Letters to the Editor

PUBLICATION of brief reports of important discoveries in physics may be secured by addressing them to this department. The closing date for this department is five weeks prior to the date of issue. No proof will be sent to the authors. The Board of Editors does not hold itself responsible for the opinions expressed by the correspondents. Communications should not exceed 600 words in length.

On the Application of Captive Balloons to Carry Photographic Emulsions

NIELS ARLEY
Institute of Theoretical Physics, University of Copenhagen, Copenhagen, Denmark
October 29, 1947

BY the recent discovery of Powell and his co-workers of a new meson about twice as heavy as the usual one, the great value of the photographic emulsion as a tool for the investigation of cosmic rays has been further stressed. It seems certain that this tool will in the future compete most favorably with the ionization chamber, the Wilson chamber, and the G-M counter. However, the photographic emulsion method has at present two drawbacks. The first one is the long time of several weeks required for the exposure of the emulsions. This drawback is very serious because it has hitherto excluded the applicability of this method in that part of cosmic-ray investigations which are at the present time of greatest importance, *viz.*, high altitude investigations. The second drawback is that for intensity reasons the emulsions cannot be exposed at sea level but have to be placed at the top of high mountains, often far away from the laboratories.

To overcome these two difficulties we would like to suggest the application of captive balloons to carry the emulsions. With present day technique, using, e.g., the light and very strong nylon strings already used in deep sea explorations, it seems not impossible to make a captive balloon carrying photographic emulsions stay at very high altitudes for a sufficiently long time to allow the exposure of the emulsions. Since this method would obviously overcome both of the above-mentioned drawbacks, thereby greatly increasing the value of the photographic emulsion method, it would be extremely important to investigate more closely the possibility of realizing it.

Statistical Geometry and Fundamental Particles

NATHAN ROSEN
University of North Carolina, Chapel Hill, North Carolina
November 3, 1947

IN connection with my recent paper of the above title,[1] I have learned of a paper by de Broglie,[2] in which he proposed introducing a Gaussian error function in the interaction between the electron and the electromagnetic field. The constant (having dimensions of length) which appeared in this function was considered by de Broglie as a measure of the uncertainty in the position of the point of application of the field to the charge (or inversely). Since these ideas are essentially the same as some of those forming the basis of my paper, I regret having failed to make a reference there to the work of de Broglie.

[1] Nathan Rosen, Phys. Rev. **72**, 298 (1947).
[2] Louis de Broglie, C. R. Acad. Sci. Paris **200**, 361 (1935).

Velocity Dependence of Nuclear Forces

H. SNYDER
Brookhaven National Laboratory, Upton, New York
AND
R. E. MARSHAK
University of Rochester, Rochester, New York
November 3, 1947

NEUTRON-PROTON scattering experiments at 90 Mev are being carried out in Berkeley at the present time. As proton beams of several hundred Mev become available, both neutron-proton and proton-proton scattering experiments will be performed at even higher energies. We wish to underline the great care which must be exercised in using high energy scattering experiments to draw precise conclusions about the nature of nuclear forces. If the meson field-theoretic origin of nuclear forces is taken seriously, the static potential description must of necessity breakdown for relativistic energies of the nucleons. This fact has been recognized by previous authors[1] who found the velocity dependent corrections to the nuclear interaction to terms of order $(v/c)^2$ (v is the velocity of the nucleon) and then solved the approximate Dirac equation for the two nucleons to the same order. This type of procedure corresponds to Breit's treatment of the two-electron problem[2] and suffers from the defect that it is only valid to order $(v/c)^2$.

In the Born approximation, one can obtain a complete relativistic expression for the nucleon-nucleon scattering cross section. In analogy with Møller's treatment of the scattering of fast electrons by electrons, one only considers the virtual emission and re-absorption of *one* meson quantum (Born approximation!), but otherwise takes rigorous account of the retardation of the meson field and the recoil of the nucleons. In this method of calculation, one foregoes explicit knowledge of the nuclear interaction in configuration space and finds directly the scattering cross section.

We have performed a Møller-type calculation for the scalar and vector meson fields, assuming in each case the type of coupling which leads to a convergent static potential (scalar coupling for the scalar theory, vector coupling for the vector theory). These meson theories do not lead to tensor forces (the scalar theory even leads to a repulsive potential!); however, they illustrate the error introduced into the high energy scattering cross section through the use of static potentials. All meson theories which yield tensor forces also lead to divergent static potentials (e.g., the pseudoscalar meson with pseudovector coupling) and hence cannot be calculated with the present method. Our calculations only apply to neutron-proton scattering since we have not considered the identity of the two nucleons.

Our results are:

Scalar theory-neutral meson

$$\sigma(\theta)=\frac{M^2g^4[1-(v^2/c^2)\cos^2(\theta/2)]^2}{[(\mu c)^2+4p^2\sin^2(\theta/2)]^2[1-(v^2/c^2)]}. \quad (1)$$

Vector theory-neutral meson

$$\sigma(\theta)=\frac{M^2g^4\{1+2(v^2/c^2)\cos\theta+(v^4/c^4)[1+2\sin^2(\theta/2)]\}}{[(\mu c)^2+4p^2\sin^2(\theta/2)]^2[1-(v^2/c^2)]}. \quad (2)$$

In Eqs. (1) and (2), g is the coupling constant, M is the mass of a nucleon, μ that of the meson, p is the momentum, v the velocity, and θ the scattering angle, all in the center-of-mass system. The static potential in the scalar theory is $(g^2e^{-\mu cr/\hbar})/r$, in the vector theory $(-g^2e^{-\mu cr/\hbar})/r$; both theories lead to the same "static" cross section in the Born approximation, namely:

$$\frac{M^2g^4}{[(\mu c)^2+4p^2\sin^2(\theta/2)]^2}.$$

If charged mesons are emitted, the corresponding scattering cross sections are obtained from (1) and (2) by replacing θ by $\pi-\theta$.

Equations (1) and (2) show that the "non-static" forces alter both the angular distribution and the total scattering cross section, and that their effect is appreciable (a factor 2) in the several hundred Mev region. It is interesting to note that the vector theory leads to a much larger effect than does the scalar theory. We reiterate that our calculations are intended only to illustrate the magnitude of the effect of the "velocity-dependence" of nuclear forces so as to engender the proper amount of skepticism about too close an evaluation of high energy scattering experiments.

The above calculations were started last summer at the Brookhaven National Laboratory during the second author's stay as a consultant.

[1] G. Breit, Phys. Rev. **51**, 248 (1937); E. Feenberg, Phys. Rev. **55**, 602 (1939); C. Møller and L. Rosenfeld, Kgl. Danskl Vid. Sels. Math.-Fys. Medd. **17**, 8 (1940); L. Hulthen, Ark. f. Mat. Astr. och. Fys. **30A**, 9 (1943), **31A**, 15 (1944).
[2] G. Breit, Phys. Rev. **34**, 553 (1929).
[3] C. Møller, Zeits. f. Physik **70**, 786 (1931).

Interaction of Neutrons with Electrons

J. M. Jauch and K. Watson
Department of Physics, The State University of Iowa, Iowa City, Iowa
October 27, 1947

EVEN without the assumption of a specific nuclear interaction, an electron may interact with a neutron by purely electromagnetic effects for two reasons. In the first place, the magnetic moment of the neutron interacts with the magnetic moment of the electron. An additional interaction of the electron with the neutron is predicted by the meson theory. According to this theory the neutron is part of the time decomposed into a proton and a meson thus causing the time average of the charge to be spread over a finite region in space. In a strong electric field this charge cloud around the proton is partly polarized, thus giving rise to a van der Waal's type of force.

In an interesting experiment Havens, Rabi, and Rainwater[1] have interpreted the apparent decrease of the total cross section for slow neutrons with increasing energy in lead as caused by the second of the above-mentioned effects. The purpose of this letter is to point out that their estimation of 4×10^{-31} cm^2 for the cross section of the scattering due to polarization is at variance with the value calculated from the meson theory by a factor $\sim10^4$.

Watson[2] finds for the potential of a charged particle in the neighborhood of a neutron the expression (units $\hbar$ c and cm)

$$V(r)\sim-1/10(e^4g^2/\mu^3)1/r^4 \quad (\text{for } \mu r\geq1),$$

$e^2\sim1/137$, $g^2\sim1/10$ (dimensionless coupling constant) μ = meson mass in cm^{-1}. The formula does not hold for $\mu r\ll1$. Instead the potential is expected to reach a finite value for $r\to0$. Apart from numerical factors of order ~1 $V(r)$ is the same for scalar, pseudoscalar, and vector theories. The low energy cross section for the scattering of neutrons on bound electrons with this potential turns out to be $\sim10^{-35}$ cm^2.

From this result we must conclude that either the interpretation of the experimental results given by Havens, Rabi, and Rainwater is incorrect or that there exists an additional interaction between electrons and neutrons which does not follow from meson theory.

[1] W. W. Havens, Jr., I. I. Rabi, and L. J. Rainwater, Phys. Rev. **72**, 634 (1947).
[2] K. Watson, Ph.D. Thesis, University of Iowa (Phys. Rev. **72**, 1060 (1947)).

Relative Cross Sections of Reactions Induced by High Energy Neutrons in C, N, O, and F

William J. Knox
Radiation Laboratory, Department of Physics, University of California, Berkeley, California
October 30, 1947

WHEN a nucleus is bombarded with very high energy neutrons a large variety of nuclear reactions can occur, resulting in the formation of most, if not all, the radioactive species below the bombarded nucleus. However, in the region of light elements such as C, N, O, and F the activities of suitable half-life for easy detection are few enough that relative cross sections for the reactions producing these activities can be obtained from simple analysis of decay curves taken on the bombarded substance.

Various samples of carbon, Be_3N_2, BeO, and LiF have been bombarded with high energy neutrons[1,2] from the 184-in. cyclotron in order to determine the relative cross sections of certain nuclear reactions which occur. Beryllium and lithium compounds were used because these elements give no interfering activities in the range of half-lives investigated. The neutrons used were produced by the action of 190-Mev deuterons on a ½-in. Be target. These neutrons