calculation leads to the following distribution of the outgoing electrons in energy and angle,

$$dN / N = 2\varepsilon^2 [(3 - 2\varepsilon) + \lambda \cos\theta (2\varepsilon - 1)] d\varepsilon. \quad (1)$$

Here ϵ is the ratio of the electron energy to the maximum possible energy, θ is the angle between the directions of motion of the μ-meson and the electron, and λ is a constant depending on the ratio between the vector and pseudovector terms in the combination of μ-meson and electron field-operators. Explicitly we have

$$\lambda = 2ab / (a^2 + b^2), \quad (2)$$

where a and b are the coefficients of the two terms. In our earlier paper[1] we argued that a and b should be real. The quantity λ must lie between -1 and 1, and the value zero is not excluded. The integrated angular distribution of the electrons is proportional to $(1 + 1/3\ \lambda \cos\theta)$, so that the maximum possible forward-backward asymmetry is a factor of two. Even if λ should be markedly different from zero, the observation of the $\mu - e$ correlation may be very difficult because of the depolarization of the mesons in the course of their slowing down, and especially for μ^+-mesons because of the formation of muonium (the system $\mu^+ + e^-$).

Next we consider the effect of the longitudinal neutrino in β-decay. It is known from experiment that the β-decay interaction operator is a sum of scalar and tensor covariants. Either interaction term gives rise to a polarization of the electrons along the direction of their motion, of magnitude (v/c) (or $-v/c$), the ratio of the electron velocity to light velocity. The high-energy electrons are thus completely polarized in the direction of their motion.

Note added in proof.(February 21, 1957).

Very recently Wu, Ambler, Hayward, Hoppes and Hudson showed that in the β-decay of oriented Co^{60} nuclei there is actually a lack of mirror-symmetry. This definitely establishes the non-conservation of parity in β-decay. The experiments of Wu et al. agree with the theory of the longitudinal neutrino; however, the precision of the experiments does not seem high enough for a quantitative verification. The experiments of Wu et al. imply that the neutrino has its spin parallel to its direction of motion, while the antineutrino has its spin antiparallel.

Garwin, Lederman and Weinrich have observed a correlation in the $\pi \to \mu \to e$ decay. The magnitude of the correlation is large, which seems to imply a value of the parameter λ equal to unity. The energy-dependence of the correlation seen in this experiment does not agree with Eq. (1). It is difficult to say at present whether the discrepancy is within the limits of error of the measurements.

I am very much obliged to Professor Lederman for kindly sending me the manuscripts of both papers before publication.

1 L. D. Landau, J. Exptl. Theoret. Phys. (U.S.S.R.) 32, 405 (1957).
2 L. Michel, Proc. Phys. Soc. (London) A63, 514 and 1371 (1950).
3 Sargent, Rinehart, Lederman and Rogers, Phys. Rev. 99, 885 (1955).
4 Boneth, Levi-Setti, Panetti, Rossi and Tomasini, Nuovo Cim. 3, 33 (1956).
5 T. Lee and C. Yang, Phys. Rev. 104, 254 (1956).

Translated by F. J. Dyson
103

Concerning a Possible Method for the Polarization of a Proton Beam

E. K. ZAVOISKII

(Submitted to JETP editor December 14, 1956)
J. Exptl. Theoret. Phys. (U.S.S.R.) 32, 408
(February, 1957)

A BEAM of protons (likewise deuterons, tritons, He^3, etc.) passing through a thin ferromagnetic slab, magnetized to saturation, should become "magnetized" due to pick–up by the protons of the polarized ferromagnetic electrons. As a result of such electron pick–up, the atoms of hydrogen obtained will be polarized as regards their electron spin and if, outside the magnetic field, they are again ionized by passage through a thin foil (or a gas beam), then the protons will come out partly polarized.

The fraction of polarized protons coming out of the second foil (only atoms of hydrogen being considered entering the foil), will be equal to half the fraction of the neutral atoms polarized according to their electron spin. The degree of polarization of the hydrogen atoms is determined by the probability of the protons picking up the "ferromagnetic" electrons in comparison with the probability of picking up the unpolarized electrons. The magnitude of the polarization obviously will depend on the velocity of the protons and the type of the ferromagnet. If it is assumed that $3d$ and s electrons will be picked up with equal probability, then the degree of polarization of a proton beam passing through an iron foil should approach $\sim 15\%$.

The beam intensity of the polarized protons depends on the proton beam passing through the ferromagnetic slab. Experiments show that thin foils bombarded by 10–40 kilovolt protons can withstand a beam of several micro amperes/cm^2, and the degree of electron pick–up by the protons reaches tems of percent.

The possibility of using a pulsed technique for such a polarizer should be mentioned. This should be very practical for many accelerators. This method also makes possible the direct formation of negative ions of hydrogen with polarized muclei. For this, of course, one must use the negative ions emerging from the second foil.

A study of the polarization of the protons and its dependence on velocity may also be of interest in elucidating questions on the nature of ferromagnetism.

In conclusion it should be mentioned that, in principle, polarization of the protons should be achievable likewise using the polarized electrons of paramagnetic substances and metals.

Translated by A. Turkevich
104

Inelastic Interaction of Protons with Energies Greater than 7 bev with Carbon and Hydrogen Nuclei

K. I. ALEKSEEVA AND N. L. GRIGOROV
Moscow State University

(Submitted to JETP editor December 7,1956)
J. Exptl. Theoret. Phys.(U.S.S.R.) 32, 404–405 (February,1957)

WE have measured the cross section for inelastic interaction of high energy protons with carbon and hydrogen nuclei. The measurements were carried out in the stratosphere at an altitude of 20–25 km at a geomagnetic latitude of 31° N, where the minimum kinetic energy of the primary protons is 7 bev and 60% of all the protons have energies between 7 and 20 bev.

The apparatus for determining these inelastic interaction cross–sections was constructed as follows. The telescope defining the vertical beam of cosmic rays consisted of three rows of self quenching Geiger–Müller tubes connected in three-fold coincidence (referred to as the counter telescope); some distance below these was a row of hodoscopic counters covering almost the complete solid angle of the apparatus. In between the middle and lower rows of telescopic counters there was placed an absorber made of 8 cm of lead and 0.9 cm aluminum. The absorbers being investigated, for example, of graphite (density $d = 1.0 - 1.1$ gm/cm^3; thickness per unit area of absorber $d = 16.0$ gm/cm^2), were placed on a trolley and every three minutes were interposed into the space between the top and middle rows of the telescopic counters in such a manner that the measurements with the graphite and without the graphite (and likewise the measurements with the paraffin and graphite) alternated. In order to register the products of the interaction of the protons with the material of the absorber, the telescope and absorbers were surrounded by a large number of counters. All the counters (including those in the telescope) were connected to a vacuum tube hodoscope. The apparatus was lifted into the stratosphere in September 1955 by sounding balloons. The results were sent to the ground by radio.

The cross section for inelastic interaction of protons with carbon nuclei was determined by two methods: (1) From the attenuation of the flux of single shower producing particles falling on the lead absorber by the graphite absorber in the telescope; this attenuation was governed by the inelastic interactions of the protons with the carbon nuclei (the measurements gave the decrease in the number of electron-nucleon showers from the Pb due to the insertion of the graphite into the telescope): (2) Through the direct measurement of the number of electron–nucleon showers arising in the graphite.

Using the attenuation method, we obtained the following values of the mean free path and the cross section for inelastic interaction of protons with carbon nuclei (corrections have been made for accidental coincidences, for the formation of δ-showers in the graphite and for interactions due to α particles in the primary cosmic rays):

$$L_p^C = 67^{+13}_{-9}\ g/cm^2\ ;\ \sigma_p^C = 300 \pm 50\ \text{mb}.$$

Direct measurements of the number of interactions in the graphite gave the following values for the mean free path and for the inelastic interaction cross section:

$$L_p^C = 73 \pm 7\ g/cm^2\ ;\sigma_p^C = 270 \pm 30\ \text{mb}.$$

All the values have indicated statistical errors.

The cross section for inelastic interaction of protons with protons was established from the difference of numbers of electron–nucleon showers registered with paraffin and with graphite using an apparatus of the same type (the paraffin absorber had a density $d = 0.90 - 0.95$ gms/cm^3