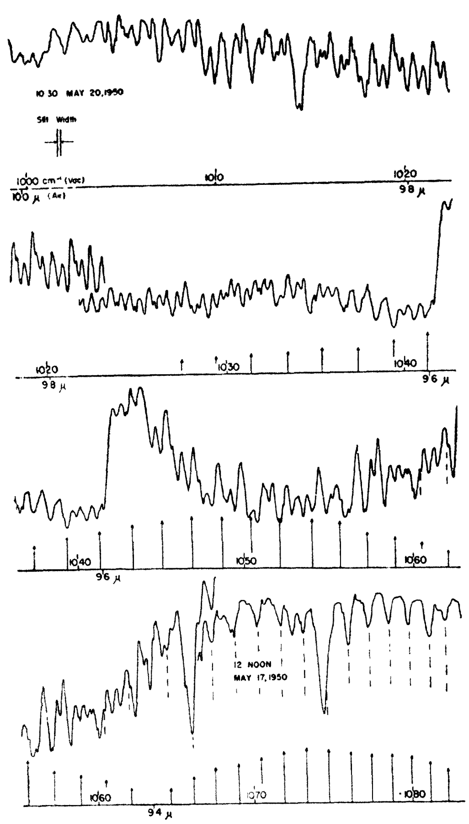

FIG. 1. The ozone band at 9.6μ in the solar spectrum.

It is not yet known whether other bands contribute to the absorption in this region or whether the structure, apart from the comparatively weak CO_2 lines, is entirely due to ozone.

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† Now at the A. F. Cambridge Research Laboratories, Cambridge, Massachusetts.

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Neutron Scattering Resonances of Lithium*

ROBERT K. ADAIR†
University of Wisconsin, Madison, Wisconsin
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It has been noted that lithium, in contrast to most elements, scatters slow neutrons with a positive phase shift or a negative scattering length.[1] Since such behavior may be associated with the presence of a virtual level near threshold, it seemed interesting to search for such a level by measuring the total neutron cross section of lithium as a function of energy.

The cross section was determined in a manner similar to that described for sodium.[2] Measurements were made from 20 to 1400 kev with a neutron energy spread of about 20 kev. Elastic scattering is presumed to be the only process contributing appreciably to the cross section. The cross section near an isolated resonance for the scattering of neutrons with unit orbital angular momentum to form a compound state of spin J will then equal:

$$[(2J+1)/2(2I+1)](4\pi/k^2)\sin^2\delta_{lJ}$$

where

$$\delta_{lJ}=\tan^{-1}(\Gamma_{lJ}/E_r-E)+\varphi_l$$

is the neutron phase shift. Γ_{lJ} is the width of the resonance and E_r is the resonance energy. I is the spin of the target nucleus and k is the neutron wave number. φ_l is equal to the phase shift associated with hard sphere scattering. This will be equal to $-ka$ for $l=0$ where a is the nuclear radius and will be negligible in this experiment for higher l-values. The total cross section is then equal to the sum over l and J values of these partial cross sections.

Figure 1 shows the total cross section of lithium. Since the spin of Li^7 is $\frac{3}{2}$ of the peak cross section should equal $[(2J+1)/8]4\pi k^{-2}$ times the isotopic abundance of Li^7 (92.5 percent). The height of the 270-kev peak is then only compatible with $J=2$. If the peak were the result of the interaction of S-neutrons a dip should be observed, either before or after the peak, due to interference between resonance scattering and background scattering. Following Wigner[3] it is convenient to write the width Γ of a level as $\Gamma_l=2k\gamma^2T_l$ where T_l is the centrifugal potential barrier for l-neutrons. The reduced width, γ^2, is then energy independent. The width of the 270-kev level was measured to be 45 kev. If the resonance were caused by D neutrons the reduced width would be greater than $3\hbar^2/2ma$ where m is the mass of the neutron. This violates a completeness relation of Wigner.[3] These considerations lead us to attribute the peak to the interaction of P neutrons with Li^7 to form an excited state of Li^8 with spin 2. The reduced width of this level is then $(\Gamma/2k)[(ka)^2+1]/(ka)^2$, or $3.5\cdot10^{-13}$ Mev cm. Because of the centrifugal barrier for P-neutrons this level will have no effect on the low energy cross section.

This 270-kev resonance coincides with a peak in the $Li^6(n,\alpha)$ cross section.[4] It seems possible that some of the alpha-particles contributing to this peak are the result of the $Li^7(n,\gamma)Li^8$ reaction, where Li^8 decays with a half-life of 0.87 sec. to excited states of Be^8 which immediately break up into two alpha-particles.[5]

The rise in cross section to 1.6 barns at 1400 kev is explained as being mainly due to a broad elastic scattering resonance. The shape of a broad level is complicated by the variation of Γ and φ_l with energy as well as by the $1/E$ dependence of the cross section [Eq. (1)]. A qualitative fit to the experimental results could be obtained only by attributing the rise to the resonant interaction of S-neutrons to form a state of spin 2 in Li^8 at a neutron energy of about 1.15 Mev. Inelastic scattering to the 480-kev excited state of Li^7 would tend to reduce the observed cross section. The results are best fitted by assuming the inelastic scattering width is small. The width at resonance of this level was taken as 2.4 Mev, leading to a reduced width, $\Gamma/2k$ of $5.6\cdot10^{-13}$ Mev cm. Taking the binding energy[6] of a neutron to Li^7 as 2.03 Mev, these levels lie 2.27 and 3.03 Mev above the ground state.

The S-wave resonance will have a large influence on the scattering at low energies. In this connection it is convenient to speak of the coherent scattering length l, the average of $-\delta/k$, over isotopes and spin orientations. Using Eq. (2) for δ and neglecting

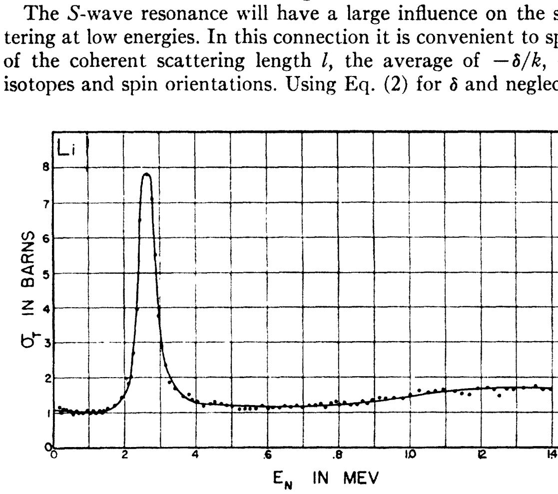

FIG. 1. Total neutron cross section of lithium as a function of neutron energy.

the contribution of Li^6, the scattering length of lithium at zero energy equals $\frac{3}{8}(a-\gamma^2/E_r)$, or $-0.7\cdot 10^{-13}$ cm which is numerically of only qualitative significance because of the uncertainty in estimating the parameters γ^2 and E_r and the approximation involved in using the single level resonance theory.

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Nuclear Dipole Vibrations*

HELMUT STEINWEDEL AND J. HANS D. JENSEN
Institut für theoretische Physik, Universität Heidelberg, Germany
AND
PETER JENSEN
Physikalisches Institut, Universität Freiburg, Germany
July 10, 1950

RESONANCES recently observed by several authors[1] in (γ, x) processes at γ-energies $\hbar\omega \cong 20$ Mev have been interpreted by Goldhaber and Teller[1] as dipole vibrations due to collective motion of all protons relative to all neutrons inside the nucleus. Goldhaber and Teller treated in detail a very simplified model assuming periodic displacement of a rigid proton sphere relative to a rigid neutron sphere. However it seemed worth while to discuss the more plausible model, mentioned only shortly by these authors, of an interpenetrating motion of the proton fluid with density $\rho_p(r, t)$, and neutron fluid with density $\rho_n(r, t)$, under the condition of constant total density $\rho_0 = \rho_p + \rho_n$, and fixed nuclear radius $R = r_0 A^{\frac{1}{3}}$. This model, besides representing a case of a peculiar hydrodynamics, does not require any arbitrary parameters.

The "symmetry-energy term" in the expression for the nuclear binding energy[2] per nucleon: $K\cdot(Z-N)^2/A^2$, with $K \cong 20$ Mev, can be interpreted as $K\cdot(\rho_p-\rho_n)^2/\rho_0^2$ because of the short range of nuclear forces. By multiplication with ρ_0 we obtain an energy density:

$$\epsilon(\rho_p-\rho_n) = \rho_0\cdot K(\rho_r-\rho_n)^2/\rho_0^2 = K\cdot(2\rho_p-\rho_0)^2/\rho_0, \qquad (1)$$

which is a function only of the local density-difference. This term is to be inserted into the Lagrangian L of hydrodynamics,

$$L = \int dV \{ M[\rho_p\dot{\phi}_p + \rho_n\dot{\phi}_n] - \tfrac{1}{2}M\rho_p(\text{grad}\phi_p)^2 + \rho_n(\text{grad}\phi_n)^2] - \epsilon(\rho_p-\rho_n)\} \qquad (2)$$

with M the nucleonic mass. From $\delta\int L dt = 0$ follows Euler's equation for the relative velocity $\mathbf{v} = (\mathbf{v}_p - \mathbf{v}_n) = -(\text{grad}\phi_p - \text{grad}\phi_n)$:

$$M d\mathbf{v}/dt = -(\partial^2\epsilon/\partial\rho_p^2)\,\text{grad}\rho_p = -(8K/\rho_0)\,\text{grad}\rho_p, \qquad (3)$$

together with the continuity equation

$$\dot{\rho}_n = -\dot{\rho}_p = \text{div}\{(\rho_p\rho_n/\rho_0)\mathbf{v}\}. \qquad (4)$$

In the customary way we have linearized the equations by omitting quadratic terms in v, $\text{grad}\rho_p$, and $\dot{\rho}_p$. The velocity of propagation of relative density disturbances turns out to be

$$u = [(ZN/A^2)8K/M]^{\frac{1}{2}} \cong c/5. \qquad (5)$$

Combined with the boundary condition $v_r \equiv 0$, implying $\partial\rho_p/\partial r \equiv 0$, at $r = R$, Eqs. (3) and (4) have been solved by Lord Rayleigh.[3] Dipole vibrations of type $\rho_p = (Z/A)\rho_0 + y(r)\cos\vartheta\cdot\exp(i\omega t)$ exist with lowest eigenfrequency

$$\hbar\omega_0 = 2.08\cdot\hbar u/R = (4ZN/A^2)^{\frac{1}{2}}\cdot 60\cdot A^{-\frac{1}{3}} \quad \text{(in Mev)}. \qquad (6)$$

For comparison with experimental data see Fig. 1.

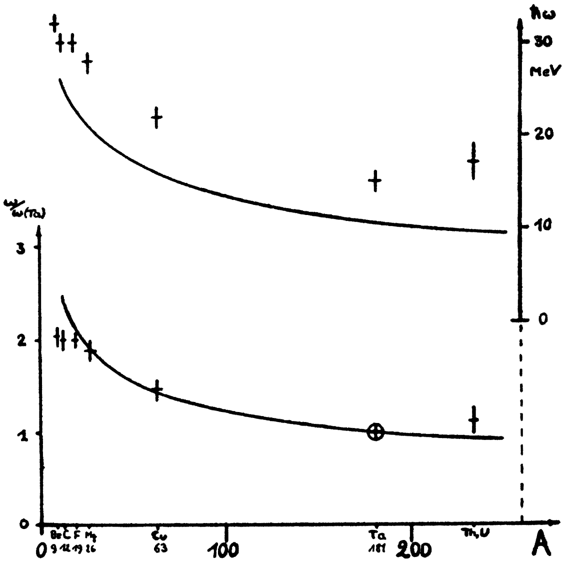

FIG. 1. Abscissa: atomic number; ordinate: resonance frequency for (γ, x). Upper curve: absolute values $\hbar\omega_0$ (in Mev); crosses experimental values. Lower curve: relative values, $\omega_0 : \omega_0(\text{Ta})$.

It is easy to include in the formalism the effects of radiative damping and of damping by dissipation of collective motion into disordered motion (heating by friction[1]) followed by nucleon emission. We introduce the radiation width Γ_r,

$$\hbar\Gamma_r/2mc^2 = (2NZm/3AM)(e^2/\hbar c)(\hbar\omega/2mc^2)^2 \qquad (7)$$

(m = electronic mass), the total width Γ which must be taken from experiments, and the phase angle φ between incident field strength and induced nuclear dipole moment, defined by $\text{tg}\varphi = \Gamma\omega/(\omega^2-\omega_0^2)$. In this motion the total cross section σ is

$$\sigma = 4\pi(e^2/2mc^2)^2(NZm/AM)(e^2/\hbar c)(2mc^2/\hbar\Gamma)\sin^2\varphi, \qquad (8)$$

and the scattering cross section is $\sigma_r = \sigma\Gamma_r/\Gamma$. For the integrated total cross section we obtain:

$$(\hbar/2mc^2)\int\sigma d\omega = 2\pi^2(e^2/2mc^2)^2\cdot(NZm/AM)(\hbar c/e^2) \qquad (9)$$

which is one-half of the corresponding value given by Goldhaber and Teller for the rigid sphere model.

* See also: J. H. D. Jensen and P. Jensen, Zeits. f. Naturforsch. **5a**, 343 (1950), and H. Steinwedel and J. H. D. Jensen, Zeits. f. Naturforsch. (to be published).

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Proton Density Variation in Nuclei

HELMUT STEINWEDEL AND MICHAEL DANOS
Institut für theoretische Physik, Universität Heidelberg, Germany
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A VERY simple estimate of the variation of proton density ρ_p inside the nucleus is afforded by the assumption that the "symmetry-energy term" in the expression for the nuclear binding energy per nucleon:

$$K\cdot(Z-N)^2/A^2, \quad \text{with} \quad K \cong 20 \text{ Mev},$$

should be understood as resulting from an energy density

$$\epsilon(\rho_p-\rho_n) = K\cdot(\rho_p-\rho_n)^2/\rho_0 = K(2\rho_p-\rho_0)^2/\rho_0, \qquad (1)$$

as proposed by Steinwedel, Jensen, and Jensen in the preceding letter. This assumption should be a good approximation at least