In Connection with the Paper of Arifov, Aiukhanov and Starodubtsev[1]

M. A. EREMEEV

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IN the paper of Arifov, Aiukhanov and Starodubtsev[1], on the question of the decrease of the number of atoms adsorbed on a surface due to a rise in temperature, the following statement occurs: "As an example of such incorrect interpretations of the role of temperature we will cite one of the recent works of Eremeev[2], in which it is affirmed that the coefficient of secondary emission of electrons, due to ionic bombardment, diminishes with an increase in the temperature of the target". However, any reader can discover entirely different statements in my paper, namely, that at target temperatures which are not too high, the target becomes covered with ions adsorbed from the primary beam, so that, as the temperature of the target increases, the number of liberated electrons decreases at the same time that the number of particles adsorbed by the target also decreases. For some reason the authors of the paper in reference 1 remain silent on this point, even though they use these results immediately in their work.

During the last three years much has become known about the process of interactions of ions with surfaces and much has become precise as a result of the applications of the more recent methods of investigation, but the adsorption of ions from the primary beam and the dependence of electron emission (from the adsorbing layer) upon the target have not encountered further objection. It was possible to assume beforehand, that for hard targets this emission does not vanish completely with the increasing depth of the adsorbing layer, which in fact has been confirmed experimentally.

Translated by D. G. Posin
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The Degree of Orientation of Nuclei

G. R. KHUTSISHVILI
Academy of Sciences, Georgian SSR

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1. THE preparation of targets with oriented nuclei is of considerable interest to nuclear physics. Through experiments with oriented nuclei it is possible to obtain valuable information regarding spin dependence of nuclear forces, spins and magnetic moments of radioactive nuclei, etc. (see reference 1).

We shall limit ourselves to the examination of the most important case in which the quantization of the nuclear spin is axially symmetric. In this case the degree of orientation of the nuclear spins is usually described quantitatively by the values f_k, expressed as follows[2]:

$$f_k = \frac{(2I-k)!}{(2I)!}\sum_m a_m \times\left[\sum_{\nu=0}^{k}(-1)^\nu \frac{(I-m)!\,(I+m)!}{(I-m-\nu)!(I+m-k+\nu)!}\binom{k}{\nu}^2\right]. \quad (1)$$

where m = projection of the nuclear spin on the axis of quantization, I = maximum projection, a_m = relative population of states having spin projection equal to m, k takes on values 1, 2, . . . $2I$. The quantities f_k are normalized in such a way as to make the maxima of their absolute values equal to one. In particular, we have (the bar denoting the average over all the nuclei of a given type in the sample),

$$f_1 = \bar{m}\,/\,I, \quad (2)$$

$$f_2 = \frac{3}{I(2I-1)}\left[\overline{m^2} - \frac{1}{3}I(I+1)\right], \quad (3)$$

$$f_3 = \frac{5}{I(I-1)(2I-1)}\left[\overline{m^3} - \frac{1}{5}(3I^2+3I-1)\,\bar{m}\right], \quad (4)$$

$$f_4 = \frac{35}{2I(I-1)(2I-1)(2I-3)} \times\left[\overline{m^4} - \frac{1}{7}(6I^2+6I-5)\,\overline{m^2} + \frac{3}{35}I(I-1)(I+1)(I+2)\right]. \quad (5)$$

In the works of references 3, 4, f_1 and f_2 have been computed for different methods of production of oriented nuclei. However, in the above researches, a case is considered for which the differences in the energies of states corresponding to various m are much smaller than kT, i.e., a case

for which the degree of orientation of nuclei is small. Now it is important to have expressions for f_k for the case of a great degree of orientation. In reference 5 expressions for a_m are given; these expressions hold also in the case where the degree of orientation is great. Yet the final formulas rendering various oriented nuclei effects (angular distribution of radioactive radiation of oriented nuclei, e.g.) contain quantities f_k, and not a_m.

In the present article we shall give expressions for f_1, f_2, f_3 and f_4 for three methods of preparation of oriented nuclei.

2. In the first instance we shall obtain quantities f_k for polarization of nuclei by external fields. Energy levels of the nuclear spin in an external field H are given by

$$E_m = -m(\mu/I)H, \tag{6}$$

where μ = magnetic moment of the nucleus. A simple calculation yields

$$f_1 = B_I(\alpha I), \tag{7}$$

$$f_2 = \frac{2(I+1)}{2I-1} - \frac{3}{2I-1}\operatorname{cth}\frac{\alpha}{2}B_I(\alpha I), \tag{8}$$

$$f_3 = \frac{5}{(I-1)(2I-1)}\left\{\left[\frac{3}{2}\operatorname{cth}^2\frac{\alpha}{2}+\frac{1}{5}\right.\right. \times\left(2I^2+2I-\frac{3}{2}\right)\Big]B_I(\alpha I) - \left.\left.(I+1)\operatorname{cth}\frac{\alpha}{2}\right\}\right. \tag{9}$$

$$f_4 = \frac{4(I+1)(I+2)}{(2I-1)(2I-3)} - \frac{5\operatorname{cth}(\alpha/2)}{2(I-1)(2I-1)(2I-3)} \times\left\{\left[21\operatorname{cth}^2\frac{\alpha}{2}+8I^2+8I-9\right]\right. \times B_I(\alpha I) - \left.14(I+1)\operatorname{cth}\frac{\alpha}{2}\right\} \tag{10}$$

In the above

$$\alpha = \mu H/IkT, \tag{11}$$

and B_I is the so-called Brillouin function:

$$B_I(y) = \frac{I+1/2}{I}\operatorname{cth}\left(\frac{I+1/2}{I}y\right) - \frac{1}{2I}\operatorname{cth}\left(\frac{y}{2I}\right). \tag{12}$$

3. Some years ago two methods for obtaining oriented nuclei in paramagnetic salts were proposed[1,6]. Those methods were based on the interaction of the nuclear spin with the spin of the electronic shell of the paramagnetic ion. The Hamiltonian describing a paramagnetic ion (nucleus possessing a spin) in an external magnetic field, can be written

$$V = \beta[g_\parallel H_z S_z + g_\perp(H_x S_x + H_y S_y)] + D \times\left[S_z^2 - \frac{1}{3}S(S+1)\right] + [AS_z I_z + B(S_x I_x + S_y I_y)], \tag{13}$$

where I = nuclear spin, S = effective spin of the electron shell, β = magneton, A, B, and D are constants, obtainable from experimental data on the superfine structure of the paramagnetic resonance. Equation (13) is valid if the electric fields of the paramagnetic ion inside the crystal are axially symmetric, (usually the symmetry is rhombohedral or tetragonal, but close enough to axial); z is the symmetry axis of the internal crystal field. This axis is the direction of quantization for the spin of the nucleus and the spin of the electron shell of our paramagnetic ion. In the formula (13), $g_\parallel$ and $g_\perp$ are the g-factors of the electron shell of the paramagnetic ion, along and perpendicular to the z-axis, respectively.

In the case of paramagnetic salts of cobalt, copper and manganese, and also for some rare earths, the constants A and B are of the order 10^{-2} cm^{-1}. Now in most cases the effective spin of the electronic shell S is equal to one half, so that the D term of (13) vanishes. We shall limit ourselves to this case. Moreover, we shall deal with a monocrystal and assume that the z-direction is the same for all ions under consideration. In the case of Tutton's salts there are two non-equivalent groups of paramagnetic ions. Therefore, in this case, the quantities f_k, obtained below, must be averaged over these two groups.

4. If A is not equal to B, the nuclei will be oriented at very low temperatures, even in the absence of a magnetic field[6]. In this case the quantities f_k with odd k's vanish, (case of the so-called "lined-up" nuclei). In particular, for most paramagnetic salts of cobalt and copper, A is much greater than B. Let us first consider the case where $B = 0$, $S = \frac{1}{2}$, $H = 0$. Equation (13) gives $V = AS_z I_z$ and we get $2I + 1$ doubly degenerate levels:

$$E_m = \pm\tfrac{1}{2}Am.$$

A straightforward calculation shows that the quantities f_k with even indices are the same as in

the case of polarization by external fields, i.e., Equations (8) and (10) hold again, where, however,

$$\alpha = A / 2kT. \tag{14}$$

5. Again let $S = \frac{1}{2}$, $H = 0$. It has been shown in reference 6 that with a Hamiltonian

$$V = AS_z I_z + B(S_x I_x + S_y I_y) \tag{15}$$

mixing of states with different m takes place. In particular the state m, $M = \frac{1}{2}$ mixes with the state $m + 1$, $M = -\frac{1}{2}$ (M is the projection of the electronic shell spin on the z-axis). In the same reference the following corresponding energy levels were obtained

$$E_m = -\tfrac{1}{4}A \pm \tfrac{1}{2}\sqrt{A^2K^2 + B^2[(I+\tfrac{1}{2})^2 - K^2]} \tag{16}$$

where $K = M + m$.

Let B be much smaller than A and kT. We shall find f_2 up to terms quadratic in B, i.e., we shall keep terms of the order $(B/A)^2$, $(B/kT)^2$ and (B^2/AkT). We shall neglect terms of higher order. Calculation for $I = 3/2$ gives

$$f_2 = \operatorname{th}\frac{A}{2kT}\operatorname{th}\frac{A}{4kT} - \frac{3}{8\left(\operatorname{ch}\frac{3A}{4kT} + \operatorname{ch}\frac{A}{4kT}\right)^2} \times \left(\frac{B}{A}\right)^2 \phi\left(\frac{A}{kT}\right), \tag{17}$$

where

$$\phi(x) = (1 - x + 2/3\,x^2)e^{x} - (1 + x)e^{-x} - 2xe^{\frac{1}{2}x} - (1 - 2/3\,x^2)e^{-\frac{1}{2}x} + e^{3/2\,x} \tag{18}$$

6. To produce polarized nuclei an external field of a few hundred oersteds must be imposed on the refrigerated salt[1,6]. At very low temperatures this induces a considerable polarization shell spins of paramagnetic ions, which in turn produces a considerable polarization of nuclei.

We shall examine quantitatively the following simple case: A monocrystal of paramagnetic salt, $S = \frac{1}{2}$, $A \gg B$ [we neglect the B term in Eq. (13)], with the external field in the z-direction. Here the energy levels are given by

$$E_m = \pm\tfrac{1}{2}(Am + \beta g_{\parallel} H). \tag{19}$$

A simple calculation shows that the quantities f_k, with k even, are the same as in the case of polarization by external fields [α given by Eq. (14)]. The odd-index f_k are obtained by multiplying Eqs. (7) and (9) by tank $\frac{g_{\parallel}\beta H}{2kT}$ [α given by Eq. (14)].

Translated by O. Bilaniuk
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The Spontaneous Fission of Thorium

A. V. Podgurskaia, V. I. Kalashnikova, G. A. Stoliarov, E. D. Vorob'ev and G. N. Flerov

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In recent years there have been several references in the literature[1-5] to the spontaneous fission of thorium. According to the data of Segrè[5], the half life of the spontaneous process is 1.4×10^{18} years. We should like to point out that the probability of spontaneous fission indicated by these investigations is considerably too high.

In references 1,3, the spontaneous fission of thorium was observed by detecting the accompanying neutrons, the number of neutrons per spontaneous fission being presumably the same as the number per induced fission (i.e., 2-3). This method is suitable for the observation of spontaneous fission in uranium, but may be susceptible to error in the case of thorium, where the ex-