the hydrogen atoms and one involving a large amplitude of motion of the oxygen atom. These vibrations are of course in addition to the three interatomic oscillations which appear in the near infrared. Assuming harmonic oscillations of a water molecule about the axis of smallest moment of inertia ($I=0.998\times10^{-40}$; this would give the highest frequency, be infrared active and be practically only a motion of the hydrogen atoms), we obtain for the 20μ band in H_2O or the 28μ band in D_2O, according to the formula $\nu=1/2\pi(K/I)^{\frac{1}{2}}$, a value of $K=9\times10^{-13}$ dyne-cm or $22kT$. The water molecule would therefore be hindered from oscillating through an angle of about $\pm27°$. If we assume that the oxygen atoms vibrate in the same field as was found for the hydrogen atoms, the wave-length of the natural vibration period of the oxygen atoms would be 57μ, which agrees well with the experimental data. The amplitude of the vibrations of the oxygen atoms would be about 0.15A.

The results obtained experimentally when compounded with the Bernal and Fowler model of liquid water or when interpreted with an order of magnitude calculation show clearly that at room temperature the molecules in liquid water are hindered by a strong intermolecular field from executing a free rotational motion.

I am pleased to thank Professor Dennison for his helpful suggestions.

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A Method for the Determination of the Selective Absorption Regions of Slow Neutrons

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FERMI and Amaldi[1] and Szilard[2] have demonstrated that each element which shows a strong capture absorption of slow neutrons absorbs neutrons of a characteristic energy. These bands of selective absorption were originally assumed to be in the thermal or near-thermal region. Rasetti and Fink[3] have shown, however, that there is no temperature effect on these bands except for cadmium.

According to the Wigner-Breit[4] theory the selective absorption is explained as a resonance phenomenon. It is assumed that the nucleus which is formed by the capture of the neutron has some excited level whose energy is equal to that of the original nucleus plus a neutron of a certain energy E_0. If a neutron of this energy falls on the nucleus there may be a nonradiative transition (inverse "Auger-effect") into the above-mentioned excited state. This excited state will then, after a certain time, go over into the ground state with the emission of radiation rather than disintegrate again with the emission of a neutron. The theory, therefore, explains also the large observed ratio of capture to scattering in strongly absorbing elements.

The probability of capture of a neutron of energy E is, according to this theory, given by:

$$\sigma_c=(a/E^{\frac{1}{2}})\cdot(\gamma/(E-E_0)^2+\gamma^2), \qquad (1)$$

where γ is the natural breadth of the energy level at E_0 as determined by its lifetime against radiation, and a, E_0 and γ are constants characteristic of the element. γ is estimated to be of the order 1 to 50 volts and E_0 of from 0 to 1000 volts. The capture cross section has, according to Eq. (1), two maxima, one at a very low energy (thermal) and one near E_0.

It is obvious that the velocity selectors for neutrons of thermal energies in use at present[5] cannot be readily extended to this energy region. We wish to propose here a simple experiment designed to measure these energies, which depends on a few relatively safe assumptions. The main assumption is that in certain elements (e.g., B and Li) the absorption is inversely propor-

[1] Amaldi and Fermi, Ricerca Scientifica **VI–II**, Nos. 9–10 (1935).
[2] Szilard, Nature **136**, 950 (1935).
[3] Rasetti and Fink, Bull. Am. Phys. Soc., New York Meeting, Vol. **11**, Nos. 1, 28 (Feb., 1936).
[4] Wigner and Breit, Bull. Am. Phys. Soc., New York Meeting, Vol. **11**, No. 30 (Feb., 1936).
[5] Fink, Dunning, Pegram and Mitchell, Phys. Rev. **49**, 103 (1936).

tional to the neutron velocity, which follows from the elementary theory of slow neutron absorption.[6] The elementary theory can be expected to hold for reactions between neutrons and nuclei which lead to the emission of alpha-particles because such processes are very probable *a priori* as compared to radiative processes, and it is therefore not necessary to assume resonance effects in order to explain the observed cross sections of these processes. Furthermore, B is a very light nucleus which cannot be expected to have the great number of closely-spaced energy levels which should occur in heavier nuclei, and therefore probably does not have an energy level for neutrons anywhere near this region. *The absorption coefficient of neutrons in B should therefore be a good measure of the energy of the neutrons absorbed.*

In order to separate the two absorption regions for an element such as Ag we may use Cd thick enough to absorb all neutrons in the low energy region. This is justified because the velocity selector experiments show practically a Maxwellian distribution of the neutrons absorbed by Cd, and furthermore, this distribution is influenced by temperature changes.[5] The resonance level of Cd seems, therefore, to lie in or near the thermal region, which is also in accord with experiments of Rasetti[7] on the dependence of the absorption coefficient of Cd on the velocity of the neutrons absorbed.

One should, therefore, measure the activity produced in some detector for which the resonance level E_0 is to be determined (e.g., Ag) with four experimental arrangements:

(1) Ag detector acitvated directly by a source of slow neutrons;
(2) same with B absorber interposed;
(3) with Cd absorber, but without B;
(4) with both Cd and B absorbers.

The difference of the measured activities of (1) and (3) should then be attributed to thermal neutrons. (2)–(4) gives the effect of thermal neutrons reduced by the B absorption. From the ratio (1)–(3)/(2)–(4) we can therefore determine the absorption coefficient of B for thermal neutrons. Similarly from the ratio (3)/(4) the absorption coefficient in B for the resonance neutrons can be determined. Since it is to be expected that the absorption coefficient is much larger in the first case it is advantageous to use different thicknesses of B for the determination of the two ratios.

TABLE I.

RUN	DETECTOR	ABSORBER	B(g/cm²)	TOTAL COUNTS	BACKGROUND	ACTIVITY
(1)	Ag	——	——	1309	231	1078
(2)	Ag	B	0.050	863	269	594
(3)	Ag	Cd	——	580	306	274
(4)	Ag	Cd+B	0.050	576	335	241
(3a)	Ag	Cd	——	649	363	286
(4a)	Ag	Cd+B	0.80	508	363	145

Ratios:

R_1(slow neutrons) $=\frac{(1)-(3)}{(2)-(4)}=\frac{804}{353}=2.28$: Abs. Coef. $=16.5$/g cm^{-2}.

R_2(fast neutrons) $=\frac{(3a)}{(4a)}=\frac{286}{145}=1.97$: Abs. Coef. $=0.85$/g cm^{-2}.

In our experiments a Ag detector of 5×6 cm, which could be rolled into a cylinder and placed around a thin-walled tube counter, was placed 2 cm above the surface of a paraffin block 12 cm on a side. A Rn-Be source of neutrons (*ca.* 400 mc) was placed 10 cm below the upper surface of the paraffin. The B absorber was powdered boron carbide spread in a uniform layer in a box made of 9-mil aluminum sheet of dimensions 7×8 cm and 2 cm deep. A similar Al box, without B, was used in the experiments (1) and (3). The Cd absorber was 0.85 mm thick and covered the paraffin surface. In all experiments a Cd shield surrounded the absorber and detector to protect from stray neutrons.

The ratio of these two absorption coefficients is 19.4, from which we deduce that the energy of the resonance absorption in Ag is $(19.4)^2$ or 375 times the thermal energy, that is, nearly 10 volts. In these preliminary data of Table I the experimental arrangement was somewhat unsatisfactory, requiring the application of certain corrections. Firstly, an estimated 10 percent of the slow neutrons could reach the detector around the edges of the thin B absorber. Applying this correction increases the coefficient from R_1 to 19.4/g cm^{-2}, corresponding to a cross section of about 450×10^{-24} cm² as compared with Dunning's[8] value of 600×10^{-24} cm². The corresponding correction for the thick B absorber is

[6] Bethe, Phys. Rev. **47**, 747 (1935).
[7] Rasetti, Segrè, Fink, Dunning and Pegram, Phys. Rev. **49**, 104 (1936).
[8] Dunning, Pegram, Fink and Mitchell, Phys. Rev. **47**, 417 (1935).

probably small. Secondly, the absorption coefficient for fast neutrons should be corrected for scattering. Estimating the cross section for scattering to be about 3×10^{-24} cm^2, which is the average value for nonabsorbing light elements, and considering that only scattering of greater than about 90° reduces the intensity of the neutron beam, we get a correction of about 10 percent for the coefficient from R_2, which is thereby reduced to 0.77/g cm^{-2}. The ratio of the absorption coefficients now gives 25, resulting in a resonance energy E_0 for Ag of about 16 volts. This numerical value may no doubt be made more accurate with improved data.

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Variations of Properties of Cosmic Shower Radiations with Altitude

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PRODUCTION OF SHOWER RADIATIONS

AN investigation of some of the properties of cosmic and shower radiations was initiated during the summer of 1935.

The first experimental work was the determination of the optimum thickness of lead for producing showers at altitudes 120, 5300, 10,800 and 14,200 feet, respectively. Three Geiger counters arranged in the form of a triangle as indicated in Fig. 1a, were connected in a circuit which recorded triple coincidences. The counter voltage and temperature were held constant.

In the first experiment there was no lead in position B. N/N_0, where N and N_0 are the respective counts per minute with and without the lead at A, was determined for each thickness of lead utilized. This provided a constant check on the operation of the apparatus and determined the thickness for the maximum shower production independent of any slow changes in the efficiency of the counters.

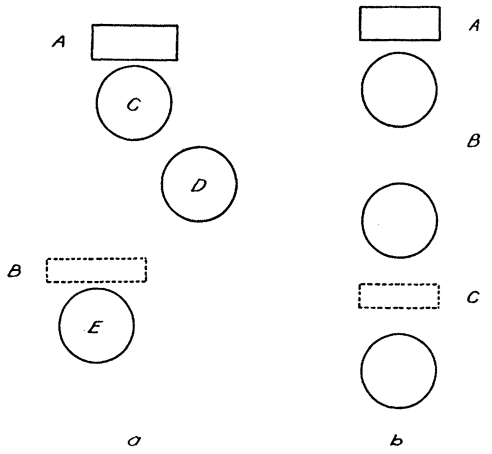

FIG. 1. Arrangement of Geiger counters.

In the second method the counters were arranged in a vertical line (Fig. 1b). Coincidences per minute were determined with the lead block in respective positions A and C. The absorption of the primary rays is the same with the block in either position. The accidentals, which were less than two percent of the smallest count, were practically constant, since the individual counting rate of the several counters was approximately the same with the lead block in either position. This was tested by placing the lead block in position B, and determining the triples per minute which were found to be the same as with the block in the C position. The increased counting rate with the block in position A may be due to one or more ionizing particles ejected from the lead plate by

1. Incident nonionizing rays.
2. Incident ionizing rays moving in a direction not included within the solid angle defined by the counters.
3. Incident ionizing rays moving in a direction within the solid angle defined by the counters but incident on the portion of the lead plate external to the area subtended by this solid angle.

The results of the two methods are shown in Fig. 2.

It will be seen that the shape of the curves is independent of altitude, as is the optimum thickness for shower production, but that both the shape and maximum vary with the method used.

ABSORPTION OF SHOWER RADIATION

To measure the absorption of shower radiation the arrangement shown in Fig. 1a was used. The showers are produced in a lead scatterer, A, and