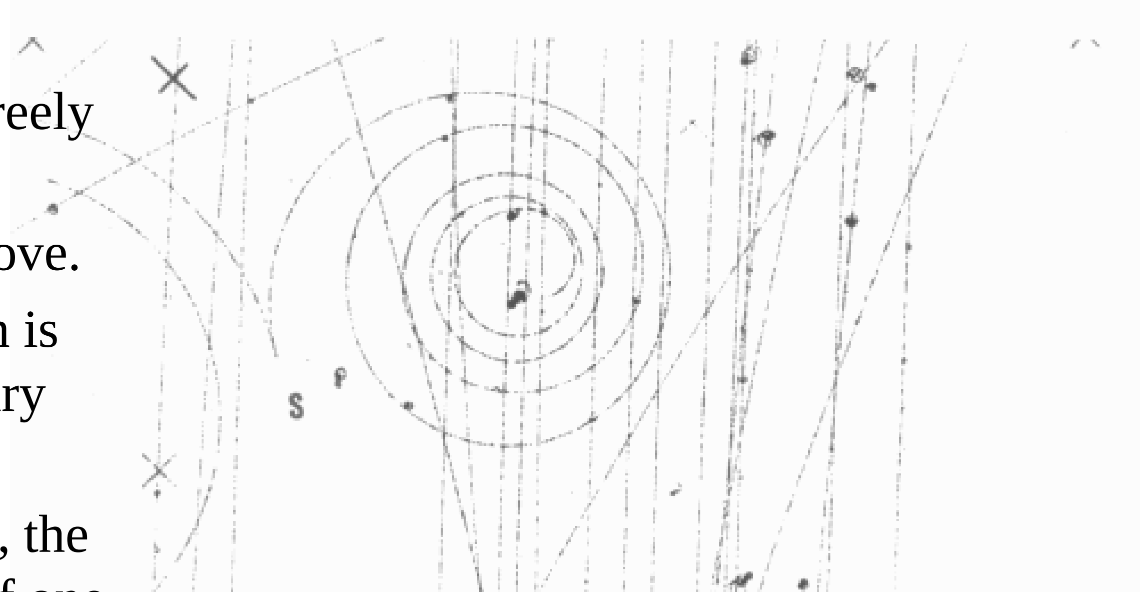
- The Greeks knew that:
  - A rubbed piece of amber would attract straw. ("Elektron" is the Greek word for amber.)
  - Some "stones" (magnetite) could attract iron.
- Electricity and magnetism were seen to be aspects of the same force and unified in the electromagnetic theory of Maxwell.
- The quantum theory of electro-magnetism, Quantum electro-dynamics (QED), has been tested experimentally to enormous precision.
- Gyro-magnetic ratio of the electron:
  $g_e = 2.0023193043617 \pm 0.0000000000015$
- Also measured g_μ , shown is $a_\mu = (g_\mu - 2)/2$:



- But QED cannot be the full story...
- Devices relying on electromagnetic effects are all pervading.

Electric Charge

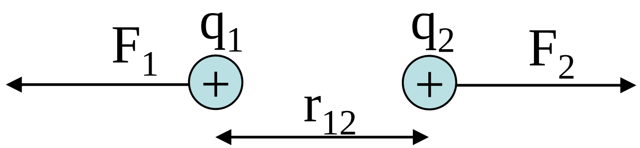
- There are positive and negative electric charges, like charges repel, unlike charges attract.
- Materials can be:
  - Conductors – charges move freely (superconductors, resistors).
  - Insulators – charges do not move.
- Charge quantized, q = ne, where n is +ive or –ive integer, e is elementary charge (charge of proton).
- Unit of charge is the coulomb (C), the charge transferred when current of one ampere (A) flows for one sec (s):
  $dq = i\,dt$ [1.1]
- $e = 1.6 \times 10^{-19}$ C.
- Charge is conserved: in any reaction, total charge before = total charge after.



- Objects are said to be "charged" when there is an imbalance of +ive and –ive charges, e.g. balloon charged by rubbing on pullover.

Force Between Electric Charges – Coulomb’s Law

- Two point charges



$$F_1 = \frac{1}{4\pi\varepsilon_0}\frac{|q_1||q_2|}{r_{12}^{\ 2}} \qquad [1.2]$$

- Force is vector, has direction (given by arrow in diagram) and magnitude.
- Permittivity constant:

$$\varepsilon_0 = 8.85\times10^{-12}\ \mathrm{C^2\ N^{-1}\ m^{-2}},$$

$$\frac{1}{4\pi\varepsilon_0} = 8.99\times10^{9}\ \mathrm{N\,m^2\,C^{-2}}.$$

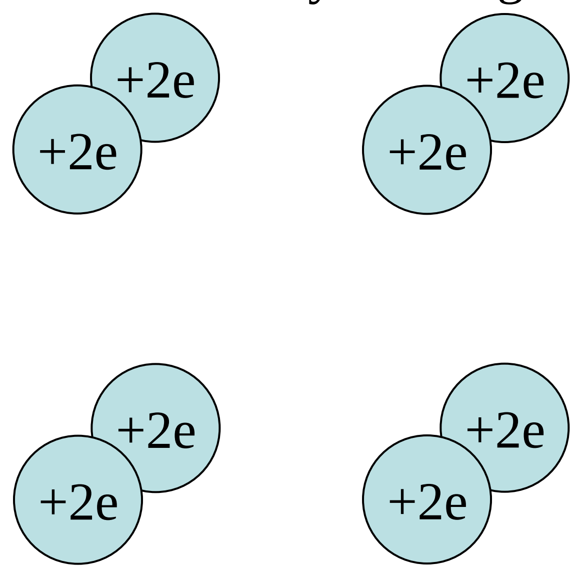
- Compare with gravitational force:

$$F = G\frac{m_1 m_2}{r_{12}^{\ 2}} \qquad [1.3]$$

- What are relative strengths of electric and gravitational forces?
- Principle of superposition: if charge 1 interacts with charges 2…n, total force on one given by:

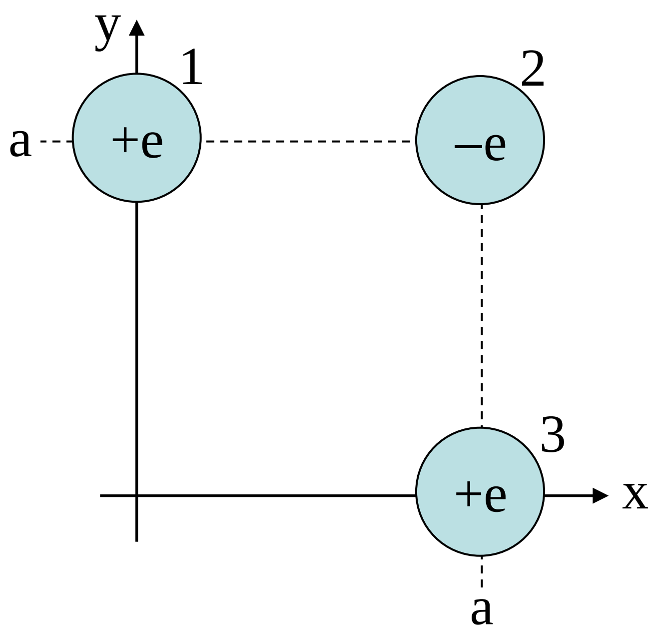
$$\vec{F}_1 = \vec{F}_{12} + \vec{F}_{13} + \ldots + \vec{F}_{1n} \qquad [1.4]$$

- Where is there zero force on a proton in the cubic array of charges below?



Principle of Superposition

- An example using Coulomb's Law in vector form.
- What is the net force on charge 2?



$\vec{r}_1 = (0, a),\ \vec{r}_2 = (a, a),\ \vec{r}_3 = (a, 0).$

$\vec{r}_{21} = \vec{r}_1 - \vec{r}_2 = (0, a) - (a, a) = (-a, 0).$

$\vec{r}_{23} = \vec{r}_3 - \vec{r}_2 = (a, 0) - (a, a) = (0, -a).$

- Force on 2 due to 1:

$$\vec{F}_{21} = \frac{-1}{4\pi\varepsilon_0}\frac{q_1 q_2}{r_{21}{}^2}\hat{r}_{21}, \text{ where}$$

$$\hat{r}_{21} = \frac{1}{|\vec{r}_{21}|}\vec{r}_{21} = \frac{1}{\sqrt{(-a)^2 + 0^2}}(-a, 0) = (-1, 0).$$

$$\text{Hence, } \vec{F}_{21} = \frac{-1}{4\pi\varepsilon_0}\frac{(e)(-e)}{a^2 + 0^2}(-1, 0)$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{e^2}{a^2}(-1, 0).$$

$$\text{Similarly, } \vec{F}_{23} = \frac{-1}{4\pi\varepsilon_0}\frac{(e)(-e)}{0^2 + (-a)^2}\frac{(0, -a)}{\sqrt{0^2 + a^2}}$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{e^2}{a^2}(0, -1).$$

Principle of Superposition

- Sum the forces:

$$\vec{F}_2 = \vec{F}_{21} + \vec{F}_{23}$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{e^2}{a^2}\left[(-1,0)+(0,-1)\right]$$

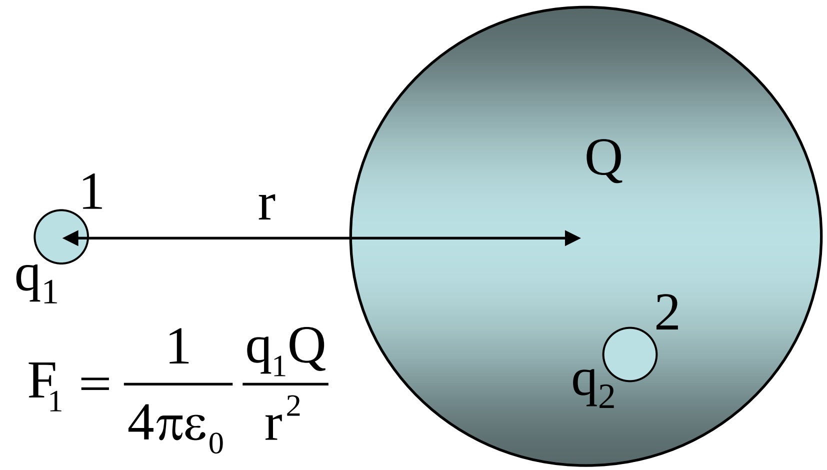
$$= \frac{1}{4\pi\varepsilon_0}\frac{e^2}{a^2}(-1,-1)$$

$$= \frac{1}{4\pi\varepsilon_0}\frac{\sqrt{2}e^2}{a^2}\left(-\frac{1}{\sqrt{2}},-\frac{1}{\sqrt{2}}\right)$$

- What is the magnitude of this force if a = 1 nm?
- Compare this with an "everyday" force, e.g. the weight of an apple!

Shell Theorem

- Charge distributed on a spherical shell.
- For charges outside the shell (1), the charged shell behaves as if the total charge is concentrated at the centre



$$F_1 = \frac{1}{4\pi\varepsilon_0}\frac{q_1 Q}{r^2}$$

- Charges inside the shell (2) experience no force: $F_2 = 0$.