

Electro-Optical Effects in Bentonite Colloids

Recently the writer¹ reported an extremely large electro-optical effect in colloidal solutions of bentonite. Further investigations, with a Babinet compensator, have revealed the following results.

A sol of a concentration of about one percent (particle size between 15 and 30μ , relaxation time of streaming birefringence about one sec.) becomes negatively birefringent for a.c. fields of 60 and 500 cycles. If this sol is diluted with distilled water the effect diminishes rapidly and vanishes for a critical value of the concentration. This critical concentration depends on the frequency of the electric field. For 500 cycles it is at 38 percent of its original value, but a dilution of one part sol in 80 parts water was needed before the effect vanished for 60 cycles. For concentrations smaller than these critical values the sols become positively birefringent in the electric field. This positive birefringence is largest when the concentration is about one-half of the above critical concentrations.

These observations confirm therefore the results of F. J. Norton² who reports a change from negative to positive birefringence when the concentration is kept constant and the frequency is increased. Our results show that the critical frequency for which the birefringence disappears increases with the concentration of the sol. It may be as small as 60 cycles for dilute solutions and it can be raised to high frequencies in concentrated sols, but so far we have not been able to get a reversal for 10^6 cycles, for which the birefringence is positive even for the very concentrated sols.

These results make it most unlikely that the phenomenon is analogous to the reversal of the Kerr effect in rosin and octyl alcohol. For these polar liquids the critical frequency increases with decreasing viscosity while in the clay colloids the most dilute and least viscous solutions have the lowest critical frequency. The transition from negative to positive birefringence is not a relaxation phenomenon.

The relaxation time of the birefringence has been investigated. As reported previously the double refraction does not follow the alternations of the field when concentrated solutions are used. However, when the concentration is decreased, one reaches a dilution where the bentonite "Kerr" cell acts as an electro-optical light shutter.

In observations with a Babinet compensator the interference lines gradually become blurred when the electric field is increased and experiments with a photo-cell amplifier connected to a cathode-ray oscillograph give a clear record of the fluctuations of the light intensity. We find that the birefringence consists in general of two parts, one which is constant and one which vibrates with twice the frequency of the electric field. The constant and alternating parts of the birefringence have always the same sign and they vanish both at the same concentration. For concentrated solutions the alternating part is negligible, for dilute solutions the constant part disappears. The concentrations for which the alternating part becomes noticeable are about 0.8 percent for 60 cycles and 0.5 percent for 500 cycles, i.e., the lower the concentration the higher is the critical frequency at which the cell begins to act as a

stroboscope. The disappearance of the alternating birefringence follows all the laws of a relaxation effect, it depends on temperature and viscosity, but there is no connection between this effect and the reversal of birefringence.

The discovery of the alternating part of the birefringence makes it possible to use bentonite in light shutters and stroboscopes. They can be operated on small voltages and be used for wide light beams. Even in the dilute solutions which are almost as transparent as pure water the "Kerr" effect is still many thousand times larger than in nitrobenzene. From a theoretical point of view, however, these new observations complicate the problem of the origin of the electro-optical effects in colloids.

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¹ H. Mueller, *Phys. Rev.* **55**, 508 (1939).

² F. J. Norton, *Phys. Rev.* **55**, 668 (1939). A larger part of our results were obtained before Dr. Norton informed me of his work.

The Neutron-Proton Scattering Cross Section

The cross section for the scattering of thermal neutrons by protons in paraffin wax has been determined rather accurately (for literature see reference 1). Taking into account the chemical binding forces acting on the protons in the paraffin, one can from these measurements calculate the scattering cross section of free protons relative to slow neutrons; in this way, a value of 14×10^{-24} cm² has been obtained.^{1, 2} This cross section has also been measured directly by studying the activity produced in different elements when activated through a shield of cadmium.³ The mean free path in paraffin, of the "resonance" neutrons of these elements, was found to be 1.1 cm, which corresponds to a value about 11.5×10^{-24} cm² for the scattering cross section of the proton. The poor agreement between the calculated and the experimental value and the importance of an accurate knowledge of the neutron-proton cross section for a number of nuclear problems made a new and more accurate determination seem highly desirable. In the following a short report of such measurements is given, a detailed account of which is to appear soon in the *Proceedings of the Royal Danish Academy*, Copenhagen.

The measurements were carried out with water as a proton scatterer and with both silver and iodine as detector and filter materials. The source (300–600 mg radium plus beryllium) was placed three cm below the upper surface of a cube of paraffin wax of ten cm sides. The detector, in a pocket of Cd-sheet (0.4 g/cm²), was placed 5 to 14 cm above the upper surface of the paraffin cube, the scatterer midway between source and detector, and the filter immediately below the scatterer. The areas of detector, scatterer and filter were 10×10 cm². Runs (of equal duration) were then made (1) with only the empty water trough between paraffin and detector, (2) with the filter, (3) with the water scatterer, and (4) with filter and water scatterer. If the recorded numbers of particles are called

N_1 , N_2 , N_3 , N_4 , respectively, the ratio $(N_3 - N_4)/(N_1 - N_2)$ gives the transmission, in the water layer, of those resonance neutrons which have suffered no energy change of more than the order of the resonance width.

Results obtained with different detectors (silver and iodine), different water layers (5, 10 and 15 mm) and different distances of the detector from the paraffin block (5 and 14 cm) agreed within the statistical errors, and the weighted mean for the mean free path of the resonance neutrons in water was found to be 0.91 cm, which corresponds to a proton cross section of 14.8×10^{-24} cm² if the cross section of oxygen is taken as 3.3×10^{-24} cm².⁴ The standard error of these figures is about five percent.

Using essentially the same method, Cohen, Goldsmith and Mitchell found a considerably larger value (20×10^{-24} cm²),⁵ with rhodium as detector. It should be remembered, however, that the resonance energy of rhodium is about one ev only, which is not much larger than the quantum energy of some of the proton oscillation frequencies, and that one must therefore expect the rhodium resonance neutrons to be scattered more strongly than slightly faster ones. Indeed the silver resonance neutrons were found, in the present experiment, to be scattered practically in the same way as the considerably faster resonance neutrons of iodine.

In conclusion I wish to express my sincere thanks to Professor N. Bohr for the opportunity to work at the Institute of Theoretical Physics, and to Dr. O. R. Frisch for valuable advice.

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¹ H. A. Bethe, *Rev. Mod. Phys.* **9**, 69 (1937).

² Arley, *Kgl. Danske Vidensk. Selsk. Mat.-fys. Med.* **16**, 1 (1938).

³ E. Amaldi and E. Fermi, *Phys. Rev.* **50**, 899 (1936).

⁴ Dunning, Pegram and Mitchell, *Phys. Rev.* **48**, 277 (1935).

⁵ Cohen, Goldsmith and Schwinger, *Phys. Rev.* **55**, 106 (1939).

The Cross Sections of Metallic Uranium for Slow Neutrons

Whitaker and Beyer¹ have shown that slow neutron cross sections are not always additive. Their data indicate that the cross sections obtained by measurements on compounds may differ greatly from those obtained by measurements made on the elements. Because of this variation in results obtained by direct and indirect measurements and because of the current interest in uranium, it seemed worth while to measure the cross section of uranium for slow neutrons with the use of the metal instead of the compounds used heretofore. The availability of one pound of uranium metal enabled us to do this. It seemed especially desirable to make measurements that will enable one to determine not only the total cross section but also the capture cross section and the scattering cross section. With this aim in view the experiments described below were done.

The uranium metal was packed in an aluminum box 8×8 cm and 0.8 cm thick. The sides of the box were made of 0.16-cm aluminum sheets. This box held 6.85 g/cm² of

uranium metal. Another identical box was used in making corrections for scattering and adsorption due to the box itself.

The experiments consisted of measuring the transmission of the uranium for the slow neutrons by detecting the intensity of the neutron beam with and without the uranium in the beam. The sample was far enough away from the detector so that no appreciable number of scattered neutrons were counted. These measurements give the total thermal neutron cross section for capture and for scattering. By repeating these measurements with the uranium sample very close to the detector one counts a fraction of the scattered neutrons. This fraction may be determined experimentally by using any material whose capture cross section and scattering cross section are both known. The capture cross section of carbon is believed to be so small as to be negligible. The capture cross section and the scattering cross section for iron have been determined and found to be 3.5 and 8.5×10^{-24} cm², respectively, by this method of change in solid angle.² Both iron and carbon have been used in these experiments to make the necessary corrections. These included a correction for the change in the path length of the scattered neutrons in the detector.

The total cross section for this uranium metal was found to be $23.1 \pm 0.5 \times 10^{-24}$ cm². The analysis for this metal does not show impurities which should influence the cross section appreciably. This measurement of total cross section agrees reasonably well with the recent determination for uranium oxide made by Goldsmith, Cohen, and Dunning.³ I am informed by Professor Dunning that they are reporting a cross section of $20.0 \pm 2.0 \times 10^{-24}$ cm². Through the courtesy of Professor Dunning a check was made for the value of the metal with the same neutron beam as was used in measuring the oxide. The result obtained was $23.3 \pm 0.5 \times 10^{-24}$ cm². The experiment for the separate determination of the capture cross section and the scattering cross section in which a silver detector was placed as close to the sample being studied as was possible, gave a result for the capture cross section of 11 ± 3 , and for the scattering cross section of $12 \pm 3 \times 10^{-24}$ cm².

While it is true that these last measurements are less direct than those for the total cross section, it is believed that the limits of error put on these values are conservative. The results are being checked by a scattering experiment of the type done by Goldhaber and Briggs.⁴

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¹ Whitaker and Beyer, Abstract No. 72, Washington Meeting of the American Physical Society, April 27-29, 1939.

² Whitaker, Beyer and Dunning, *Phys. Rev.* **54**, 771 (1938).

³ Goldsmith, Cohen and Dunning, Abstract No. 69, Washington Meeting of the American Physical Society April 27-29, 1939.

⁴ M. Goldhaber and G. H. Briggs *Proc. Roy. Soc.* **162**, 127 (1937).