## Further Evidence of the Carbon Isotope, Mass 13

A few days ago Dr. King and I announced the discovery of an isotope of carbon, mass 13, appearing in the λ4737 Swan band of neutral $C_2$. Since then I have found this isotope in two additional sources, viz., in Hopfield's absorption spectrograms of CO, and in King's furnace (emission) spectrogram of the λ3883 CN band.

Two years ago J. J. Hopfield and the author presented to the American Physical Society (Phys. Rev. **29**, 922, 1927) an analysis of the emission and absorption spectra of carbon monoxide, based on extensive experimental material obtained by Professor Hopfield with his vacuum spectrograph. The most complete absorption system is the fourth positive group, in which we were able to measure the bands from 0–0 to 15–0 (λλ1544 to 1199). These bands degrade to the red, and it was noted at the time that a faint second head appeared to the red of each main head, at a systematically increasing distance. We were however not able to fit these heads into the band system. I have now carefully measured these second heads and find that they agree quantitatively with $C^{13}$–$O^{16}$ as an assumed source. The heads can be measured with reasonable certainty in all the bands from 2–0 to 15–0, with the exception of two for which emission lines interfere. The calculated isotope shift, using reliable vibrational constants obtained by Professor Hopfield and myself, varies from 0.072 to 0.273 mm (55 to316cm$^{-1}$). The arithmetic average *obs*$-$*calc* value is 0.0035 mm and the algebraic average 0.0017 mm, in the sense that the observed shift is very slightly less than the calculated.

If the $C^{12}-O^{18}$ molecule is also present, its absorption bands should lie to the *red* of the $C^{13}$–$O^{16}$ band heads, by amounts varying from 0.006 to 0.024 mm. It is thus impossible, with the present spectrograms, to separate the two isotopes. In all cases the observed $C^{13}$–$O^{16}$ head is wide enough to include a possible $C^{12}$–$O^{18}$ head. Thus the evidence is conclusive that $C^{13}$–$O^{16}$ is present, but is strictly neutral as to $C^{12}$–$O^{18}$.

The second source of information is King's furnace spectrogram of CN λ3883 (Astrophys. J. **53**, 161, 1921). Dr. King kindly loaned me all his CN furnace spectrograms, for my work on temperature and band spectra (Astrophys. J. **55**, 273, 1922), and I still have this material. He called attention (page 162, loc. cit.) to a very faint series of doublets lying between λ3872 and λ3876. I measured these roughly, in connection with my temperature work—but was unable to fit them into the band structure. I found, however, that two of the six doublets had been observed by Kayser and Runge, in the arc spectrum. I now find that these six doublets are the isotope lines $P_{56}$ to $P_{61}$, due to $C^{13}$–$N^{14}$. They have the same doublet separation as the main doublets, and lie just to the red, in each case. In calculating the vibrational shift I have used the constants based on Heurlinger's original analysis, as calculated by Kratzer (Ann. d. Physik **71**, 72, 1923). For the rotational shift I have used new constants determined by R. T. Birge and W. O. Smith, in an unpublished quantum analysis of this band. The calculated shift varies from 0.228 to 0.451 mm (0.877 to 1.739 cm$^{-1}$).

Although the isotope lines are very faint, they can under favorable mechanical conditions be measured with reasonable acuracy. Excluding $P_{56}$, which lies too close to its parent line to measure properly, the observed isotope shift averages 0.014 mm greater than the calculated, with an average deviation from the mean of only 0.0033 mm. This indicates a small error in the vibrational constants, or an electronic shift of this magnitude (0.05 cm$^{-1}$). The latter explanation seems the more reasonable. The calculated isotope lines based on either $C^{12}$–$N^{15}$ or $C^{12}$–$N^{16}$ lie far outside the limits of error. There are definitely no other isotope lines observable in this region of the band, so that one may conclude that if isotopes of nitrogen exist, they are much less abundant, compared to $N^{14}$, than is $C^{13}$ compared to $C^{12}$.

RAYMOND T. BIRGE
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## The Comet-tail Bands*

On plates obtained by passing a high frequency electrodeless discharge (10,000 kilocycles) through commercial nitrogen at about $10^{-4}$ mm pressure, it was found that nearly

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