An Isotope of Nitrogen, Mass 15

The recent discovery of the oxygen isotopes of mass 18 and 17 by W. F. Giauque and H. L. Johnston [Nature **123,** 318, 831 (1929); Journ. Amer. Chem. Soc. **51,** 1436 (1929)] and of the carbon isotope of mass 13 by A. S. King and R. T. Birge [Nature **124,** 182 (1929); Phys. Rev. **34,** 376, 379 (1929)] is of great importance for a quantitative study of the structure of the atomic nuclei. Although no trace of an isotope of nitrogen was found by Birge in the emission spectrum of CN, he carefully points out that this might be due to the greater abundance of C^{13} with respect to C^{12}.

The absorption spectrum of NO, especially the (1, 0) band at λ2154, as well as the (0, 0) band at λ2269, which belong to the γ system and are degraded towards the violet, offer a good opportunity, not only of verifying the presence of oxygen isotopes, but also of finding nitrogen isotopes if any exist. The system of NO has been analyzed partly by Frl. M. Guillery [Zeits. f. Physik **42,** 121 (1927)] and partly by R. Schmid [Zeits. f. Physik **49,** 428 (1928)]. Schmid worked on the particular bands in question. The bands have been shown to consist of doublets each having a Q and P head. Of the (1, 0) band Schmid was able to measure only the Q heads. The position of the P heads could however be calculated with the help of the relation $Q_1(J+1)-F'(J)=P_1(J)$ given by him for the initial state. This gives 46391.3 cm^{-1} for the P_1 head. This agrees with measurements made in the course of the present work. The positions of the expected isotope heads were then calculated by means of the formulae

$$\nu_2{}^n-\nu_1{}^n=(\rho-1)\left[\omega_e'(n'+\tfrac{1}{2})-\omega_e''(n''+\tfrac{1}{2})\right]-(\rho^2-1)\left[\omega_e'x_1'(n'+\tfrac{1}{2})^2-\omega_e''x''(n''+\tfrac{1}{2})^2\right]$$

for the vibrational effect and

$$\nu_2{}^m-\nu_1{}^m\approx(\rho^2-1)\nu_1{}^m$$

for the rotational effect, where ν_1 refers to the ordinary molecule $N^{14}O^{16}$. The values of the constants corresponding to the intial state were calculated from Schmid's data and the constants for the final state could be found more accurately from the analysis of the β bands of NO by F. A. Jenkins, H. A. Barton, and R. S. Mulliken [Phys. Rev. **30,** 150 (1927)]. For the (1, 0) band the calculated shift $(\nu_2-\nu_1)$ of the Q_1 head is found to be, for $N^{14}O^{17}$, $N^{14}O^{18}$, and $N^{15}O^{16}$, −35.193, −67.030, −45.729 cm^{-1} respectively, and of the P_1 head −34.444, −65.615, −44.758 cm^{-1} respectively. The separation of the Q_1 and P_1 heads being only 27.3 cm^{-1}, all these isotope heads are expected to fall beyond the P_1 head of $N^{14}O^{16}$ and it should be possible to observe them in so far as they do not overlap one another. The calculated wave-lengths for the isotope heads are as follows: Q_1 heads; 2155.263($N^{14}O^{17}$), 2155.746($N^{15}O^{16}$) 2156.744($N^{14}O^{18}$): P_1 heads; 2156.498($N^{14}O^{17}$), 2156.982($N^{15}O^{16}$), 2157.953($N^{14}O^{18}$). For the (0, 0) band the calculated shifts of the P_1 head are for $N^{14}O^{17}$, $N^{14}O^{18}$ and $N^{15}O^{16}$ −3.199 cm^{-1}, −6.092 cm^{-1} and −4.157 cm^{-1} respectively. This corresponds to the wave-lengths 2269.568A, 2269.773A and 2269.617A. The lines corresponding to a shift from the Q_1 head fall within the band, since the separation of the heads is 22.0 cm^{-1}, so that one could not expect to detect them,

As continuous light source a hydrogen lamp was constructed according to Bay and Steiner [Zeits. f. Physik **45,** 337 (1927)] which could be operated with a 5 K.W. transformer giving about 0.5 ampere through the secondary. This gave a very intense continuous spectrum. The NO was contained in a tube 92 cm in length. The tube could be filled with NO to any desired pressure. The light from the hydrogen source passing through the absorption tube, was photographed by an E_1 Hilger spectrograph, having a dispersion of 1.561A per mm at λ2154 and 1.892A at λ2269. As comparison spectrum the copper arc lines as measured by Mitra [Ann. de Physique **19,** 315 (1923)] were used. The insensitivity of the plate in these regions was overcome by using a solution of 5 grams of vaseline in 0.5 liters of petroleum ether, according to Beach (Nature, Feb. 2, 1929).

The photographs taken with different pressures of NO in the absorption tube ranging between 1 and 5 cm pressure, all show absorption lines accompanying the main heads which look like the expected result. The mean values of measurements on five different plates give the following wave-lengths for the isotope heads:

Q_1 heads: 2155.227($N^{14}O^{17}$),
2155.730($N^{15}O^{16}$),
2156.753($N^{14}O^{18}$).

P_1 heads: 2156.493($N^{14}O^{17}$)
2156.982($N^{15}O^{16}$)
2157.976($N^{14}O^{18}$).

To be absolutely sure that these bands might not perhaps be due to some other molecule, e.g. $(NO)_2$, the absorption tube was replaced by a tube 1.2 cm in length and filled up to 75 cm pressure with NO. The light passing through this tube has to traverse about the same number of molecules of NO as in the case of the 92 cm tube with 1 cm pressure. If $(NO)_2$ molecules were present, their concentration should increase with the square of the pressure and the path being 75 times shorter, one would expect the effect due to these molecules to become 75 times as intense. The absorption of the isotope heads found is quite similar to that obtained with the 92 cm tube, except that they are a little more diffuse, as one might expect. The measured shift agrees accurately with the above results.

The effect on the (0, 0) band is very difficult to observe owing to its smallness. The wave-lengths of the displaced heads found are 2269.605($N^{15}O^{16}$) and 2269.747($N^{14}O^{18}$) which correspond within experimental error with the calculated shifts. The displaced head due to the $N^{14}O^{17}$ molecule could not be observed.

At this stage it can only be said that $N^{15}O^{16}$ is about as abundant as $N^{14}O^{18}$. The work is being carried on and it is hoped to find the abundance of N^{15} isotope more accurately. At higher pressures faint absorption lines appear beyond the isotope heads whose positions seem to agree with those calculated for $N^{16}O^{16}$, but this must be considered doubtful until further work has been done. This point will also be subject for further research.

I wish to thank Professor R. S. Mulliken who suggested the search for isotopes in these NO absorption bands and at the same time wish to thank him and Dr. A. Christy for their valuable advice.

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November 26, 1929.

The Paschen-Back Effect of Hyperfine Structure

The study of the Paschen-Back effect in hyperfine structure is of particular interest as it is the only possiblity to verify the complete theory of the gradual change of the Zeeman effect from weak to strong fields,as there are no suitable ordinary multiplets available for this purpose. The theory of the Zeeman effect for any field strength has been studied by Heisenberg and Jordan [Zeits. f. Physik. **37,** 263 (1926)] and by Darwin [Proc. Roy. Soc. **A115,** 1(1927)] for the case of ordinary multiplets. There may be shown to be a very close analogy between ordinary multiplets and the hyperfine structure separations, the former being due to the interaction between the resultant orbital moment and the resultant spin moment and the latter to the interaction between the total extranuclear moment andthe nuclear moment. The roles of s the resultant spin moment, l resultant orbital moment, and j total moment in the ordinary multiplet structure are taken by i nuclear moment, j total extranuclear moment, and f resultant moment in the hyperfine structure.[1] This correlation together with the fact that the addition to the energy in a very strong magnetic field, due to the nuclear spin (E_{ij}) and to the presence of a magnetic field (E_m) is given by

$$E_m+E_{ij}=(m_jg+m_ig_i)\omega H+am_jm_i \qquad (1)$$

allows the immediate adaption of the results of Darwin to the hyperfine structure problem. One arrives at a system of equations which are given by the key equation[2]

$$\begin{aligned}&-X_{m_j-1,m_i+1}\frac{a}{2}(j-m_j+1)(i+m_i+1)\\&+X_{m_j,m_i}(E-am_jm_i-gm_j\omega H)\\&-X_{m_j+1,m_i-1}\frac{a}{2}(j+m_j+1)(i-m_i+1)=0\end{aligned} \qquad (2)$$

where a is the interval unit of hyperfine structure; g is the Landé factor for the extranuclear electrons; ω is the frequency of the Larmor precession $e/4\pi mc^2$ in cm^{-1}; H is the magnetic field strength in gauss; E is the energy displacement in wave-number units from the hypothetical level which would exist if there were no nuclear spin and no applied magnetic field; the X's are the coefficients in the expansion of the wave function

[1] Completely analogous to the case of multiplets one can obtain selection rules, intensity relations, interval rule, and expressions for the magnitude of the hyperfine structure for different levels.

[2] The interaction energy between the nuclear moment and the external field is omitted because it is much too small to be detected.