where B_α is the principal value of the tensor

$$B_{\alpha\beta} = \frac{8e^2}{3(2\pi\hbar)^3} \int_0^{2\pi} \frac{n_\alpha(\varphi)\, n_\beta(\varphi)\, d\varphi}{K(\varphi, \pi/2)}, \qquad (8)$$

and the axes X and Y are chosen along its principal axes.

The integral equation (7) is independent of the form of the collision integral and, in particular, coincides with the equation that was obtained when we introduced the relaxation time τ. Therefore we may use immediately the results of the previous work[1] and write down the surface impedance Z_α in the limiting cases of diffuse ($q = 0$) and specular ($q = 1$) reflections of electrons from the surface of the metal:

$$Z_\alpha = R_\alpha + iX_\alpha = -\frac{4\pi i\omega}{c^2}\frac{E_\alpha(0)}{E'_\alpha(0)} \qquad (9)$$

$$= \begin{cases} \left(\sqrt{3}\,\dfrac{\pi\omega^2}{c^4 B_\alpha}\right)^{1/3}(1 + i\sqrt{3}); & q = 0. \\ \dfrac{8}{9}\left(\sqrt{3}\,\dfrac{\pi\omega^2}{c^4 B_\alpha}\right)^{1/3}(1 + i\sqrt{3}); & q = 1. \end{cases}$$

$$X_\alpha / R_\alpha = \sqrt{3}. \qquad (10)$$

Examination of the integral equation (7) shows that formulas (9) and (10) for the surface impedance are valid with accuracy to within a small numerical factor of the order of unity, for arbitrary linear relation between $\psi(0; n_x, n_y, n_z)$ and $\Psi(0; n_x, n_y, -n_z)$ on the boundary metal - vacuum.

Thus, in the region of the anomalous skin-effect dependence of the surface impedance upon frequency ($Z_\alpha \sim \omega^{2/3}$), its independence of temperature, and relation (10) are all valid not only for arbitrary law of dispersion of electrons $\epsilon = \epsilon(p)$, but also for arbitrary collision integral and any relation $\psi(0; n_x, n_y, n_z[= Q\psi(0; n_x, n_y, -n_z)$ at the boundary metal-vacuum.

In conclusion the authors wish to avail themselves of this opportunity to thank I. M. Lifshitz for the discussion of their results.

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* Anomalous skin effect occurs at high frequencies and low temperatures, when the mean free path of electrons is large compared with the depth of penetration of the field into metal.

**Here use is made of the spherical symmetry of Fermi surface.

\+ All operators operate on functions in momentum space.

++In so doing we consider that the collision operator has a center of symmetry.

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The Internal Compton Effect

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THIS letter deals with some conclusions which can be drawn from the theoretical analysis of the internal Compton effect.

In the internal Compton effect, a nucleus jumps from an excited to the ground state, with the result that the atom is ionized and a gamma ray radiated. The emission of an electron and a gamma ray when the nucleus de-excites itself is due to the interaction of the electron with the nucleus and the electromagnetic field: i.e., it is a third order effect. This is presumably why the effect has not been observed till recently. It was in 1953 that Brown and Stump[1] saw a continuous spectrum accompanying internal conversion.

The internal Compton effect was analyzed in reference 1 by use of nonrelativistic perturbation theory, i.e., with the restriction that the energy difference between the excited and ground states was much less than the electron rest energy. In the perturbation theory approach, the internal Compton effect is of third order and considered to take place in the following steps: a virtual gamma ray emitted by the nucleus is scattered from the atomic electrons and as a result a real gamma ray is radiated and an electron ionized.

The initial state (1) of the system consists of an excited nucleus, an electron in its ground state and no quanta. In the final state (2) the nucleus is in its ground state, the electron is in an excited (ionized) state and a gamma ray has been emitted. The perturbation was taken to be the nonrelativistic interaction between a charged particle and the electromagnetic field. Nonrelativistic hydrogen-like wave functions were used for the electrons. The electromagnetic field was quantized with spherical waves. Since the matrix elements of the gamma ray annihilations and creation operators are nonzero only for one quantum transition, the transition of the system from its initial to its final state can take place only through two intermediate states. For example, the nucleus emits a quantum $\hbar c' k'$ and drops to a lower state, which corresponds to the first intermediate state of the system; then the electron absorbs the emitted quantum, and so takes the system into its second intermediate state. After this the electron jumps into its final state, emitting a quantum $\hbar ck$. Thus the matrix element for the transition 1-2 takes the form

$$V_{12} = \sum \frac{V_{1\mathrm{I}} V_{\mathrm{I}\,\mathrm{II}} V_{\mathrm{II}\,2}}{(E_1 - E_{\mathrm{I}})(E_1 - E_{\mathrm{II}})},$$

where the indices I and II label the intermediate states of the system. The sum is over the nine possible pairs of intermediate states.

The calculations of reference 1 show that the probability of the internal Compton effect is very small, differing from zero only because of the nuclear multipole field. The effect is described by a differential coefficient, which is defined as the ratio of the probability that the process considered takes place to the probability of gamma ray emission when the nucleus makes the same transition. General expressions for these ratios are obtained, relating the various possible types of internal Compton effect to the different possible (electric and magnetic multipole) transitions and the parity of the emitted gamma ray. As is to be expected, these coefficients can be calculated without knowing nuclear ψ-functions and are theoretically obtained independently of any model for nuclear structure.

The final computations of the differential coefficient for the internal Compton effect with the K electrons were made using the Born approximation for the final electron state; only the long wavelength part of the continuous gamma ray spectrum was considered.

It was shown that in the nonrelativistic case, only the internal Compton effect associated with the emission of a dipole gamma ray is of practical importance. The following analytic expressions for the differential coefficient of the internal Compton effect with K electrons were obtained:

$$d\beta_K^{\mathrm{L}} = \frac{8}{3\pi}\left(\frac{l}{l+1}\right)\alpha^2\,[Z\alpha]^3\left[\frac{2mc^2}{\Delta E}\right]^{l+3/2}\frac{dE_K}{E_K},$$
$$d\beta_K^{\mathrm{M}} = \frac{8}{3\pi}\alpha^2\,[Z\alpha]^3\left[\frac{2mc^2}{\Delta E}\right]^{l+1/2}\frac{dE_K}{E_K},$$

where $d\beta_K^{Э}$ and $d\beta_K^{\mathrm{M}}$ are the differential coefficients of the Compton effect connected with electric and magnetic multipole nuclear transitions, respectively; ΔE is the difference in energy between the excited and ground states of the nucleus; E_K is the energy of the emitted gamma ray; mc^2 is the rest energy of the electron; $\alpha = e^2/\hbar c$ the fine structure constant; Z the nuclear charge and l the angular momentum quantum number which characterizes the multipolarity of the nuclear transition.

We can use this interesting result to compare the differential coefficient of the internal Compton effect with the coefficient of internal conversion. The ratios of the differential coefficient of the internal Compton effect to the corresponding coefficient α_K for internal conversion, connected with the same type of nuclear transition, are all equal and do not depend on the multipole order or on the nuclear charge:

$$\frac{d\beta_K^{Э}}{\alpha_K^{Э}} = \frac{d\beta_K^{M}}{\alpha_K^{M}} = \frac{4\alpha}{3\pi}\left[\frac{\Delta E}{mc^2}\right]\frac{dE_K}{E}$$

This suggests that there is a simple connection between the internal Compton effect and the internal conversion process. Indeed, this connection follows from the semi-classical theory of Wang Chang and Falkoff[3], which describes the continuous gamma spectrum associated with beta decay, if we assume that the probability of the internal Compton effect is equal to the product of the probability of internal conversion and the probability that the conversion electron emits a gamma ray as it is knocked out of the atom. The full agreement between the quantum mechanical calculation and the semi-classical theory shows that for small gamma ray energies the internal Compton effect can be considered as two successive, independent processes: internal conversion and subsequent emission of a gamma ray by the emitted electron. This picture of the internal Compton effect also explains why the experimental results of Brown and Stump agree so well with the predictions of a semi-classical theory.

After the present work was finished, a paper[4] appeared on the internal Compton effect associated with a magnetic multipole transition. In this paper the differential coefficient for the particular nuclear transition considered was calculated using Born approximation but without the restriction to nonrelativistic energies. In the overlap region between this paper and the present work, the two results are identical.

[1] A. M. Iakobson, Dissertation, Moscow State Teachers' Institute, 1954

[2] H. B. Brown and R. Stump, Phys. Rev. **90**, 1061 (1953)

[3] Wang Chang and Falkoff, Phys. Rev. **76**, 365 (1949)

[4] Larry Spruch and G. Goertzel, Phys. Rev. **94**, 1671 (1954)

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Radiative Capture of Thermal Neutrons without Formation of a Compound Nucleus

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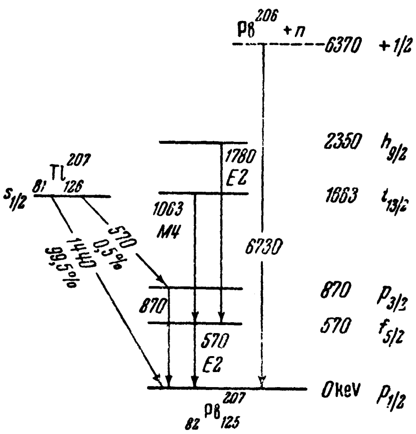
A LARGE amount of experimental data has recently been accumulated in which it is shown that nuclear reactions may take place at low energies of incident particles (1-10 mev) without the formation of a compound nucleus. For example, in reactions of the (d, p), (d, n) and (p, γ) types, the captured particle has little effect on the structure of the nucleus. The state of the resultant nucleus is most frequently affected by the captured particle, which may be located at successive excited levels.[1-8]. This explains the fact that in the reactions (d, p) and (d, n) the probability of exciting successive single-particle levels is considerably greater than for levels of other types.[1-3] In the present note we wish to draw attention to the fact that such a reaction as the radiative capture of thermal neutrons may also apparently take place without the formation of a compound nucleus.

Let us consider the reaction $Pb^{206}(n, \gamma)Pb^{207}$. The lower excited levels of Pb^{207} are well known from various sources [α-decay of Po^{211}, K-capture in Bi^{207}, β^--decay of Tl^{207} and (d, p) and (d, t) nuclear reactions].[9-11] The scheme of these levels and their quantum characteristics are shown in the figure. The ground state of Pb^{207}, in accordance with the experimental value of the spin, must be written as $p_{1/2}$. The 870 kev level is excited in α-decay of Po^{211} and in β^--decay of Tl^{207}. Since Tl^{207} has an $s_{1/2}$ ground level (all odd isotopes of $_{81}Tl$ have spin ½) the 870 kev level must have spin ½ or 3/2. If the spin were 5/2, β-decay to this level would be strongly forbidden ($\Delta I = 2$) and could not be observed. However, this β-transition cannot be an allowed type since the observed intensity of the 870 kev γ-line is small. It is most probably a transition of the first order of forbiddenness. In this case the parity of the 870 kev level is opposed to the parity of the ground state of $_{81}Tl^{207}$ and consequently, agrees with the parity of the ground state of $_{82}Pb^{207}$.



Scheme of the levels of $_{82}Pb^{207}_{125}$. The dashed line represents the state of Pb^{207} resulting from capture of a thermal neutron; the solid lines are established levels of Pb^{207}. $E1$ transitions to the $p_{3/2}$ level which are allowed by the selection rules $(+\frac{1}{2} \to p_{3/2})$ are not observed.

The absence of a γ-transition from the isomeric level $i_{13/2}$ to the 870 kev level also indicates that the spin of the 970 kev level must be less than 5/2. The shell model[12,13], in agreement with the data mentioned, describes this as a $p_{3/2}$ level. It must be a hole-level since it is completely filled in the ground state of $_{82}Pb^{207}$.

Pb^{207} is obtained from the capture of thermal