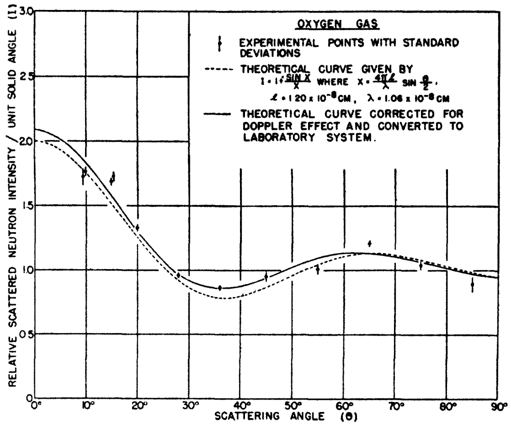

FIG. 2. Angular distribution of 0.07-ev neutrons scattered from oxygen gas.

angles the counter may be exposed to steel which is in the neutron beam without receiving too large a background. For angles above 30° baffles were arranged to prevent neutrons singly scattered from the steel from reaching the counter. Despite these precautions, at most angles background counts and true counts were approximately equal. The background from doubly scattered neutrons is appreciable (~10 percent), and an approximately calculated correction has been applied. No attempts were made to reduce it in the work here reported, but for work on other gases a system of baffles inside the gas cell has been planned.

In Figs. 2 and 3 are plotted the experimental results together with simple theoretical curves for both gases. (The vertical scale has been arbitrarily adjusted to fit the curves to the experimental points.) It will be seen that there is evidence of a pattern due to the form of the molecule.

The quantum-mechanically correct method of calculating the scattering requires a separate calculation for each possible rotational transition of the molecule (inelastic, elastic, and superelastic), and the summation of intensities after allowing for Doppler effect and the motion of the center of mass.[1] For a heavy molecule this requires a very large computational effort and has not been attempted. The curves drawn in Figs. 2 and 3 were obtained by a semiclassical calculation in which the neutron is represented by a wave, but the molecule is replaced by a rigid system of point scatterers. The method assumes elastic scattering only and is the same as the normal procedure for x-ray scattering,[2] with the atomic structure factors replaced by constants. No account has been taken of paramagnetism in the oxygen molecule,[3] but small corrections

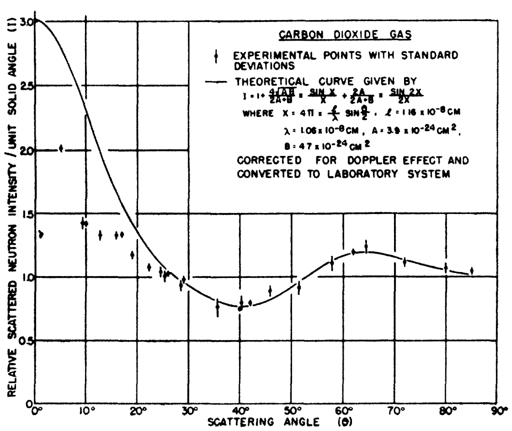

FIG. 3. Angular distribution of 0.07-ev neutrons scattered from carbon dioxide gas.

have been applied for Doppler effect and conversion to the laboratory system of coordinates. The good agreement with experiment in the case of oxygen leads one to expect that the exact formulas condense, to a close approximation, to the semiclassical result.[4] Of interest in this connection is a forthcoming letter by J. A. Spiers on the scattering of slow neutrons by deuterium gas.

Carbon dioxide, unlike oxygen, shows a marked deficiency in intensity at small angles. A possible cause of this is intermolecular interference, which in a liquid causes the scattering to be small for angles between zero and the first diffraction ring. The carbon dioxide in our experiment is near the liquid phase, and, as shown by Eisenstein and Gingrich[5] for x-ray scattering from argon, the vapor pattern may exhibit features characteristic of the liquid. If our conditions are compared with theirs, by the Law of Corresponding States, it is found that the deficiency in scattering is in good agreement but that the carbon dioxide shows no excess scattering corresponding to the liquid peak found for argon.

The study of gas scattering was suggested by Dr. B. W. Sargent. The spectrometer was the work of Mr. A. J. Pressesky, Mr. P. R. Tunnicliffe, and one of us (DGH).

[1] J. Schwinger and E. Teller, Phys. Rev. **52**, 286 (1937); M. Hamermesh and J. Schwinger, Phys. Rev. **69**, 145 (1946).
[2] See A. H. Compton and S. K. Allison, *X-rays in Theory and Experiment* (D. Van Nostrand Company, Inc., New York, 1935), second edition, p. 159.
[3] O. Halpern, Phys. Rev. **72**, 746 (1947).
[4] See E. Fermi and L. Marshall, Phys. Rev. **71**, 666 (1947), Section 4.
[5] A. Eisenstein and N. S. Gingrich, Phys. Rev. **62**, 261 (1942).

Inelastic Scattering of 14.5-Mev Neutrons by Lead*

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April 7, 1949

ACCORDING to the statistical theory of nuclei[1] half the collisions of neutrons of wave-length short compared to the nuclear radius will result in inelastic scattering or absorption. The inelastically scattered neutrons are expected to have an approximately Maxwellian distribution in energy corresponding to the temperature of the residual nucleus.[2]

Previous investigations of the inelastic scattering by heavy nuclei of neutrons of energy above 3 Mev have been carried out by Grahame and Seaborg,[3] Soltan,[4] and Amaldi *et al.*[5] The results indicate reasonable agreement with theory for the magnitude of the cross section for inelastic scattering and absorption, but Grahame and Seaborg find for a Ra-Be source almost no inelastically scattered neutrons between the energies of 3 and 7 Mev, and Soltan finds no inelastically scattered neutrons between 3 and 11 Mev for Li+D neutrons.

The availability of 14.5-Mev neutrons with an anergy spread of only ±0.5 Mev permits measurements of inelastic scattering in which the previous difficulties caused by the distribution in energy of the primary neutrons are not present. 14.5-Mev neutrons were obtained by bombarding a thick tritium gas target with deuterons from the Los Alamos electrostatic generator.

A lead sphere of radius about one-half mean free path for energy loss by the neutrons (4 cm) was constructed with a small central spherical cavity in which threshold detectors could be placed. In such a spherical geometry the effects of elastic scattering do not need to be considered since just as many neutrons are elastically scattered into the detector as are elastically scattered out, if the radius of the sphere is small compared with the distance from the source (40 cm). The threshold detectors were prepared in the form of long, thin foils which were rolled up tight to approximate a pseudosphere when placed in the cavity and which could be unrolled and wrapped helically around a Geiger tube.

A threshold detector should have, ideally, zero detection cross section below a threshold energy and an approximately constant cross section above this energy. The aluminum (n,p) reaction has a threshold of about 3 Mev, a cross section above threshold of 0.03 barn and a half-life of 10.2 minutes. $Cu^{63}(n,2n)$ has a threshold of about 11 Mev, a cross section of 0.25 barn, and a half-life of 10.4 minutes.

The experimental procedure consisted of placing the sphere with the internal detector in the neutron beam for 10 minutes and then counting the induced foil activity. A second 10-minute run was then made with a duplicate detector but without the sphere. Normalization of the neutron flux was accomplished by placing a monitor foil of the same material as the detector foil in a standard position far enough from the sphere to minimize back-scattering. After irradiation the monitor foil and the detector foil were counted simultaneously on two Geiger counters for 10 minutes. Careful observations showed that only the 10-minute half-lives were excited. In this case, the ratio of total counts above background is the same as the ratio of foil activities at the end of irradiation.

The cross section for absorption and for inelastic scattering to below the detector threshold is given by

$$\sigma_{\text{in}} = -(1/Nr)\ln T$$

where N is the number of atoms per cc and r is the thickness of material between source and detector. T is the transmission and, using detector foils of equal mass and monitor foils of equal mass, is the ratio of the foil activities, A_d, with the sphere in and out, normalized to the same neutron flux by the ratio of monitor foil activities, A_m,

$$T = (A_d/A_m)\ \text{in}/(A_d/A_m)\ \text{out}.$$

When the transmission is computed in this fashion, the irradiation time, the waiting time, and the counting time do not need to be known.

The cross section of lead as determined by the aluminum detector was measured to be 2.20 ± 0.17 barns, and for the copper detector 2.29 ± 0.12 barns. The cross section is essentially the same for both detectors, which suggests that the inelastically scattered neutrons which are degraded in energy below the copper threshold are also degraded below the aluminum threshold, or, a 14.5-Mev neutron loses over 11 Mev in its first inelastic collision in lead. This result agrees with the findings of Grahame and Seaborg[3] for Ra-Be neutrons, and of Soltan[4] for Li+D neutrons. The absolute value of the cross section for inelastic scattering and absorption is in excellent agreement with the results of other workers,[3-5] and is about 10 percent less than one-half the total cross section, indicating a sticking probability of less than unity.

* This paper is based on work performed at Los Alamos Scientific Laboratory of the University of California under government contract W-7405-eng-36.

[1] H. A. Bethe, Phys. Rev. **57**, 1125 (1940).
[2] V. F. Weisskopf, Phys. Rev. **52**, 295 (1937).
[3] D. C. Grahame and G. T. Seaborg, Phys. Rev. **53**, 795 (1938).
[4] A. Soltan, Nature **142**, 252 (1938).
[5] E. Amaldi, D. Bocciarelli, B. N. Cacciapuoti, and G. C. Trabacchi, *Fundamental Particles* (Physical Society, London, 1947), p. 97.

On the Question of Atmospheric Ammonia*

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March 14, 1949

In a letter to the editor of the Physical Review,[1] Mohler, Goldberg, and McMath reported spectroscopic evidence for ammonia in the earth's atmosphere, based on close agreement, to within ± 0.05 cm^{-1}, between 8 intense lines in the ammonia spectrum and features of the solar spectrum in the 2μ-region.

Since these lines would be components of combination bands of the ammonia spectrum, it would, therefore, seem desirable to verify the existence of NH_3 in the earth's atmosphere, by investigating one or more of the fundamental bands at 2.92, 2.99, 6.14, and 10.5μ, since they are certainly more intense than the combination bands.

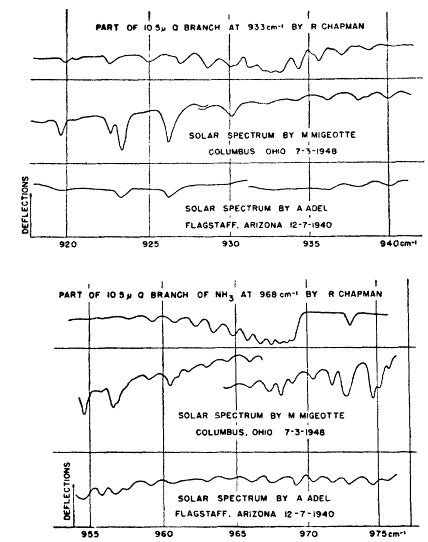

FIG. 1. Spectrograms for comparison.

The 2.9μ-region of the solar spectrum is complicated by the presence of many water vapor lines and will be investigated when winter water vapor conditions are most favorable. The 6.14μ-band of ammonia is almost impossible to detect, under any conditions, due to the very heavy water vapor absorption in this region. Fortunately, the 10.5μ-band of ammonia falls in a region of the solar spectrum where there are only a very few lines.

Comparison of our recent solar spectrograms and those of A. Adel,[2] published in 1941, with our laboratory spectrograms of the 10.5μ-band of ammonia, reveals no evidence of the two well-known Q branches, at 931 and 968 cm^{-1}, in the solar spectrum.

Figure 1 presents the spectrograms concerned, and, except for one or two lines, there is a good agreement between the records of Adel and Migeotte.

It has been determined by D. L. Wood of our laboratories that 1-mm pressure of ammonia in a 10-cm cell is detectable in this region. This fact and the lack of evidence for any absorption of NH_3 in the 10.5μ-region of the solar spectrum, indicate that only trace amounts of ammonia are present in the earth's atmosphere, and it is doubtful that the lines identified as ammonia lines in the 2μ-region arise from atmospheric absorption.

It is possible, however, that a local concentration of ammonia near the point of observation would give rise to an apparent atmospheric absorption.

* The work described in this letter was carried out, in part, under contract between Wright-Patterson Air Force Base of the Air Materiel Command and the Ohio State University Research Foundation.
** Now at the University of Liege, Belgium.

[1] Mohler, Goldberg, and McMath, Phys. Rev. **74**, 352 (1948).
[2] A. Adel, Astrophys. J. **94**, 451 (1941).

Erratum: The Detection of Gamma-Rays with Thallium-Activated Sodium Iodide Crystals

[Phys. Rev. **75**, 796 (1949)]

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On page 799 the symbol TlI (standing for thallium iodide) should have appeared after "100 milligrams of" in place of the symbol Tl, which appeared inadvertently.