It should be pointed out that exactly the same fractional correction to the magnetic interaction of the nuclear moment occurs in the FM_F (weak field) representation. Thus the Breit-Rabi formula for the energy levels in a $J=\frac{1}{2}$ state will still be obeyed formally in spite of the above second-order effects; however, the apparent nuclear moments must be corrected as indicated.

Mr. Robert Frosch obtained the off-diagonal hyperfine matrix elements employed in this calculation.

[1] P. Kusch, Phys. Rev. **78**, 615 (1950).

[2] G. Becker and P. Kusch, Phys. Rev. **73**, 584 (1948).

[3] R. V. Pound, Phys. Rev. **73**, 1112 (1948).

[4] Recent experiments by W. Knight and T. Wentinik with several gallium compounds confirm the result of Pound. Their results were communicated to the writer by Dr. Knight.

[5] Private communication to P. Kusch.

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The Disintegration of Hf^{181}

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THE radiations from Hf^{181} have been studied in this laboratory using the methods of coincidence spectrometry, in an attempt to determine the decay scheme of this isotope. A Hf^{181} source was taken from a standard unit (No. 31, Oak Ridge Catalog No. 3) of Hf_2O_3 bombarded for approximately $2\frac{1}{2}$ months in the Oak Ridge pile. A spectrographic analysis of the material before bombardment indicated the only impurity in appreciable quantity to be 0.15 percent Zr. The measurements reported here were performed in a period between 4 and 7 months after removal of the Hf from the pile. The source was mounted on 2.5 mg/cm² mica and inserted into the beta-ray spectrometer,[1] which had been modified to use ring focusing.[2] A secondary counter was then placed directly behind the source; and coincidences were recorded between pulses in the spectrometer counter and the secondary counter. For $e-\gamma$-coincidence measurements, a platinum screen cathode Geiger counter with a copper wall was used as the secondary counter. A curve indicating gamma-counter efficiency as a function of quantum energy was obtained by determining points at 0.090 Mev, 0.238 Mev, and 1.25 Mev. The two low energy points were obtained by the coincidence method using the known decay scheme of ThB, and the high energy point was obtained by the coincidence method using the known decay scheme of Co^{60}. For $e-e$ coincidence measurements, a commercial end-window Geiger counter was used as the secondary counter.

When the gamma-counter was used as the secondary counter, coincidences were observed between the internal conversion electrons from the 130-kev transition[3, 4] in Ta^{181}, selected by the spectrometer, and gamma-quanta actuating the secondary counter. Absorption of the gamma-quanta in lead indicated these coincidences to be caused by the 471-kev gamma-ray and in addition possibly to the 337-kev gamma-ray. No coincidences were observed between the 130-kev transition and any gamma-quanta when a 6-μsec. delay was introduced into either counter channel.

When the beta-counter was used as the secondary counter, coincidences were observed when the spectrometer was adjusted to select internal conversion electrons due to the 130-kev transition or to select electrons from the beta-spectrum alone. With the spectrometer adjusted to select internal conversion electrons due to the 130-kev transition, delayed coincidences were observed with a delay introduced into the secondary counter channel but not with a delay introduced into the spectrometer counter channel. With the spectrometer adjusted to select electrons from the beta-spectrum alone, the coincidence rate was increased when the resolving time was increased or when a delay was introduced into the spectrometer counter channel.

All of these results indicate that the beta-decay of Hf^{181} leads to the 20-μsec. metastable state which then decays via the 130-kev and 471-kev transitions in cascade. The work of Jensen[5] indicates that the 130-kev transition originates in the metastable state; and it is thus concluded that this transition precedes the 471-kev transition.

The measurements reported here do not serve to determine the positions in the decay scheme of the 337-kev or the 134-kev transitions. It has been suggested recently by Deutsch and Hedgran[6] that the 337-kev transition is due to an impurity rather than to Hf^{181} decay. The measurements reported here are consistent for the most part with either some such possibility, or with the complete decay scheme of Chu and Wiedenbeck.[3]

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* Contribution No. 120 from the Institute for Atomic Research and Department of Physics, Iowa State College, Ames, Iowa. Work was performed in the Ames Laboratory of the AEC.

[1] Jensen, Laslett, and Pratt, Phys. Rev. **75**, 458 (1949).

[2] Pratt, Boley, and Nichols (to be published in Rev. Sci. Inst.).

[3] K. Y. Chu and M. L. Wiedenbeck, Phys. Rev. **75**, 226 (1949).

[4] Since the spectrometer was operated at a low resolution of 4.9 percent in order to achieve as large a transmission as possible, the internal conversion electrons due to the 130-kev and 134-kev transitions were not resolved. However, both Chu and Wiedenbeck (see reference 3) and Jensen (see reference 5) have found the 134-kev transition to be considerably weaker than the 130-kev transition; and thus the effect of the former may presumably be neglected.

[5] E. N. Jensen, Phys. Rev. **76**, 958 (1949).

[6] M. Deutsch and A. Hedgran, Phys. Rev. **79**, 400 (1950).

The Structure of Methyl Bromide from Microwave Spectra*

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SINCE the original publication[1] on the structures of the methyl halides a mistake in the calculations for methyl bromide has been called to our attention by Dr. A. H. Sharbaugh. Subsequent checking led to the conclusion that there was too small a percentage mass change from Br^{79} to Br^{81} to give satisfactory solutions of the methyl bromide structure equations using these two isotopes in combination with the value, derived from infra-red data, of the moment of inertia, I_A, about the figure axis of the molecule. Consequently, the microwave absorption spectra for the $J=1$ to $J=2$ rotational transition of $C^{13}H_3Br^{79}$ and $C^{13}H_3Br^{81}$ have been measured in this laboratory with the results shown in Table I.

A total of 18 lines was measured and values of frequencies for absorption lines for which $K=1$ as well as those for which $K=0$ were used in finding ν_0. In each case a constant stretching correction of 0.52 Mc/sec. was added to the observed frequency for lines of $K=1$, corresponding to the value of the stretching coefficient, D_{JK}, of 129 kc/sec. as found by Simmons and Anderson[2] for $C^{12}H_3Br$ using the equation[3]:

$$\nu_r=2B_0(J+1)-4D_J(J+1)^3-2D_{JK}(J+1)K^2. \qquad (1)$$

Table I. Frequencies of the hypothetical unsplit rotational lines, ν_0, for $C^{13}H_3Br^{79}$ and $C^{13}H_3Br^{81}$ and resulting moments of inertia from the rotational transition $J=1\rightarrow2$.

Molecule	ν_0 (Mc/sec.)	B_0[a] (Mc/sec.)	I_B[b] ($\times10^{-40}$ g-cm²)
$C^{13}H_3Br^{79}$	36477.67 ±0.09	9119.507	91.99_{02}
$C^{13}H_3Br^{81}$	36331.10	9082.860	92.36_{13}

[a] See text.

[b] Using $h=6.62373\times10^{-27}$ erg-sec. as given by J. W. M. DuMond and E. R. Cohen, Rev. Mod. Phys. **21**, 651 (1949).

TABLE II. Molecular dimensions of methyl bromide determined from different isotopic combinations.*

Molecular pair used	d_{CBr} (10^{-8} cm)	d_{CH} (10^{-8} cm)	∠HCH
$C^{12}H_3Br^{79}-C^{13}H_3Br^{79}$	1.9387	1.101	110°47′
$C^{12}H_3Br^{79}-C^{13}H_3Br^{81}$	1.9386	1.101	110°47′
$C^{12}H_3Br^{81}-C^{13}H_3Br^{79}$	1.9388	1.101	110°48′
$C^{12}H_3Br^{81}-C^{13}H_3Br^{81}$	1.9387	1.101	110°48′
Average values	1.9387	1.101	110°48′

* The constants used in these calculations were: $M_H=1.00813$, $M_{C^{12}}=12.00386$, $M_{C^{13}}=13.00761$, $M_{Br^{79}}=78.9417$, $M_{Br^{81}}=80.9400$, all in a.m.u.; $h=6.62373\times10^{-27}$ erg-sec., and the atomic mass unit $M=1.6599\times10^{-24}$ g.

The values of B_0 were then determined by using as a first approximation to the D_J values for $C^{13}H_3Br^{79}$ and $C^{13}H_3Br^{81}$, respectively, the values 11.1 kc/sec. and 10.7 kc/sec. found by Simmons and Anderson.

The data in Table I have been combined with the previous data obtained by Gordy, Simmons, and Smith[1] for the C^{12} compounds and with the infra-red I_A value, 5.496×10^{-40} g-cm², in the original equations,[1] yielding the results given in Table II. In contrast to the consistent values shown, the combination of data for $C^{12}H_3Br^{79}$ and $C^{12}H_3Br^{81}$ or for $C^{13}H_3Br^{79}$ and $C^{13}H_3Br^{81}$ gives unreliable values for d_{CBr} somewhat less than those listed.

The average structure constants given in Table II may be seen to fit well into the sequence of decreasing values of d_{CH} and increasing values of ∠HCH found for the methyl fluoride to methyl iodide series.[1]

* This work was supported by a Frederick Gardner Cottrell grant and by a grant-in-aid from the University Center in Georgia.

[1] Gordy, Simmons, and Smith, Phys. Rev. **74**, 243 (1948).

[2] J. W. Simmons and W. E. Anderson, Phys. Rev. (to be published).

[3] G. Herzberg, *Infra-Red and Raman Spectra of Polyatomic Molecules* (D. Van Nostrand Company, Inc., New York, 1945), p. 31.

Spin Dependence of Neutron Scattering by Na^{23}

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FROM recent measurements[1] it has been found that the "potential scattering" of Na^{23} for slow neutrons appears to be very strongly spin-dependent. Na^{23} has a nuclear spin I of $\frac{3}{2}$, so that there are two states of $Na^{23}+n$. The $J=2$ state has a cross section $\sigma_+\sim0.8$ barn; for the $J=1$ state, $\sigma_-\sim8.8$ barns. (The ± denotes $J=I\pm\frac{1}{2}$.) These values do not include statistical spin factors (see below).

This result was obtained in the following way. The reaction $Na^{23}+n$ has its first resonance, predominantly a scattering resonance, at a neutron energy of 3 kev. This is a much smaller energy than the average spacing between resonances, which is of the order[2] of 100 kev. It is therefore probably a good approximation to interpret interference effects (between "potential scattering" and "resonance scattering") in the region below 3 kev in terms of the 3-kev resonance alone, neglecting the effect of other resonances. Since the "strength" $\sigma_0\Gamma^2$ of the 3-kev resonance is known ($\sim16\times10^6$ barn-ev²), the detailed nature of the interference effects gives the magnitude of the potential scattering for the spin state associated with the resonance, and also for the other spin state. The specific identification of the spin states is possible both from additional information on the 3-kev resonance and from coherent scattering data.[1]

In greater detail, the procedure is as follows. The cross section for a free Na nucleus can be written as $\sigma=g_+\sigma_++g_-\sigma_-$, where g is the statistical spin factor, $(2J+1)/2(2I+1)$. Now the 3-kev resonance is known to belong to the "+" spin state—i.e., $J=2$. Then from the experimental cross-section data one finds that near zero energy the destructive interference between this resonance and the corresponding potential scattering gives a resultant σ_+ almost equal to zero. From this, we have that near zero energy (1) the total scattering cross section is approximately $g_-\sigma_-$ alone, (2) the value of $(g_+\sigma_+)_{\text{pot}}$ is approximately equal to $(g_+\sigma_+)_{\text{due to 3-kev resonance}}$. The latter is $\sim\sigma_0\Gamma^2/4E_r^2$, thus ~0.5 barn. If we now interpret $g_-\sigma_-$ as $(g_-\sigma_-)_{\text{pot}}$ (i.e., we assume there are no nearby resonances for $J=1$), then $(g_+\sigma_+)_{\text{pot}}\sim0.5$b, $(g_-\sigma_-)_{\text{pot}}\sim3.3$b. Since $g_+=\frac{5}{8}$ and $g_-=\frac{3}{8}$, this gives the result stated above, $(\sigma_+)_{\text{pot}}\sim0.8$b, $(\sigma_-)_{\text{pot}}\sim8.8$b.

It is of interest to compare these values with $4\pi R^2$, where R is the nominal nuclear radius, $1.5\times10^{-13}A^{\frac{1}{3}}$ cm. For sodium, $R=4.3\times10^{-13}$ cm and $4\pi R^2=2.3$b. It is seen that the effective nuclear radius for σ_+ is ~0.6 the nominal value, and the effective radius for σ_- is about twice the nominal value. Sodium is such a comparatively light nucleus, only about three nucleons in "diameter," that it is not too surprising to find the effective nuclear radius differing so greatly from the nominal value. However, it is quite unusual, and therefore rather interesting, to find such a large spin dependence in the scattering, with $\sigma_-/\sigma_+\sim11$.

One can interpret the spin dependence in terms of potential wells which for the two spin states have different depths but the same range. Using the crude model of rectangular wells of radius[3] 4.3×10^{-13} cm, the only reasonable values for the well depths which give the observed "scattering lengths"[4] are $V_+\sim17$ Mev, $V_-\sim24$ Mev. (No other values of V_+ or V_- between ~4 Mev and ~50 Mev give the observed values of the scattering lengths.) With this model the observed spin dependence can be regarded as due to a near-resonant condition in the potential scattering. (A potential-scattering resonance,[5] as opposed to a resonance in the compound nucleus, does not involve intimate interaction and binding-energy-sharing between the incident neutron and the individual nucleons of the target nucleus.)

The numerical values resulting from the rectangular well model should not be taken too seriously, of course. However, there is certainly a moderate difference in the potential wells representing the two spin states of $Na+n$. The magnitude of the spin effect recalls the well-known strong spin dependence for neutron-proton scattering. There may well be a correlation between the two cases. In this connection one should note that in the spin-orbit-coupling nuclear model, the last odd proton alone would be responsible for the total nuclear spin[6] of Na. In the spin-orbit-coupling model, in other words, the nucleus would be considered to consist of a "core," even Z-even N and with zero spin, plus a single proton; thus the spin dependence of scattering by Na would be entirely due to the spin dependence of the n-p interaction. Although there may be some element of truth in this representation, however, a model quite this simple is not correct. Its principal failing is that this "last-odd-particle" model, in which the spin of an odd-A nucleus is determined entirely by the orbit of the single unpaired nucleon, is definitely not satisfactory for Na. Na is one of the relatively few odd-A cases for which the predicted spin from this model does not agree with experiment—rather it seems that several particles are involved.

One might hope that other odd Z-even N nuclei would show a similar strong spin dependence for neutron scattering, and it is planned to investigate nuclei of this type and of other types further. It may be difficult to obtain information as to the spin dependence of potential scattering in many cases, however. In Na, the effect is large and the analysis fairly simple because of two fortuitous circumstances: the effect is large because the potential scattering is nearly resonant, and the separation of "potential" and "resonance" effects is fairly simple because the neutron energy at the first (compound-nucleus-) resonance is much smaller than the average spacing between resonances.

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[1] Hibdon, Muehlhause, Selove, and Woolf, Phys. Rev. **77**, 730 (1950).

[2] Adair, Barschall, Bockelman, and Sala, Phys. Rev. **75**, 1124 (1949).

[3] This value is taken from the approximation $1.5\times10^{-13}A^{\frac{1}{3}}$.

[4] E. Fermi and L. Marshall, Phys. Rev. **71**, 666 (1947).

[5] The term "potential-scattering resonance" may appear to be self-contradictory, but is not: such a resonance is very broad as compared to compound-nucleus-resonances, so that even near a potential-scattering resonance the value of σ_{pot} varies relatively slowly—e.g., σ_{pot} could very well not vary much over a range of tens or hundreds of kilovolts.

[6] M. G. Mayer, Phys. Rev. **78**, 16, 22 (1950).