Beta Decay.

C. S. Wu

Columbia University - New York, N. Y.

I. – Classical Beta Decay Experiments.

What I shall try to present here is an integrated picture of β decay, starting from the fundamental assumptions postulated in Fermi's theory of β decay, and gradually lead to its general formulation. By comparing with experimental evidences, we will show how the coupling constants involved in β interaction are uniquely determined. Furthermore, we will also illustrate how the symmetry properties of β interactions and the nature of the neutrino are investigated through the so-called « parity experiments ». Finally we will review the question of universal Fermi (V—A) interaction and the conserved vector current theory. Unfortunately, there will be no time for detailed derivations for the theoretical formulae used. However, a detailed bibliography will be provided for the purpose.

β decay is perhaps the best example for illustrating how modern research is being developed. Experimental observations often stimulate theoretical thinking. When theoretical physicists are confronted with puzzling facts they usually propose and speculate on new ideas. Then, of course, the experimental physicists have to meet the challenge and try to prove or disprove those often seemingly wild but often turned out to be correct, proposals.

First, I am going to talk about something which happened a long time ago in the course of development of the theory of β decay. I hope this little episode may comfort you whenever the skies may appear to be gloomy and dark, so that you won't get too discouraged. During the 1930's when experimental results concluded that the β spectrum was a continuous one, Niels Bohr raised the question of the conservation of energy in β decay in his famous « Faraday Lecture ». Here is an except from his lecture:

> « At the present stage of atomic theory, however, we may say that we have no argument either empirical or theoretical for upholding the energy principle

in the case of β-ray disintegration and we are even led to complications and difficulties in trying to do so ... the feature of atomic stability ... may force us to renounce the very idea of energy balance. »

Pauli disagreed with the above view, instead he proposed the neutrino hypothesis at the Solvay Congress in 1933 in order to explain the observed continuous β spectrum. The reception at the Congress, except for two young physicists, was skeptical and not too enthusiastic. The two young physicists were E. FERMI and F. PERRIN.

Concerning the exciting episode of the continuous β spectrum, BOHR is known to have remarked at the time: « One should be prepared for further surprises with β^- decay. » Later this prophecy came true not once, but many times, only in a much more dramatic way than anticipated. Probably so will be the future surprises in weak interactions.

1. – Fermi's formulation of beta decays.

There are two fundamental assumptions in Fermi's theory, first the neutrino hypothesis, and the second, the analogy with electromagnetic radiation theory. Of course at that time we all knew that the β interaction could not account for nuclear forces. In fact, RUTHERFORD once remarked that as far as the nucleus is concerned, β decay practically never happened, because the time scale is so different. Also the best thing to fashion the theory after, is the electromagnetic theory.

From a classical point of view, electromagnetic radiation is due to a time-dependent interaction between the radiation system (say, an atom) and its surrounding electromagnetic field. This is given by the well-known expression

$$H = -\sum_n \frac{e_n}{m_n c} \boldsymbol{p}_n \cdot \boldsymbol{A}(\boldsymbol{r}_n, t) . \tag{1}$$

The summation is over all particles of the system. $\boldsymbol{A}$ is the vector potential, and $\boldsymbol{p}_n$ the momentum of the n-th particle. This interaction leads to an exchange of energy between the system and the field.

Quantum-mechanically, radiation involves emission or absorption of photons. Therefore in the quantum-mechanical treatment of radiation the vector potential $\boldsymbol{A}$ can be regarded as a time-dependent operator, which can create or annihilate photons:

$$A(\gamma) = \psi_\gamma^*(\boldsymbol{r}) + \psi_\gamma(\boldsymbol{r}) , \tag{2}$$

where ψ_γ^* creates a photon, and ψ_γ annihilates a photon.