energy of the H-bridge equal to 6 to 7 kcal./mole, as one might expect. This is an additional effect which is superposed on structure relaxation that is typical for all liquids. A comprehensive report will be published soon.[8]

[1] G. Stokes, Trans. Camb. Phil. Soc. **8**, 287 (1945).
[2] H. O. Kneser, Ergeb. d. exakt. Naturwiss. **22**, 121 (1949).
[3] P. Debye, Zeits. f. Elektrochemie **45**, 174 (1939).
[4] J. Frankel, *Kinetic Theory of Liquids* (Oxford University Press, London, 1946).
[5] K. Wirtz, Zeits. f. Naturforsch. **3a**, 672 (1948).
[6] Glasstone, Laidler, and Eyring, *The Theory of Rate Processes* (McGraw-Hill Book Company, Inc., New York and London, 1941).
[7] J. Lamb and J. M. M. Pinkerton, Proc. Roy. Soc. **A199**, 114 (1949).
[8] A. Gierer and K. Wirtz, Zeits. f. Naturforsch. **5a**, 270 (1950).

Mobility of Electrons and Holes in Diamond*

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THE mobility of electrons and holes in a diamond crystal counter has been measured using a method somewhat similar to that of McKay.[1] The range of the carriers (either holes or electrons), released by α-particles entering through one electrode, and the rise time of the pulses were measured in an unpolarized sample 2 mm thick. Polarization was eliminated by illuminating the sample with ultraviolet light from a mercury arc, with no field applied, immediately before measurements were taken. During the time measurements were taken no appreciable polarization charge accumulated.

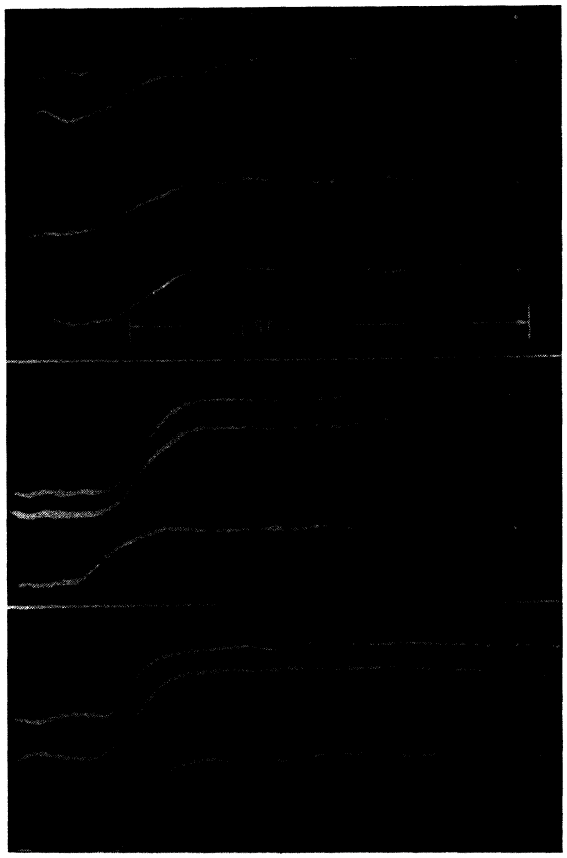

FIG. 1. Electron pulses in diamond. Top: 300 volts across crystal; center: 1200 volts across crystal; bottom: 5000 volts across crystal. Crystal thickness: 2 mm.

The value of range was obtained by measurements of the variation of pulse height with applied voltage. Fields up to 25,000 volt/cm were used. The results give:

$$\text{electrons: } \mu T = 3.5\times10^{-5}\pm10\%\ \text{cm}^2/\text{volt}$$
$$\text{holes: } \mu T = 3.8\times10^{-5}\pm15\%\ \text{cm}^2/\text{volt},$$

where μ = mobility, T = mean free time.

Pulse rise times at various voltages were measured from photographs (Fig. 1) of pulses displayed on a cathode-ray oscilloscope. Delay line amplifiers with an over-all rise time (20 to 80 percent) of 0.009 μsec. were used to amplify the pulses in order to display them on the oscilloscope which had characteristics similar to that described by Kelley.[2] The rise time-voltage dependence for electrons was as expected and gave a value $T = 0.009\pm10$ percent μsec. The dependence for holes deviates from expectation at higher values of voltage. In the low voltage region, where the behavior appeared normal, the value for holes was $T = 0.008\pm15$ percent.

From the values of μT and T the mobility values are:

$$\text{electrons: } \mu = 3900\pm15\%\ \text{cm}^2/\text{sec.-volt},$$
$$\text{holes: } \mu = 4800\pm20\%\ \text{cm}^2/\text{sec.-volt}.$$

Preliminary measurements for electrons have been obtained on a second diamond 1.98 mm thick. For this sample both the range and free time are less than for the first diamond. The value of free time was therefore less accurate since the pulse rise times differed less from the amplifier rise time. Results for electrons are

$$\mu T = 2.1\times10^{-5}\ \text{cm}^2/\text{volt} \quad \text{and} \quad T = 0.0076\ \mu\text{sec}.$$

Thus $\mu = 2760$ cm²/sec.-volt with an estimated error considerably greater than that on the first value.

* This work was supported by the ONR.
† AEC Predoctoral Fellow.
[1] K. G. McKay, Phys. Rev. **74**, 1606 (1948); **77**, 816 (1950).
[2] G. G. Kelley, Rev. Sci. Inst. **21**, 71, 264 (1950).

Upper Limit on the Cross Section for the Scattering of Neutrinos*

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SEVERAL previous experiments have been performed to attempt to detect the scattering of neutrinos. Crane[1] has given a summary of such results. In an experiment very similar to the author's, Nahmias[2] has set the lowest upper limit of 10^{-30} cm²/atom in air. The present availability of tritium in large quantities seemed to make it possible to set a better value for the upper limit of the cross section.

A Geiger counter was used for detection of the neutrinos. It was assumed that any ionizing event in the counter gas due to neutrinos would give a count. The source of neutrinos was 5 curies of tritium.

The procedure was to count alternately with the tritium placed alongside the counter for several hours and then count with the tritium removed to a considerable distance for several hours. Many trials were made of the background counting rate and of the gross counting rate of background plus neutrinos, always alternating between the two.

In each of the two experiments performed, it was found that the net counting rate was less than the probable error computed by statistical means. It was assumed that any counting rate greater than the probable error could have been detected, and an upper limit on the cross section was computed.

Using a Geiger counter filled with neon at 10 cm Hg pressure, a gross counting rate of (23.45±0.10) counts/min. and a background counting rate of (23.63±0.11) counts/min. were obtained. This gave a net counting rate of (−0.18±0.21) count/min. Assuming that any counting rate greater than 0.21 count/min.

could have been detected, this gives an upper limit of 5×10^{-32} cm²/atom. The number of atoms/cm³ in the counter was calculated to be 6×10^{18}. The number of disintegrations per second in the tritium was 1.8×10^{11}, and it was estimated that one-twentieth of these passed through the counter. The average path length through the counter was 1.2 cm. Supposing the main means of scattering would be by the electrons and assuming eight electrons per atom would be effective in scattering, this gives an upper limit of 6×10^{-33} cm²/electron.

Using another Geiger counter filled with twenty atmospheres of helium, a gross counting rate of (28.95±0.31) counts/min. and a background counting rate of (29.12±0.34) counts/min. were obtained. The net counting rate in this case was (−0.17±0.65) count/min. Using 0.65 count/min. as an upper limit on the counting rate, 7×10^{-34} cm²/atom was the upper limit on the cross section. In calculating this figure, the number of neutrinos and the fraction which passed through the counter were the same as above. The number of atoms/cm³ was 5×10^{20}, and the average path length through the counter was 3.5 cm. Assuming the two electrons in helium to be equally effective for scattering, the upper limit of the cross section is 4×10^{-34} cm²/electron.

* This work was supported by the joint AEC and ONR program.
[1] H. R. Crane, Rev. Mod. Phys. **20**, 278 (1948).
[2] M. E. Nahmias, Proc. Camb. Phil. Soc. **31**, 99 (1935).

Neutron Binding Energies

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UP to the present, authors[1] who have calculated neutron binding energies in the heavy isotopes have bridged between the radioactive series by smooth interpolations or by use of the mass formula. There are now sufficient data to give unambiguous energy differences between the $4n$, $4n+3$, and $4n+2$ series, apart from experimental error. Although the possible formation of excited states casts doubt on the result of any single type of experimental neutron binding energy measurement, agreement between the results of two properly chosen methods removes it. In a (d, p) reaction, if (Z, A) is the target nucleus, then $E_n(Z, A+1) = Q_R+Q_d+E_\gamma$, where $E_n(Z, A+1)$ is the neutron binding energy in $(Z, A+1)$, Q_R is the Q-value for the reaction, Q_d is the deuteron binding energy and E_γ is the *total* gamma-energy emitted by the product nucleus, if formed in an excited state. Thus, if the total gamma-energy between the excited and ground states is not included, the calculated binding energy would be equal to or *less* than the true binding energy.

Conversely, for the (d, t) reaction, $E_n(Z, A) = -Q_R+Q_t-Q_d-E_\gamma$. Here the target nucleus is still called (Z, A), and Q_t is the triton binding energy. If an excited state were formed and the total gamma-decay energy not included, the calculated binding energy would be *greater* than the true binding energy. Therefore agreement between the neutron binding energies in a given nucleus as measured by the (d, p) and (d, t) reactions gives this energy unambiguously. Similar considerations show that a (γ, n) reaction gives a result greater than or equal to the true energy, while the result from an (n, γ) reaction is ambiguous unless the gamma-decay scheme is determined. The energies listed in Table I are the results of various investigations for the last neutron in the isotope given. The last column gives conclusions based on the above reasoning. Thus the energy differences between the $4n$, $4n+3$, and $4n+2$ series are known.

Now it seems rather certain that the disintegration energies of Pb^{209}, Pb^{210}, and Bi^{210} are 0.69 Mev, 0.07 Mev, and 1.17 Mev, respectively.[2] The use of these, the disintegration energy[2,3] of Po^{214} and the neutron binding energies in Pb^{208} and Pb^{207}, shows that about 0.4 Mev must be added to the sum of the measured

TABLE I. Neutron binding energies.

Isotope	Neutron binding energy (Mev) measured by (d, p)[a]	(d, t)[a]	(γ, n)[b]	(n, γ)[c]	Neutron binding energy (Mev)
83^{210}	4.14±0.03			4.170±0.015	≥4.17
83^{209}		7.44±0.05	7.45±0.2		≤7.44
82^{209}	3.87±0.05				≥3.87
82^{208}	7.37±0.03	7.37±0.05	7.44±0.10	7.380±0.008	7.38
82^{207}	6.71±0.03	6.69±0.05	6.95±0.10	6.719±0.016	6.72
82^{206}		8.10±0.05	8.25±0.10		≤8.10

[a] J. A. Harvey, Phys. Rev. **79**, 241 (1950).
[b] McElhinney, Hanson, Becker, Duffield, and Diven, Phys. Rev. **75**, 542 (1949); H. Palevsky and A. O. Hanson, Phys. Rev. **79**, 242 (1950).
[c] Kinsey, Bartholomew, and Walker, Phys. Rev. **78**, 77 (1950); Phys. Rev. **78**, 481 (1950); private communication.

binding energies in Pb^{209} and Bi^{210}. If it is assumed that *only one* of these measurements is in error, the following arguments lead to the choice of 3.87 Mev for the binding energy of Pb^{209}. First, if the 0.4 Mev were added to the experimental binding energy in Pb^{209}, the resultant energy would be greater than that in Bi^{210}. However, it is expected that the addition of an odd proton outside the closed Pb^{208} shell would *increase* the binding energy of an odd neutron outside that shell. Second, the neutron binding energy in Pb^{209} would be only 0.5 Mev less than that of the neutron in Pb^{210}. This difference is expected to be 1.0 Mev or more. Third, if 4.17 Mev were the binding energy of the odd neutron in Bi^{210}, it would be less than that in Bi^{212}, contrary to expectations. The latter (4.36 Mev) is derived from the binding energy in Pb^{208}, the disintegration energies of Th C (2.25 Mev), Ac C'' (1.44 Mev),[4] and known alpha-energies.[2,3]

These experimental energy differences between the four series make it possible to determine other binding energies using energy cycles. Knowledge of these energies may serve as a means of refining the empirical mass formulas. More importantly, they can provide a check on the validity of total decay energies. Arguments like those in the preceding paragraph are also being made for the latter purpose. Work along these lines at present indicates that some of the most critical decay energies are those of Ra B, Ra C, Bi^{213}, $Ms\mathrm{Th}_1$ and $Ms\mathrm{Th}_2$.

[1] A. Berthelot, J. de phys. et rad. (VIII) **3**, 17 (1942); K. Way, Phys. Rev. **75**, 1448 (1949); M. O. Stern, Rev. Mod. Phys. **21**, 316 (1949); A. H. Wapstra, Physica **16**, 33 (1950).
[2] See G. T. Seaborg and I. Perlman, Rev. Mod. Phys. **20**, 585 (1948) for references.
[3] Perlman, Ghiorso, and Seaborg, Phys. Rev. **77**, 26 (1950).
[4] H. D. Evans, Proc. Phys. Soc. London **63**, 575 (1950).

The Solar Flare of November 19, 1949 and Cosmic Rays

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WITHIN recent years a great number of physicists, among them Forbush,[1] Ehmert,[2] and Unsöld,[3] have investigated extensively with ion chambers and counters the sudden variations in cosmic-ray intensity coincident with disturbances of the earth's magnetic field, changes in radiofrequency waves from the sun, and ionospheric disturbances and their correlation with solar flares.

As to our contribution to the investigation with the former method, our recording apparatus consists of 3 ion chambers containing Ar at up to 60 atmospheres; one of the chambers is unshielded, one shielded with 12 cm Fe, and one with 110 cm Fe. Normally we have a fourth vessel, likewise under 110 cm Fe, but this one was not in use for the moment. The charge required to compensate the ionization in the vessels is measured every two hours for the unshielded vessel, every hour for the other two, in the form of an excess over a well-known compensation charge.