

valuable in estimating the relative probability of excitation to the various levels which are difficult to observe spectroscopically. I think sufficient resolving power could be obtained to separate the 4.7 volts and 4.9 volt levels. The method has the great advantage that the collisions take place in a completely field-free space.

The intensity of the 11.5 volt peak is surprising. If it is the result of two successive collisions as explained above, it should be less intense than the 4.7 volt, 4.9 volt, and 5.4 volt peak. No satisfactory explanation of its intensity has been found. Foard, in an abstract (*Bull. Am. Phys. Soc.*, Dec. 13, 1929), has described some similar experiments using a magnetic analysis. He seems to have obtained slightly higher resolution. He finds a peak at 7.7 volts, the 1^2S_1 energy level. This peak does not occur either in my experiments or in those of Whitney. Otherwise the same peaks were found.

In the present experiment, the electron gun could be rotated to give an angular distribution of the scattered electrons and some results have been obtained. They are not very accurate, and agree in general with those of Arnot (*Proc. Roy. Soc.*, vol. 125, p. 660), so nothing further need be said about them.

These experiments were made possible by the kindness of Prof. A. M. Tyndall in placing the facilities of the Wills Physical Laboratory at the University of Bristol at my disposal. The work was done while I held an 1851 Exhibition Senior Studentship.

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Glancing Angle of Reflection from Calcite for Silver ($K\alpha_1$) X-Rays.

WE have measured the first order glancing angle at which the $K\alpha_1$ line of silver is reflected from the cleavage planes of calcite by a method independent of any used by those who have obtained the most reliable results so far. The weighted mean value of fourteen independent observations reduced to 18°C . is $5^\circ 17' 13.81'' \pm 0.06''$.

This value was obtained from spectrograms taken on a new spectrometer specially designed to utilise the displacement method introduced by H. S. Uhler (*Phys. Rev.* [11], 11, 1-20; 1918). A full description of the method, instrument, and results will be given later.

The value of the wave-length corresponding to the above glancing angle is $0.558238\text{ A.} \pm 0.000002\text{ A.}$ obtained by using 3.02904 A. for the 'effective' grating space of calcite (Siegbahn, "Spectroscopy of X-Rays", 1924 edition).

The thermal coefficient of expansion at 18°C . for the grating space of calcite obtained from the most trustworthy sources, without approximations, is $0.000102_3/^\circ\text{C}$. This value differs by about 2 per cent from the generally quoted value originally given by W. Stenström (Dissertation, Lund, 1919) as a sufficient approximation.

It is interesting to note that our value of the glancing angle is $1.4''$ smaller than that given by G. Kellström (*Zeit. f. Phys.*, 41, 516; 1927) for the first order of calcite, namely, $5^\circ 17' 15.2''$. The probable error of the unweighted mean of Kellström's seven determinations for this order is $\pm 0.04_5''$. The unweighted mean of his four second order determinations is also larger than ours and has relatively four times this probable error. With such a difference existing, one wonders if the grating spaces of the crystal specimens used were the same. We employed an unusually selective piece of calcite which was

cleaved from an excellent specimen of Iceland spar contained in the Marsh collection of Yale University.

Our value is larger than those of K. Lang (*Ann. d. Physik*, 75, 489; 1924), A. Leide (Dissertation, Lund, 1925), and A. P. Weber (*Zeit. f. Wiss. Photo.*, 23, 149; 1925), although coming within $0.11''$ of Lang's and $0.36''$ of Leide's results when their probable errors are added to their respective mean values.

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The Nuclear Moment of Lithium.

THE fact that the hyperfine structures of spectral lines are so much narrower than the multiplets in the same spectrum is due principally to the fact that the latter are produced by the magnetic moment of the electrons, while the former originate from the magnetic moment of the nucleus, which is usually attributed to nuclear protons, and is, therefore, about 1840 times smaller.

The hyperfine structure of the Li^+ spectrum, discovered by Schüler (*Zeit. f. Phys.*, 42, 487; 1927) is of the same order of magnitude, however, as the multiplet separations themselves. From this fact Heisenberg (*Zeit. f. Phys.*, 39, 516; 1926) drew the conclusion that the magnetic moment of the lithium nucleus was of the same order of magnitude as that of an electron, and therefore caused by electrons in the nucleus and not by protons. The experiments of Taylor (*Zeit. f. Phys.*, 52, 846; 1929) on the Stern-Gerlach effect with lithium atoms failed, however, to indicate the expected large magnetic moment for the nucleus.

In the following we will show that the nuclear magnetic moment is not very large, and that the wide hyperfine structure is caused by the presence of a single $1s$ electron in the configurations considered.

In a recent letter to NATURE (125, 16; 1930), Fermi has given an expression for the interaction between the nuclear moment and the external electrons derived from quantum mechanics.¹ For an s -state in an hydrogenic atom the doublet separation (s -states have $j=1/2$ and thus split into two levels) will be

$$\Delta\nu = \frac{8}{3} R\alpha^2 \frac{Z^3}{n^3} \cdot \frac{g(i)}{1840} \cdot (i + \frac{1}{2}).$$

In this expression we denote by $g(i)$ the ratio between the magnetic and mechanical moments of the nucleus, its Landé g -value, but in units 1840 times smaller than used for electrons, in order to obtain the magnetic moment of a spinning proton as unity. Since the mechanical moment of a spinning proton is $1/2$ quantum unit, its $g(i)$ is thus 2. The mechanical moment of the nucleus is denoted by i .

Applied to doubly ionised lithium the lowest s -state would have a doublet separation of

$$\Delta\nu = 0.228 g(i) \cdot (i + \frac{1}{2}) \text{ cm.}^{-1}.$$

For the $1s\ 2s$ and $1s\ 2p$ configurations of Li^+ we may assume that the hyperfine structure is mainly due to the presence of the $1s$ electron. The added electron will have some screening effect on the $1s$ electron, but as it is an outer electron this effect will be very small. Furthermore, the screening effect of the $1s$ electron upon the $2s$ or $2p$ electron will be large, and as these

¹ The same expressions were known to us before from unpublished material of H. Casimir, presented at a meeting in Copenhagen last April. For a general state in an hydrogenic atom Casimir obtains for the interaction energy:

$$\Delta E = Rhc\alpha^2 Z^3/n^3(l + \frac{1}{2})j(j+1) \cdot g(i)/1840 \cdot ij \cos(i, j).$$

electrons have $n=2$ their interaction with the nucleus will be far smaller than that of the $1s$ electron, and will be neglected here.

To obtain finally the hyperfine structure for the $1s\ 2s\ ^3S$ and $1s\ 2p\ ^3P$ states of Li^+ , use is made of the expressions derived by Goudsmit and Bacher (*Phys. Rev.*, **34**, 12; 1929). Assuming for simplicity $i=1/2$, which does not affect the order of magnitude of our results, we expect to a first approximation:

	Calc.	Obs.
3S_1	$\Delta\nu = 0.17\ g(i)$	0.6 cm. ⁻¹
3P_2	$= 0.14\ g(i)$	0.3
3P_1	$= 0.085\ g(i)$	0.3

The result is that the expected separations are not of an order of magnitude 1840 times smaller than the multiplet separation of 3P , which is approximately 5 cm.⁻¹.

Recently Schüler and Brück (*Zeit. f. Phys.*, **58**, 735; 1929) have given a tentative analysis of the Li^+ hyperfine structure leading to $i=1/2$, and giving the separations mentioned as observed in the above table. With respect to the uncertainty in the screening effect and interpretation, their results indicate a $g(i)$ -value of about 3 to 6. (It was hoped that this value would be approximately 2.) The application of these formulae to hyperfine structure in other atoms, which can be done to a first approximation by replacing $(Z/n)^3$ by Zz^2/n_0^3 , also seems to lead to rather large values for $g(i)$.

If the tentative interpretation of this hyperfine structure given by Schüler and Brück is correct, the hyperfine splitting is *inverted*. Another example where this is the case is the cadmium isotope with $i=1/2$ (Schüler and Brück, *Zeit. f. Phys.*, **58**, 737; 1929). This means that the magnetic moment of the nucleus is related to its mechanical moment as if it were due to *negatively* charged particles. However, it is possible, though improbable, to have a complicated configuration of positive particles for which the resultant magnetic moment is oppositely directed to the mechanical moment. Something similar occurs for the extra-nuclear electrons in certain complicated configurations which show a negative Landé g -value (for example, $^6F_{1/2}$, with $g = -2/3$).

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Moment of Inertia of Hydrogen from Band Spectra.

THE commonly accepted value of the moment of inertia of the hydrogen molecule, in the normal state, is due to Hori (*Zeit. f. Phys.*, **44**, 834; 1927). In deriving this value, Hori expressed the rotational energy as $E_m = B_0 m^2 + D_0 m^4$, and calculated empirical values of D_0 directly from the data. The term $D_0 m^4$ is due to the swelling of the molecule with rotation, and it is now well established that the theoretical values of D_0 hold accurately in the case of electronic levels for which there is no resultant electron momentum to complicate matters. This is the situation in the normal level of hydrogen ($^1\Sigma$). Hori's values of D_0 are several times as small as those given by theory and, what is more important, are positive, whereas a *swelling* of the molecule with rotation requires that they be negative. Hori made note of this discrepancy in sign, but was unable to explain it. We find, however, in agreement with Schaafsma and Dieke (*Zeit. f. Phys.*, **55**, 164; 1929) that Hori's data, although relatively inaccurate and meagre, do indicate negative values of D_0 , and we are unable to locate the origin of

his published values. It should be pointed out, in addition, that Hori's data give probable errors for B_0 (his A_0) and D_0 (his β) ten to one hundred times as large as his published errors for these quantities.

There are now available much more extensive and accurate data for the normal state of hydrogen. Schaafsma and Dieke (*loc. cit.*) have published rotational energy data, based on H_2 plates obtained by Dieke and Hopfield (*Phys. Rev.*, **30**, 400; 1927) on the 50 cm. vacuum spectrograph at the University of California. One of us (see H. H. Hyman and R. T. Birge, *NATURE*, **123**, 277; 1929) has recently obtained similar data from spectrograms taken with Prof. Hopfield's new 10-ft. vacuum spectrograph. Using all available data from these sources, and employing the various known theoretical relations, we have calculated values of B as a function of v , and find

$$B_0 = 60.587 - 2.7938(v+1/2) + 1.0500 \times 10^{-2}(v+1/2)^2 - 24.058 \times 10^{-4}(v+1/2)^3.$$

In this equation, the actual vibrational energy levels are given by $v=0, 1, 2$, etc., and the available data run from $v=1$ to 12 inclusive. The equation is entirely satisfactory from $v=1$ to 9. The higher values of v lie close to dissociation and the observed values of B_0 are smaller than those given by the equation.

The most important constant is of course B_0 , corresponding to the lowest actual vibrational level ($v=0$). The absorption bands of the $B-A$ system, observed and measured by Dieke and Hopfield (*loc. cit.*) lead directly to a value of B_0 , but the probable error is quite large. On the other hand, only one emission band (observed by Witmer, *Phys. Rev.*, **28**, 1223; 1926) is available for this purpose, and the data in this case are very fragmentary. It is therefore necessary to evaluate B_0 by extrapolation, using the equation just given, with $v=0$. The extrapolation in this case is quite trustworthy *provided* the B_0 curve is really smooth. The result is $B_0 = 59.192$ cm.⁻¹. Using the new conversion factor $(27.66 \pm 0.04) \times 10^{-40}$, given by Birge (*Phys. Rev.*, Supplement **1**, 1; 1929), one then obtains $I_0 = 0.4673 \times 10^{-40}$ gm.cm.², and $r_0 = 0.7500 \times 10^{-8}$ cm. Hori found $B_0 = 57.77$, giving $I_0 = 0.479 \times 10^{-40}$. This differs from our value by 2.2 per cent.

In this connexion we should like to emphasise that Hori's published $I = 0.467 \times 10^{-40}$ refers to the true state of zero vibration ($v = -1/2$) and would now be denoted I_e . Nearly everyone has quoted and used Hori's I_e value as though it were I_0 . Our own value of B_0 is given by the constant term in our equation (60.587), and this leads to $I_e = 0.4565 \times 10^{-40}$, $r_e = 0.7412 \times 10^{-8}$. It is interesting to note that Wang (*Phys. Rev.*, **31**, 579; 1928) obtained $I_e = 0.459 \times 10^{-40}$, from a theoretical wave mechanics calculation. We believe that the probable error in the values of B_1 to B_9 , as given by the above equation, is 0.1 per cent, or less. So far as the uncertainty of the extrapolation is concerned, the probable error in B_0 and B_e is not more than 0.2 per cent. It is, however, shown in the following letter by Birge and Jeppesen that B_0 is definitely perturbed, so that our value is not correct. Whether B_e is correct cannot be tested, since this constant refers to a molecular state which does not exist.

This work has been carried out with the advice and assistance of Prof. R. T. Birge, to whom we wish to express our sincere thanks.

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