Mesons and Nuclear Forces

Hideki Yukawa

(Mrach 6, 1951)

1. Introduction

Since the time of Galilei and Newton, the motion of visible and invisibles substances has been the main subject of investigation in physics, particularly in ~~its~~ connection with the forces ~~acting on~~ affecting the motion. It started from the motion of planets under the gravitational forces of the sun. Then the motion of earthly bodies under the gravitational forces due to the earth itself became the principal subject of physics proper. Since the beginning of nineteenth century, however, the atomic structure of matter on the one hand and the electromagnetic forces between charged bodies on the other have become the problems of ever increasing importance in physics. Towards the end of the last century, it was already known that the atom itself consisted of two parts, the one being anumber of negative charged <u>electrons</u>. As for the nature of the other part, which was charged positively, however, we had to wait until 1911, when Rutherford gave a convincing evidence for the atom model, according to which the positive electricity together with almost all the mass of the atom is concentrated upon the atomic <u>nuceus</u>.[1] Thus, throughout the first quarter of the twentieth century, the motion of the ~~trajectory~~ electrons under the electric attraction of the nucleus and the mutual repulsion on the one hand and the emission and absorption of electromagnetic radiation by atoms and molecules on the other were among the topics of utmost importance and of general interest. In the world of atoms gravitational forces were already of little consequence, because of the fact that the masses of atomic ~~of~~ or subatomic particles were exceedingly small. During these twenty five years, two entirely new theories, i. e. <u>quantum theory</u> and <u>relativity</u>

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theory, were born and the former has grown to be quantum mechanics. Quantum mechanics together with relativity theory succeeded in giving new and correct interpretations to almost all physical and chemical phenomena, which were supposed to have their origin outside the atomic nucleus.

However, comparatively little progress was seen in the elucidation of phenomena, which were connected directly with the structure of atomic nucleus itself. This was obviously because so little was known about the constituents of atomic nuclei and still less about the ~~fø~~ nature of forces which were supposed to be effective inside the nucleus.

2. Structure of Nuclei and Nature of Nuclear Forces

The year 1932 was not only the year of great discoveries, but also the beginning of new era. Among other things, the discovery of the neutron was utmost importance, particularly because we found for the first time the real hope of understanding nuclear phenomena by starting from the new assumption that it consisted of a number of protons and neutrons. Up to that time, physicists were obliged to adopt the nuclear model consisting of protons and electrons. They applied quantum mechanics to this model and arrived at so many conclusions which were contradictory to experimentally well-established properties of nuclei that they had to doubt the applicability of quantum mechanics to nuclear phenomena. When we adopted the new model, most of these contradictions disappeared at once.

However, we had to face at the same time another equally important problem: "What is the nature of nuclear forces acting between a proton and a neutron, between two protons and between two neutrons ?"

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matter

structure　motion　　force

laws of motion

1. gravitational forces

(molecular forces)

molecules

atom

1. (electron

nucleus

2. (proton

3. neutron

II. nucleon

laws of quantum mechanics and relativity theory

2. electromagnetic forces

field

mass — energy

$E = mc^2$

(concentrated form of energy)

field of force

(dispersed form of energy)

particle　　wave

quantum theory

6. neutrino

I. lepton

3. nuclear forces

field

III.
4. photon

IV.
5. meson

μ-meson

π-meson

τ-meson

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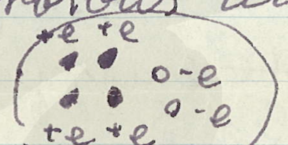
Before the discovery of the neutron, physicists used to think that the electromagnetic forces might play a predominant rôle even inside the atomic nucleus. However, this was very unlikely, ~~because~~ even if we adopted the old model, ~~for the atomic nucleus, in~~ according to which the nucleus consisted of protons and electrons, because the electric attraction acting between protons and electrons were

^4_2He :



to be partly offset by the repulsion between two protons ~~and~~ or between two acting electrons. ~~and~~ Even if we ignore the ~~elect~~ repulsion, ~~and~~ the electric attraction itself was too small to account the whole strength of nuclear forces. In order to see how strong are the nuclear forces, ~~we must recall~~ you have only to the famous Einstein's ~~relation~~

$$E = mc^2,$$

which is one of the most important consequences of ~~Einstein's~~ relativity theory. If ~~we or~~ you sum up, for instance, the ~~total~~ masses of four protons and two electrons, you have

52 / 51) 26.5 / 253 / 100

285 / 931 / 285 / 855

55 / 51) 280 / 255 / 250

4 (p) (n) = (He) + e

$4 \times 1.00812 + \frac{2}{1837}$
(neutral hydrogen atom)

$= 4.03298$ ~~0.001~~ 265

0.0011 / 1837) 2000 / 1837 / 1630

28

in units of $O^{16} = 16$,
~~= 4.0336~~

while the mass of ^4_2He (neutral atom) is

4.0039.

286

The difference is about 0.0285 ~~286~~ which corresponds to ~~a little less than~~ about ~~26.6~~ 26.5 MeV. or $285/0.51 = 52$ times ~~the mass of the~~ energy of the electron.

On the other hand

$$\frac{e^2}{r} = mc^2 \cdot \frac{r_0}{r}.$$

$$r_0 = 2.8 \times 10^{-13}\ cm,$$

so even for $r \sim 10^{-13}$ cm,

$$\frac{e^2}{r} = 2.8\, mc^2,$$

Thus, ~~protons and~~ ~~each~~ electrons must be bound to protons at a distance much shorter than 10^{-13} cm in He-nucleus. This is possible only if there is an additional attractive force, which is much stronger ~~as~~ than electrostatic attraction at very short distances. Thus, even in the old model, you had to introduce somewhere specific n. f.

* Furthermore, the mass of the neutron turned out to be larger than the sum of those of the proton and the electron. (4)

Now, if you adopt the new model for the nucleus, ~~we~~ you must at the same time regard the neutron as another type of elementary particles, because if you regard it as a compound of a proton and an electron, you are left again with the same contradictions which were inherent in the old model.* Then, the necessity of specific nuclear forces, which ~~could~~ can not be reduced to gravitational and electromagnetic forces ~~are~~ becomes even more obvious.*

~~So other~~ the our next ~~question~~ problem ~~to be solv~~ was ~~the~~ to ~~find~~ determine the ~~properties~~ nature of n.f.

2. Nature of N.F.

First of all, it was almost self evident

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* $M_N = 1.00893$

$2M_N + 2M_H = 4.0341$

$M_{He} = 4.0039$

0.0302

binding energy = 28 MeV. = 55 mc^2

2.016246
2.01786
4.03410