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NUCLEAR ISOMERISM AND ATOMIC SPECTRA

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Submitted to JETP editor March 13, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **35**, 284-286 (July, 1958)

In two earlier works[1] we predicted a shift of the atomic spectrum of In^{115} III as the result of nuclear isomerism.

This result can be generalized to include all odd nuclei, subject to the following assumptions: (1) In accordance with the shell model, the nuclear transitions are single-particle transitions. (2) In nuclei with optical protons, the shift is connected with the Coulomb interaction. In nuclei with optical neutrons the shift is due to the electron-neutron interaction. (3) In the first approximation, the effect is expressed in terms of perturbation theory in the Rosental-Breit form.[2] The "unperturbed" wave functions of the electron are calculated for uniform charge distribution over the nuclear volume.

It can be shown that the absolute value of the shift is determined only by the difference in the nucleon distributions in the nucleus. Since the nuclear excitation is connected only with the change in the state of the optical nucleon, the effect is expressed, in the final analysis, by the difference between the mean-squared radii of the optical nucleons. This is an important property of the phenomenon and determines its significance; it can yield new information on the outer shell of the nucleus and on the mechanism of nuclear excitation.

The sign of the shift depends, on one hand, on the entire nuclear configuration and, on the other, on the quantum numbers of the two corresponding nuclear states. For a given configuration, the sign, in the case of the potential of a harmonic oscillator, is determined by the sign of the difference $N - N'$, where N and N' are the principal quantum numbers of the ground and excited states respectively. An analogous result is obtained for the quantum orbital number l in the case of a well with infinite walls. Incidentally, in the latter case the shift is proportional to the difference in the orbital momenta of the corresponding nuclear states and, thus, the measurement of the shift consists in principle of measuring these momenta.

The theoretical value of the shift ΔE was calculated for two transitions, $1g_{9/2} - 2p_{1/2}$ and $2d_{3/2} - 1h_{11/2}$ (these transitions are characteristic of a large number of isomers with an optical proton). The shape of the well was found to have little effect on the result of the calculation, carried out with the aid of four potentials independent of the velocity (harmonic oscillator, rectangular well with infinite walls, and diffuse well of two types, given in references 3* and 4).

For these transitions, in nuclei with odd Z and even N, the shift ΔE was found to be greater than 10^{-2} cm^{-1} for s electrons. This can apparently be observed experimentally. The Nilsson nonspherical potential leads in our case to practically the same results as the harmonic oscillator. This is due to the degeneracy of the eigenfunctions of the harmonic oscillator, which were assumed in reference 5 as the basis vectors.

In nuclei with even Z and odd N, the isomer excitation causes a change in the neutron distribution, which in turn leads to a change in the energy of interaction between the electron and the neutron. Although here the theoretical order of magnitude of the shift is at the experimental limits of observation (in Hg^{197} II, for example, $\Delta E \approx 10^{-4}$ cm^{-1} for the transition $3p_{1/2} - 1i_{13/2}$), it would be particularly important to be able to observe this effect. Actually, we deal here in principle with a pure electron-neutron interaction (if we neglect the possible exchange effect), even in those particular conditions when the neutron is bound.† In those conditions, the effective mass of the nucleon in the nucleus is less than the mass of the free nucleon and the magnetic moment of the nucleon can also be expected to have another (greater) value in the nucleus than in the free state.[6] However, inasmuch as the magnetic moment of the neutron is due essentially to its interaction with the electron,[7] the attraction between the electron and neutron will be stronger in the case of a bound neutron (let us note that this can increase the theoretical value of the shift, which we have calculated for the free neutron).

An experimental observation of the isomer shift can lead to a new method of investigating the nuclear structure and will permit checking assumptions 1 and 2. At the present time, F. Bitter (private communication) is attempting to observe the isomer shift in Hg^{197} by means of double magnetic and optical resonance.

The author is grateful to Academicians S. Titeica, H. Jussim and D. Bogdan for many valuable remarks and to Academician E. Bedereu and Professor Ia. A. Smorodinskii for interest in this work.

*I am grateful to R. L. Lawson who was kind enough to supply me with the corresponding wave functions, calculated on the Berkeley differential analyzer (some of the functions were calculated specially for our problem).

†In the case of an isotopic shift, this effect is masked by the Coulomb interaction.

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Translated by J. G. Adashko
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SOUND ABSORPTION IN FERROMAGNETIC DIELECTRICS IN A MAGNETIC FIELD AT LOW TEMPERATURES

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Submitted to JETP editor March 29, 1958

J. Exptl. Theoret. Phys. (U.S.S.R.) **35**, 286-287 (July, 1958)

IT was shown by Akhiezer and the author[1] that the sound absorption in ferromagnetic dielectrics, which is associated with the internal friction in a system of elementary excitations, phonons and spin waves, is, at low temperatures, principally determined by the spin waves and does not depend on the temperature. An external magnetic field changes the relaxation time in such a system and leads to a change in the temperature dependence of the sound-absorption coefficient.

The relaxation times of spin waves and phonons are determined from the expressions

$$1/\tau_k = 1/\tau_k^{(1)} + 1/\tau_k^{(2)}, \quad 1/\tau_f = 1/\tau_f^{(1)} + 1/\tau_f^{(2)},$$

where $\tau_k^{(1)}$ is the relaxation time of the spin waves and is connected with the interaction of the spin waves with spin waves; $\tau_k^{(2)}$ is the relaxation time of the spin waves connected with phonon interaction; $\tau_f^{(1)}$ is the relaxation time of the phonons relative to phonon interaction, while $\tau_f^{(2)}$ is the relaxation time of the phonons relative to the spin-wave interaction.

As was shown by Akhiezer,[2] the following elementary processes are of the greatest importance: the conversion of two spin waves into a single spin wave, the conversion of two phonons into a single phonon, and the scattering of spin waves by phonons.

In the presence of an external magnetic field, the energy of the spin wave depends on the field and has the value $\epsilon_0 + 2\beta H$, where ϵ_0 is the energy of the spin wave in the absence of a magnetic field, H is the intensity of the magnetic field, β is the Bohr magneton. This dependence leads to a dependence of the relaxation times of phonons and spin waves on the magnetic field. Carrying out the calculation gone through in detail in reference 2, we can determine the relaxation time in the presence of the field. In such a case, it is shown that the relaxation time has a different form relative to the spin-spin interaction for the cases of large and small value of $2\beta H/\kappa T$ (κ is Boltzmann's constant, $2\beta/\kappa \sim 10^{-4}$):

$$\tau_k^{(1)} \approx \frac{\Theta_c \hbar}{w^2}\left(\frac{\Theta_c}{T}\right)^{1/2} \ln^2 \frac{w + 2\beta H}{T}, \quad \frac{H}{T} \ll 10^4, \quad T \ll \frac{\Theta^2}{\Theta_c},$$

$$\tau_k^{(2)} \approx \frac{\Theta_c \hbar}{w^2}\left(\frac{\Theta_c}{T}\right)^{1/2} \exp\left\{\frac{2\beta H}{T}\right\}, \quad \frac{H}{T} \gg 10^4, \quad T \ll \frac{\Theta^2}{\Theta_c}.$$