protons with energy 18.1 mev and is based on the optical model with a diffuse boundary of the nucleus.

It is seen from the comparison, that we observed a fourth minimum at large angles, which qualitatively corresponds to the theoretical calculations[14] (the fourth minimum is in the region of 160° for Nickel). Deeper first minima, obtained in Ref. 10, can probably be explained by better energy resolution of the apparatus due to the use of the many-channel analyzer.

Figure 3 shows data for nickel and copper. It is seen from these curves that, in the range of angles up to 110°, the cross section for elastic scattering qualitatively corresponds to the "black body" model; for larger angles, the cross section for these two neighboring elements differs considerably. Since the size of the nickel and copper nuclei are very nearly the same, the observed difference in the cross section could characterize the influence of such factors as spin, magnetic or quadrupole moment, and also the shape of the diffuse boundary. For a final check of this supposition it is proposed that a study of the elastic scattering from various isotopes be undertaken.

[1] E. Amaldi, Nuovo Cimente, 3, 203 (1946).

[2] L. M. Goldman, Phys. Rev. 89, 349 (1953).

[3] C. Baker and J. Dodd, Phys. Rev. 85, 1051 (1952).

[4] W. E. Burcham and W. M. Gibson, Phys. Rev. 91, 1266 (1953).

[5] J. W. Burkig and B. T. Whiyht, Phys. Rev. 82, 451 (1951).

[6] P. C. Gugelot, Phys. Rev. 87, 525 (1952).

[7] B. L. Cohen and R. V. Neidigh, Phys. Rev. 93, 282 (1954).

[8] B. Cork, Phys. Rev. 87, 78 (1953).

[9] R. Britton, Phys. Rev., 88, 283 (1953).

[10] J. E. Dayton, Phys. Rev., 95, 756 (1954).

[11] A. I. Akhiezer and I. J. Pomeranchuk, Usp. Fiz. Nauk, 39, 153 (1949).

[12] R. E. LeLeviere and D. S. Saxon, Phys. Rev. 87, 40 (1952).

[13] D. M. Chose and F. Rohrlich, Phys. Rev. 94, 81 (1954).

[14] R. D. Wood and D. S. Saxon, Phys. Rev. 95, 777 (1954).

Translated by M. Polonsky
106

Concerning the Electric Charge of the Neutron

I. S. Shapiro and I. V. Estulin
Moscow State University

(Submitted to JETP editor December 2, 1955)
J. Exptl. Theoret. Phys. (U.S.S.R.) 30, 579-580 (March, 1956)

According to the present point of view, the neutron does not have an electric charge. This conviction was originally based on experimental data concerning the ionization caused by neutrons during their passage through gases[1]. An estimate of the upper bound for the neutron charge , based on these data, gives a value less than 1/700 of the electron charge e.[2] However, a considerably more precise estimate of the upper bound for the neutron charge can be obtained if it is based on the neutrality of atoms and molecules. Recently, Rabi (see Ref. 3), experimenting with a molecular beam of CsI, came to the conclusion that the charge of this molecule, if not equal to zero, is less than $10^{-10}\ e$. Considering this, and assuming that the proton charge is equal to the charge of an electron, or differs from it by a small quantity equal in magnitude and opposite in sign to the charge of the neutron, it can be obtained that the charge of the neutron is less than $2 \times 10^{-12}\ e$. An analysis of this type assumes that the law of conservation of charge is absolutely accurate. At the present time one cannot exclude the possibility of constructing theories (many dimensional type) with more general conservation laws, in which strict conservation of electric charge, taken separately, does not necessarily hold. It should be also noted that, for instance in a 5-dimensional theory by Ramer[4] , any particle of a finite mass, including a neutron, is given an electric charge. In view of the above considerations, it is interesting to consider the question of the possibility of the direct determination of an upper boundary for the charge of a free neutron.

From the experiments on the observation of the neutron-electron interaction[5] it is difficult to make any conclusions about the magnitude of an upper boundary for the neutron charge in view of the uncertainty of the data concerning the meson cloud of the nucleon.[1] A direct estimate of the magnitude of the upper bound of the neutron charge can be obtained from the fact that the interaction cross section of a thermal neutron with the nucleus does not depend on the charge of the nucleus. This gives evidence for the smallness of the Born parameter:

$$2\pi Zqc / 137v \ll 1, \quad (1)$$

where q is the ratio of the electric charge of the neutron to the charge of the electron, v – speed of neutron, and c – speed of light. For a thermal neutron ($v \sim 2 \times 10^5$ cm/sec) and for a heavy nucleus $Z \cong 90$ we obtain, based on Eq. (1), the estimate $q << 10^{-6}$. In the present work a direct experiment leading to a considerably smaller value of the upper bound of the neutron charge is reported. This experiment consisted of an attempt to observe the deflection of a neutron beam in an electric field.

Let us assume that a narrow beam of thermal neutrons, having kinetic energy W, passes through a plane electric condenser of length l, and perpendicular to the direction of the electric field intensity E. With the charge of a neutron equal to qe, the deflection of the beam Δx directly at the exit from the condenser will be

$$\Delta x = qEl^2 / 4W. \quad (2)$$

By measuring the deflection Δx one can, using Eq. (2), determine q.

In the experiment conducted in the present work the intensity of the neutron beam, which was filtered by graphite in front of the collimator, was approximately 10^6 neutrons / cm^2 – sec. The width of the beam was determined by a collimator consisting of two sheets of cadmium with slit openings 2 mm wide and 50 cm from each other (figure 1). Perpendicular to the plane of the slits aluminum plates of the electric condenser b were placed. The distance between the condenser plates was 7.5 mm. In front of the receiver of the thermal neutrons c was placed an exit slit of Cadmium which could be moved by means of a micrometer screw in the direction perpendicular to the neutron beam and parallel to the direction of E (axis X on figure 1). A special vernier allowed the slit to be placed at any point of axis X with a precision of 0.01 mm. The width of the slit in the main experiments was 1 mm. All parts of the

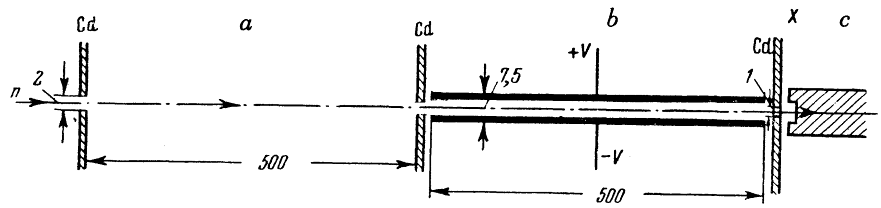

FIG. 1. Apparatus: a– neutron collimator; b– electric condenser; c–neutron receiver. Dimensions are given in mm.

equipment after careful centering were fastened on the rigid metal frame. As will be seen from the following, direct measurements with neutrons proved the exactness of the centering of the apparatus.

The average neutron energy used in the experiment, measured by absorption of neutrons in boron, was $W = 0.026$ ev. The background in the neutron receiver for the conditions of this experiment was 2% of the number of counts caused by the neutrons of the direct beam. The contribution of the neutrons above cadmium (absorption) did not exceed this value.

The spatial distribution of neutrons in the beam was studied by moving the slit along the axis X every 0.5 mm. As is seen from Fig. 2, on which are shown the results of these measurements, the dimension of the region with maximum neutron intensity corresponds to the width of the collimator slits (2 mm). The half width of the curve is approximately 4.5 mm. Dotted lines show the position of the condenser plates. The distribution found is fully explained by the geometry of the apparatus, corresponding exact centering of all parts of the apparatus, and absence of scattering on the edges of the cadmium diaphragms. It is also seen from figure 2 that the neutron beam does not touch the condenser plates.

In measurements with the electric field, the voltage on the condenser plates was 10 kv, and the exit slit was put at the points on the axis X shown by crosses in figure 2. During the placement of the slit at points on the axis X corresponding to the descending parts of the neutron distribution curve, a 0.03 mm deflection of the neutron beam should have caused 1% change in the number of registered neutrons. The measurements were conducted in such a way that the readings with the electric field were alternated with the readings without the field. In the table are given the values obtained for the quantity $\Delta N/N$, where ΔN – is the reading difference with and without the field, and N – is the total number of registered neutrons. The numbering of points corresponds to the labeling in Fig. 2. In the table are also given the probable statistical errors. In the last column of the table is given the smallest displacement of the neutron beam which could be detected in this experiment.

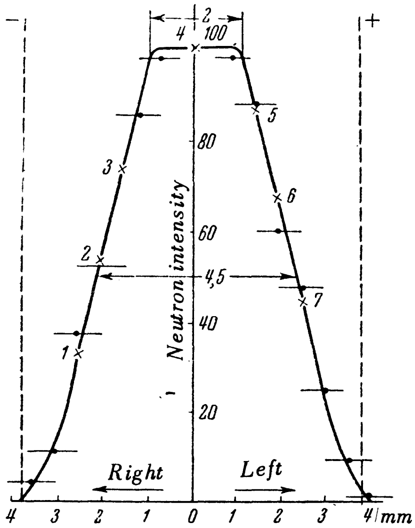

FIG. 2. Dependence of the intensity of neutrons on the position of the exit slit on the axis perpendicular to the neutron beam and parallel to the electric field intensity.

As is seen from the table, the effect does not exceed the experimental errors. In other words,

Number of the point	Relative effect $\Delta N/N$ in %	The smallest detectable displacement of the beam in mm
1	+0,3±1,0	0,03
2	–0,2±0,5	0,02
3	–0,8±0,8	0,05
4	–0,8±0,7	1,00
5	–0,6±0,5	0,05
6	–0,8±0,7	0,05
7	–0,55±0,4	0,02

the displacement of the beam under the influence of the electric field was not detected. This means that the displacment of the neutron beam was less than 0,02 mm. Considering this fact and Eq. (2), we obtain the following value for the upper bound of the neutron charge.

$$q < 6\times10^{-12}.$$

In conclusion we express our thanks to I. M. Frank for the discussion of the present work and to V. P. Kudriashov who helped us during the conduction of the experiment.

*Based on the angular anisotropy of the scattering of thermal neutrons from venom atoms, Feld[3] gives, without deduction, the estimate $q < 10^{-18}\,e$. It is not completely clear, however, how this number was obtained.

[1] P. I. Die, Proc. Roy. Soc. London 136 A, 727 (1932).

[2] S. Fluegge, *Introduction to Nuclear Physics* (with J. Mattauch, *Nuclear Physics Tables*) Interscience Publisher, N.Y., 1946.

[3] Experimental Nuclear Physics, edit. E. Segre, vol. 2, Ch. 7 IIL, Moscow, 1955 (Russian translation).

[4] Iu. B. Ramer, J. Exptl. Theoret. Phys. (U.S.S.R.) 20, 199 (1950).

[5] L. Foldy, Phys. Rev., 87, 693 (1952).; *Interactions of neutrons with electrons*, Usp. Fiz. Nauk 49, 301 (1953).; D. Y. Hughes, J. A. Harwey, M. D. Goldberg and M. I. Strafne, Phys. Rev., 90, 497 (1953).

Translated by M.Polonsky
107

Transformation of the λ-Transition in Helium to a Special Transition of the First Kind in the Presence of a Heat Flow

V. P. PESHKOV
Institute for Physical Problems
Academy of Sciences, USSR

(Submitted to JETP editor December 15, 1955)
J. Exptl. Theoret. Phys. (U.S.S.R.) 30, 581-582 (March, 1956)

IT is known that the λ-transition in liquid helium, as well as the transition to a superconducting state in the absence of a field, are typical examples of transitions of the second kind, that is, occurrences without release of heat and without change in volume. However, the superconducting transition in the presence of a magnetic field, and, consequently, of superconducting surface currents, changes from a transition of the second kind to a transition of the first kind, that is, it takes place with absorption or release of heat. Although the temperature of the transition from a superfluid to a normal state in liquid helium is lowered at increased pressure, the λ-transition remains a transition of the second kind, and it was assumed in the