1959 VARENNA SUMMER SCHOOL ON "WEAK INTERACTIONS"

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AN International summer school of physics is held every year in Varenna, Italy. This is organized by the Italian Physical Society and each summer various courses are given on topical and fast developing fields in physics. The lectures are held in the Villa Monastero, on the lake of Como. Eminent scientists in the field are invited to deliver courses of lectures, and students are usually selected from among the young and less experienced research workers from practically all over the world. The first summer school of this type was held in the summer of 1953.

In 1959 there were four summer schools of which one was on "Weak Interactions". This was held from June 29 to July 11. The following topics were dealt with by the various lecturers:

(1) "Symmetry properties of strong and weak interactions"—G. Lüders; (2) Survey of problems regarding the fundamental constituents of matter and their interactions; Theory of angular correlation and the β-decay of oriented nuclei —Rosenfeld; (3) Strange particle decay processes—R. H. Dalitz; (4) V-A theory—R. Gatto; (5) Relation between neutrinos, gravitation and geometry—J. A. Wheeler; (6) Theory of neutrino—B. Touschek; (7) μ-decay and μ-capture —J. Steinberger.

In addition to these "courses" a number of seminars on related subjects were delivered by leading experimentalists. O. Kofoed-Hansen discussed in great detail the problem of determining the coupling constants from investigations on nuclear β-decay. Various experimental methods for measuring electron and photon polarization were dealt with by H. Frauenfelder. A. Pettermann discussed the theoretical aspects of the g-factor of the μ-meson. V. L. Telegdi reported some of his latest results on μ-capture in complex nuclei and on the accurate determination of the lifetime of the μ-meson. In the following paragraphs is presented the significant status of work in this field as emerged from the reports and courses given at the summer school.

The first parity experiment by Ambler, Hayward, Hoppes, Hudson and Wu was designed to test whether β-particles emitted from aligned nuclei (whose spins are lined up along an axis) were emitted preferentially in one direction or the other (along this axis). The results of this experiment using aligned Co^{60} are well known; beta asymmetry was observed with the electrons going off preferentially in the direction opposite to that of the nuclear spin. The nucleus of Co^{60} thus behaves like a left-handed screw or has negative helicity. So parity is not conserved in beta-decay, since right and left are distinguishable.

Since the theory of nuclear β-decay in its simplest form is a description of neutron decay, a complete experimental specification of this process alone should enable one to determine all the relevant coupling constants. In view of this, a series of experiments have been performed on the β-decay of polarized neutrons at the Argonne National Laboratory in the United States. In these experiments a collimated neutron beam was scattered at small grazing angle from a magnetized cobalt mirror; under these conditions only neutrons with spins in one direction are reflected. The angles $\theta(\vec{J}_n\ \vec{p}_e)$ and $\theta(\vec{J}_n, \vec{p}_{\bar{\nu}})$ between the neutron spin and the electron momentum and the anti-neutrino measured. The asymmetry coefficients A and determine $p_{\bar{\nu}}$, the proton-recoil directions were measured. The asymmetry coefficients A and B of the equations,

$$W[\theta(\vec{J}n, \vec{p}e)] = 1 + A\cos\theta(\vec{J}_n, \vec{p}_e)$$

and $$W[\theta(J_n, \vec{p}_{\bar{\nu}})] = 1 + B\cos\theta(\vec{J}_n, \vec{p}_{\bar{\nu}})$$

were found to be $A = -0 \cdot 11 \pm 0 \cdot 02$ and $B = 0 \cdot 88 \pm 0 \cdot 15$. From a comparison of these with the predicted values of A and B for the various possible couplings it was conclusively shown that the interaction in beta-decay is dominantly V (vector) and A (axial vector) with opposite phase relation, *i.e.*, of the type V-A. Further, using the same experimental set-up, a coefficient "D" was also measured which occurs in the term $\vec{J}_n\ (\vec{P}_e/E_e) \times (\vec{p}_{\bar{\nu}}/E_{\bar{\nu}})$ in the electron-antineutrino angular distribution function for the beta-decay of oriented nuclei. This coefficient can be non-zero only if the beta-interaction is not invariant under time-reversal. The measured value of $D = 0 \cdot 09 \pm 0 \cdot 07$ indicates that the time-reversal invariance is valid in beta-decay (within the experimental accuracy).

Considerable additional evidence concerning the "V-A theory" of beta-decay interactions is now available from an accurate analysis of classical beta-decay experiments like electron-neutrino angular correlations, ft-values of mirror nuclei, etc. A direct determination of the helicity of the neutrino in the electron-capture process of Eu^{152m} was carried out by Goldhaber, Grodzins and Sunyar who showed that the helicity is negative. In a Gamow-Teller (GT) beta-transition, the angular momentum carried away by the two leptons is one unit. In the tensor (T) interaction, both leptons are preferentially emitted in the same direction and since the electron is left-handed the anti-neutrino must have a negative helicity. On the other hand, in the axial vector (A) case, the electron and antineutrino are emitted preferentially in opposite directions; so the anti-neutrino has a positive helicity; consequently the neutrino should have negative helicity. Since it has been found experimentally that the helicity of the neutrino is negative in the electron capture decay of Eu^{152m} one clearly concludes that the beta-interaction in a GT transition is axial vector. Such a direct determination of neutrino helicity has not so far been possible in a pure Fermi transition.

A number of beta-gamma circular polarization correlation studies on mixed transitions shows that the interference between GT and Fermi transitions is the maximum possible.

The measurement of the capture cross-section for antineutrinos in an inverse beta-process has an important bearing on the two-component neutrino theory and the law of conservation of leptons. The experimental results of Cowan and Reines give the value $\sigma = (11 \pm 4) \times 10^{-44}$ cm.^{2} is comparable to the theoretical cross-section calculated for the two-component theory. The existence of the law of conservation of leptons, together with the two-component neutrino theory demands that the rate of double beta-decay be zero and the angular distribution asymmetries have their maximum value. The observed upper limits for the rate of double beta-decay are in good agreement with the long life for this process predicted for Dirac neutrinos and strongly in disagreement with the short life expected for Majorana neutrinos $(\nu = \bar{\nu})$.

The two-component theory of the neutrino proposed by Lee and Yang, Salam and Landau and the law of conservation of leptons can account very successfully for all the experimental facts in $\pi \rightarrow \mu \rightarrow e$ decays which are relevant to these assumptions. The polarization of the negative and positive electrons from muon decays as measured by the degree of circular polarization of the bremsstrahlung and annihilation radiation or by Moller scattering conclusively shows that the positron has positive helicity and the electron negative helicity. It can then be shown, (assuming the two-component neutrino theory and the law of conservation of leptons) that the neutrinos (and anti-neutrinos) involved in the $\pi \rightarrow \mu \rightarrow e$ and nuclear beta-decay interactions are the same.

The shape of the energy spectrum of electrons from muon decays is characterized by a parameter "ρ" known as Michel parameter. The two-component theory of the neutrino predicts that ρ is zero if the two neutral particles accompanying the decay electron are identical particles, and equal to 3/4 if one neutrino and one anti-neutrino are emitted along with the electron. Earlier experimental values of ρ varied widely from 0·68 to 0·72. The latest value reported by the Columbia University group is $\rho = 0{\cdot}810 \pm 0{\cdot}025$. The deviation from $\rho = 3/4$ if true is serious; however, the trend in the measured values thus far, and the fluctuations, do not force us to assume that the deviation is serious; the measured value supports the view that a neutrino and an anti-neutrino are associated with the decay electron. Further, the energy dependence of the asymmetry co-efficient in μ-decay agrees also with the predictions of the two-component theory.

The electron decay mode of the pion has been the subject of much theoretical and experimental investigation. Feynman and Gell-Mann had predicted that the branching ratio $\frac{\pi \rightarrow e + \nu}{\pi \rightarrow \mu + \nu}$ should be $1{\cdot}36 \times 10^{-4}$. Until early 1958, all attempts to detect the electron decay mode of the pion had yielded negative results and a much smaller branching ratio than the above. Recently, at CERN (Geneva) and also at Columbia, the ratio has been accurately determined and found to be in excellent agreement with the predictions of the V-A theory. The absolute rate of μ-decay can also be compared with the rate of neutron decay. The close equality of the vector coupling constant in these processes was first pointed out by Feynman and Gell-Mann. Recent measurements by the Chicago group on the life-time of muons yield a value $(2{\cdot}261 \pm 0{\cdot}007) \times 10^{-6}$ sec. From the measured ft-value in the beta-decay of O^{14} one gets the pure Fermi coupling constant $= (1{\cdot}41 \pm 0{\cdot}01) \times 10^{-49}$ erg-cm.^{3} The predicted life-time of the muon using this value is $(2{\cdot}26 \pm 0{\cdot}07) \times 10^{-6}$ sec. The close agreement between the absolute magnitude of the coupling constant in beta-decay and in μ-decay leads to the concept that these weak interactions may be part of a "Universal Fermi Interaction" as had been considered in a number of earlier papers on a purely qualitative basis.

Thus classical beta-decay theory and the non-conservation of parity have together made possible a determination of the interaction constants of beta-decay. It also appears that all the weak interactions are linked together in an overall manner by the same interaction constants, the V-A type of interaction, the law of conservation of leptons and the two-component neutrino ; where non-leptons alone participate in the decay process, the situation is more complex.

One should perhaps conclude by remarking how wonderful Varenna is, and the Villa Monastero in particular, for holding summer schools of this nature. An exceedingly strong tradition in this field has been built up by the Italian Physical Society through schools run by them since 1953 at Varenna. A very high level has been maintained in the atmosphere, both academic and social, of these schools. The dissemination of physics in this manner is not only fruitful but so greatly enjoyable.

ULTRASONICALLY DISPERSED SODIUM

It is well known that many chemical reactions involving sodium become more efficient as regards rate, yield, control, temperature conditions, etc., if the metal is used in a highly dispersed form so that the size of the sodium particles is very small and a very large surface area becomes available for reaction. The surface area of spherical particles of sodium 1 μ in diameter is 6×10^4 sq. cm. per gm. The common method of producing sodium dispersions is by stirring molten sodium and the dispersing medium together mechanically at 10,000-20,000 rev./min. when particles between 3 and 15 μ are produced.

It has been recently found that much finer dispersions of sodium in a hydrocarbon medium can be obtained by employing ultrasonic technique. Pratt and Helsby have described a simple laboratory apparatus capable of producing 200 gm. quantities of sodium dispersions by this method (*Nature*, 1959, **184**, 1694). A molten mixture of sodium and the hydrocarbon dispersing medium (yellow petroleum jelly in this case), with boiling point higher than the melting point of sodium, 97° C., is contained in a pyrex cylinder (15 cm. $\times$ 6 cm.) from which air has been displaced by an inert gas. The bottom surface of the cylinder is sealed on by a "neoprene" ring to an ultrasonic magnetostrictive transducer with a resonant frequency of 25 kc./s. The mixture in the inert atmosphere is then subjected to the ultrosonic frequency for about 10 minutes till the colour of the dispersion becomes constant (deep blue, the result of scattering of light by the minute particles) indicating that the equilibrium state of the dispersion has been reached. The finished dispersion is then siphoned off, by increasing the pressure of the inert gas, into a collecting vessel, also depleted of air but containing an inert atmosphere. The sodium particles in the jelly being out of contact with air and moisture, keep well and can be safely transported. The sodium is liberated for reaction either by melting the jelly, or dissolving it in petrol.

Sodium dispersed in yellow petroleum jelly reaches an exceptionally fine state of subdivision, 1 μ or less. The superiority of the use of the ultrasonically dispersed sodium over that of the mechanically dispersed metal has been demonstrated in the exothermic reaction between sodium and chlorobenzene to produce sodium phenyl. With the ultrasonically dispersed sodium the reaction is initiated at once, even at 20° C., and the reaction rate is 10-20 times greater. Other reactions which are likely to benefit from the use of ultrasonically dispersed sodium are Claisen condensations, Wurtz reactions, preparation of sodium alkyls, aryls and alcoholates, metalations, replacement of active hydrogen atoms and the purification of hydrocarbons.