Erratum: Internal Pair Formation

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IN transcribing to the manuscript an error occurred in the coefficient of J_{l-1} in Eq. (10a). This coefficient should be

$$l[\tfrac{3}{2}(W_+^2+W_-^2)+1]+1+W_+W_-.$$

All numerical results were obtained from the correct formula.

The H.F.S. Anomaly of the Potassium Isotopes*

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THE h.f.s. spectrum of atoms in a state for which $J=1/2$, and which results from the transitions $\Delta m_I=\pm 1$, $\Delta m_J=0$, contains doublets whose frequency separation is $2g_I\mu_0H/h$. One component of the doublet arises in the state $m_J=1/2$ and the other in the state $m_J=-1/2$. If the doublet separation is observed at some fixed field for each of two isotopes, the ratio of the nuclear g-values of the two isotopes can be found. At sufficiently high fields the mean frequency of the doublet is very nearly $\Delta\nu/(2I+1)$ and if the nuclear g-value is approximately known, it is possible to find $\Delta\nu$ very accurately from the mean frequency of the doublet.

We have observed the h.f.s. spectrum of both K^{39} and K^{41} at a magnetic field of about 12,000 gauss. At this field $g_J\mu_0H/h \cong 73(\Delta\nu^{39})\cong 130(\Delta\nu^{41})$. The doublet separations are then about $2g_I^{39}\mu_0H/h=4.8\times 10^6$ sec.$^{-1}$ and $2g_I^{41}\mu_0H/h=2.6\times 10^6$ sec.$^{-1}$, and the mean frequencies of the doublets are about 115×10^6 sec.$^{-1}$ and 63×10^6 sec.$^{-1}$ for K^{39} and K^{41} respectively. The line-widths are about 2×10^3 sec.$^{-1}$ and measurements of the center of the lines can be made to about 100 sec.$^{-1}$.

From measurements of the frequencies of the components of each of two doublets for each isotope and by use of the result of Millman and Kusch for $g_I(K^{39})/g_J(^2S_{1/2})$, we find

$$(g_I^{39}/g_I^{41})=1.8218\pm 0.0002$$

and

$$(\Delta\nu^{39}/\Delta\nu^{41})=1.81768\pm 0.00001.$$

The h.f.s. ratio is in agreement with the value observed by Kusch, Millman, and Rabi,[2] 1.8178 ± 0.0002. As K^{39} and K^{41} have the same angular momentum, $(\Delta\nu^{39}/\Delta\nu^{41})$ calc. $=(g^{39}/g^{41})$ obs., and

$$\Delta\equiv\frac{(\Delta\nu^{39}/\Delta\nu^{41})_{\text{obs}}-(\Delta\nu^{39}/\Delta\nu^{41})_{\text{calc}}}{(\Delta\nu^{39}/\Delta\nu^{41})_{\text{calc}}}=-(0.226\pm 0.010)\text{ percent.}$$

If the nucleus is assumed to be a point dipole which interacts with the magnetic field produced by the electrons, then Δ should be equal to zero. However, if a nucleus of finite extent is considered, the interaction of the electron with the nucleus over that portion of the electron orbit which lies within the nucleus will depend upon the distribution of magnetic moment within the nucleus and an observable value of Δ may appear for two isotopes, since the distribution of moment may be different for the two nuclei. Bohr and Weisskopf[3] have calculated this effect for simple nuclear models. The nuclear magnetic moment may be considered as composed of two intrinsically different parts, a spin and an orbital moment. The h.f.s. anomaly can then, to the first approximation, be determined by g_S and g_L, the g-factors corresponding to these two moments, and by g_I, the g-factor of the total nuclear moment. The fractional change in the total h.f.s. separation, resulting from the finite nuclear volume, is then

$$\epsilon=(K_S)_{\text{Av}}\frac{g_S}{g_I}\frac{g_L-g_I}{g_S-g_L}+(K_L)_{\text{Av}}\frac{g_L}{g_I}\frac{g_I-g_S}{g_S-g_L},$$

where the contributions of the spin and orbital moments to the total interaction energy are decreased from the values corresponding to a point dipole, by the fractional amounts K_S and K_L, respectively. If two isotopes differ by an even number of neutrons, it seems reasonable to assume them to have the same g_S and g_L. Then, if $(K_S)_{\text{Av}}$ and $(K_L)_{\text{Av}}$ do not differ appreciably, the influence of the finite nuclear size on the h.f.s. ratio, becomes

$$\Delta\cong 0.3b\frac{g_Sg_L}{g_S-g_L}\left(\frac{1}{g_I(1)}-\frac{1}{g_I(2)}\right),$$

where b, which depends on the atomic number, the nuclear radius, and the atomic state, has been tabulated by Bohr and Weisskopf.[3]

The case of K^{39} and K^{41} is of particular interest, since these two isotopes have the same total nuclear angular momentum. Their g_I values, however, are quite different ($g_I^{39}=-0.260$, $g_I^{41}=-0.143$), so that Δ is appreciable.

The above relationship for Δ predicts that the ratio $(\Delta\nu^{39}/\Delta\nu^{41})$ is smaller than the ratio (g_I^{39}/g_I^{41}) by approximately 0.18 $[g_Sg_L/(g_S-g_L)]$ percent. If for the spin g-factor that of the odd proton ($g_S=-5.6$) is used, there are two reasonable choices left for g_L. According to the model proposed by Schmidt,[4] the orbital momentum is that of the odd particle in the nucleus. Then $g_L=-1$ for Z odd and Δ is about -0.22 percent. Margenau and Wigner,[5] however, assume the orbital momentum to be due to the nuclear matter as a whole, and g_L becomes then equal to $-Z/A$ and Δ equal to about -0.097 percent. The experimental result of $\Delta=-0.23$ percent thus tends to support the single particle model of the nucleus. A similar phenomenon has been observed[6,7] for the Rb isotopes where the effect could also be best described by choosing $g_L=-1$.

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2 Kusch, Millman, and Rabi, Phys. Rev. 57, 765 (1940).
3 A. Bohr and V. F. Weisskopf, Phys. Rev. 77, 94 (1950).
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5 H. Margenau and E. Wigner, Phys. Rev. 58, 103 (1940).
6 S. Millman and P. Kusch, Phys. Rev. 58, 438 (1940).
7 F. Bitter, Phys. Rev. 75, 1326 (1949).

Non-Local Fields

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IN a paper entitled "Quantum Theory of Non-Local Fields,"[1] Yukawa remarks that such a field "may well happen to be approximately equivalent to some mixture of local fields." Now the solutions of his equations are superpositions of plane waves, which are identical with those describing particles of arbitrary spin. Yukawa's Eqs. (3) and (14) correspond to those which I used in my paper[2] of 1939; namely, my Eqs. (1.1) and (1.3)

$$\Box A_{ik\cdots l}=\kappa^2A_{ik\cdots l};\quad (\partial/\partial X_i)A_{ik\cdots l}=0.$$

One sees the correspondence immediately by comparing the properties of plane waves in their rest-systems in both theories. The coefficients $C(0,0,0,-\kappa;l,m)$ in Yukawa's Eq. (20) correspond to the amplitudes $A^0{}_{ik\cdots l}$,[3] describing a particle of spin l atrest (l is the number of indices of A^0).

From the equivalence of the solutions we may conclude that the theories are equivalent. It seems that we have the right to interpret the r_μ-space as spin-space, and the X_μ-space as a local space of the particle. In fact, as r_μ is bound to the equation $r_\mu r^\mu=\lambda^2$, and by this is an angular variable only, it seems rather questionable whether it describes a finite extension of the particle.

As all that can be said at the moment refers to the force-free case, it may be that one can introduce interactions in such a way that the equivalence of the two theories will be lost.

1 H. Yukawa, Phys. Rev. 77, 219 (1950).
2 M. Fierz, Helv. Phys. Acta 12, 3 (1939).
3 See reference 2, p. 6.