MPHYCC-13 (Nuclear and Particle Physics)

PG. Sem-III

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Two Body Problem and Nuclear Forces

 # The Nuclear Force: Lord Rutherford, in 1919, through a series of investigations, was successful in carrying out the first ever induced nuclear transmutation, viz the disintegration of nitrogen nucleus through its bombardment by α-particles obtained as a result of natural radio-activity of Radium and Thorium. The identification of the products of this artificial nuclear reaction led to the discovery of a fundamental particle the proton, which has had the status of being the first fundamental nuclear particle. This nuclear reaction may be written as:

$$\left[{}_{7}N^{14} + 2\,He^{4} \right] \longrightarrow \left[{}_{8}O^{17} + {}_{1}H^{1} \right]$$

(Nitrogen) (α-particle) (Oxygen) (Proton)

After the discovery of the proton, it was erroneously confended that atomic nuclei were constituted of electrons and protons. But this nuclear model soon ran into difficulties under quantum mechanical examination; and then the structure and the constituent particles of the nucleus remained unexplained until 1932 when Chadwick, through a series of experiments performed by Bothe, Joliot and himself, discovered another uncharged fundamental particle - the neutron which has a mass almost equal to that of the proton. This fundamental neutral particle had the right properties to be called a nuclear constituent. Since then and to date, protons and neutrons are taken to be the building blocks of all atomic nuclei. The protons and neutrons, being nuclear constituents, are known under a common name also as 'nucleons'.

Ever since the constituent particles of the atomic nucleus became known, the central problem of nuclear physics and perhaps the most intriguing one, has been the investigation of the nature and origin of the forces which hold the nucleons (neutrons and protons) together in a nucleus. Before plunging into the complexities of these forces; to make an overall assessment of the problem and make a survey of the characteristics of the familiar and much simple forces, viz. the electromagnetic and gravitational forces.

The electromagnetic interactions are charge-dependent, are attractive as well as repulsive and are comparatively of long range character as evident by their inverse-square dependence upon distance. The inverse-square law Coulomb forces may be conceived of as due to an exchange of photons between the interacting charges.

The natural unit of charge, viz. the charge of an electron 'e', ($= 1.6021 \times 10^{-19}$ coulomb) tells us how strongly the electrons are coupled to the electromagnetic fields or in a broader sense how strongly elementary charges interact with each other. To have an idea of the strength of this coupling, we form a dimensionless quantity called the dimensionless coupling constant as follows:

As we know, c and ℏ (h cross) are the two venerable constants of quantum physics. If we consider a particle of mass 'm', then combining it with c and ℏ, we can construct some other constants such as:

mc^2, which has the dimensions of energy.

$\hbar/mc^2$, " " " time, and

$\hbar/mc$, " " " length.

If then two electrons are considered to be separated by distance equal to one natural unit of distance viz. $\hbar/mc$, the electrostatic energy of repulsion between them, in natural units of energy, may be written as:

$\alpha = \frac{e^2}{(\hbar/m$ ...

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[Since e ...

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In S.I. unit ...

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$$\alpha = \frac{e^2}{(\hbar/mc)} \cdot \frac{1}{(mc^2)} = \frac{e^2}{\hbar c} \text{ (in C.G.S. electromagnetic units)}$$

$$= \frac{(4.80298 \times 10^{-10} \text{ e.s.u of charge})^2}{(1.0545 \times 10^{-27} \text{ erg-sec}) \times (3 \times 10^{10} \text{ cm/sec})}$$

$$= \frac{(4.80298 \times 10^{-10})^2}{(1.0545 \times 10^{-27}) \times (3 \times 10^{10})}$$

$$= 7.2972 \times 10^{-3}$$

[Since erg = dyne - cm and dyne - cm^2 = (e.s.u of charge)^2]

$$\simeq \frac{1}{137.037} \simeq \frac{1}{137}$$

In S.I. units, $\alpha = \frac{1}{4\pi\varepsilon_0} \cdot \frac{e^2}{\hbar c}$

$$= \frac{(9 \times 10^9 \text{ N-m}^2/\text{coul.}^2) \times (1.6 \times 10^{-19} \text{ coul.})^2}{(1.0545 \times 10^{-34} \text{ J-s}) \times (3 \times 10^8 \text{ m/s})}$$

$$= 7.2972 \times 10^{-3} \frac{\text{N-m}^2}{\text{N-m}^2}$$

[$\because$ Joule = Newton - meter]

$$= 7.2972 \times 10^{-3} \simeq \frac{1}{137}$$

A measure of the electromagnetic interaction is this coupling constant. This constant plays a fundamental role in atomic spectroscopy and therefore is known as fine structure constant.