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)	$\angle$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.; $h = 6.62373 \times 10^{-27}$ erg-sec., and the atomic mass unit $M = 1.6599 \times 10^{-24}$ 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 $\angle$HCH found for the methyl fluoride to methyl iodide series.[1]

[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 Na²³

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FROM recent measurements[1] it has been found that the "potential scattering" of Na²³ for slow neutrons appears to be very strongly spin-dependent. Na²³ has a nuclear spin I of $\frac{3}{2}$, so that there are two states of Na²³+n. The $J=2$ state has a cross section $\sigma_+ \sim 0.8$ barn; for the $J=1$ state, $\sigma_- \sim 8.8$ barns. (The $\pm$ 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 Na²³+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 ($\sim 16 \times 10^6$ 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 $(g_+\sigma_+)_{pot}$ is approximately equal to $(g_+\sigma_+)_{due\ to\ 3-kev\ resonance}$. The latter is $\sim \sigma_0 \Gamma^2/4E_r^2$, thus ~ 0.5 barn. If we now interpret $g_-\sigma_-$ as $(g_-\sigma_-)_{pot}$ (i.e., we assume there are no nearby resonances for $J=1$), then $(g_+\sigma_+)_{pot} \sim 0.5$b, $(g_-\sigma_-)_{pot} \sim 3.3$b. Since $g_+ = \frac{5}{8}$ and $g_- = \frac{3}{8}$, this gives the result stated above, $(\sigma_+)_{pot} \sim 0.8$b, $(\sigma_-)_{pot} \sim 8.8$b.

It is of interest to compare these values with $4\pi R^2$, where R is the nominal nuclear radius, $1.5 \times 10^{-13} A^{\frac{1}{3}}$ cm. For sodium, $R=4.3 \times 10^{-13}$ 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 $\sigma_-/\sigma_+ \sim 11$.

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 $V_+ \sim 17$ Mev, $V_- \sim 24$ 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.

[1] Hibdon, Muehlhause, Selove, and Woolf, Phys. Rev. 77, 730 (1950).
[2] Adair, Barschall, Bockelman, and Sala, Phys. Rev. 75, 1,124 (1949).
[3] This value is taken from the approximation $1.5 \times 10^{-13} A^{\frac{1}{3}}$.
[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 with compound-nucleus-resonances, so that even near a potential-scattering resonance the value of σ_{pot} varies relatively slowly—e.g., σ_{pot} could vary very well not vary much over a range of tens or hundreds of kilovolts.
[6] M. G. Mayer, Phys. Rev. 78, 16, 22 (1950).