Evidence for the Enrichment of Carbon in the Heavier Isotope by Diffusion

An apparatus similar to that described by Hertz[1] for the separation of gaseous isotopes by diffusion has been constructed by one of us (D.E.W.) and used to produce methane gas in which the relative abundance of C^{13} is several times its value in normal methane.

The diffusion apparatus[2] consists of thirty-five "separation members," each involving its own circulating mercury diffusion pump and auxiliary porous tubing. Starting with twenty-five liters of pure methane gas at a pressure of 8 mm of mercury, twelve hours of circulating the gas suffices to establish an isotopic concentration equilibrium in the apparatus, at which time the enriched sample (200 cc at 6 mm pressure) may be removed for analysis. Calculations, based upon mass spectrometer measurements of the concentration factor achieved with the isotopes of neon, indicate that, under favorable conditions, this end-product might be expected to contain as high as fifteen or twenty atomic percent of C^{13}. For the abundance in ordinary carbon Jenkins and Ornstein[3] obtained 0.95 ± 0.1 percent by intensity measurements on the band spectrum, while Aston[4] obtained 0.71 ± 0.07 with the mass spectrograph.

Spectroscopic observation, on the diffused sample were made by the second author (F.A.J.) and gave evidence for a considerable enrichment in C^{13}. About $\frac{1}{2}$ mm of the methane was introduced into a small discharge tube containing 10 mm of purified argon. This gave an intense source of the Swan system of C_2 bands. Fig. 1 shows a comparison of the C_2 bands from ordinary methane (upper) and from the enriched sample (lower). The head marked by a single dot is the 1,0 band, $\lambda 4737$, of $C^{12}C^{12}$. The corresponding head of $C^{12}C^{13}$ at $\lambda 4744$, marked by two dots, is considerably more intense in the lower spectrum. Three measurements of the relative intensity of $\lambda 4744$ to $\lambda 4737$ were made from different exposures by means of density marks photographed on the same plate, and gave the values 0.143, 0.139 and 0.143. Adopting 0.142, this corresponds to an abundance of 6.6 atomic percent of C^{13}, or an enrichment by a factor of at least 7. That this is considerably less than the calculated value given above is not to be taken as significant, however, since the conditions for the diffusion in which this sample was obtained were not such as to give the most efficient separation. Further-
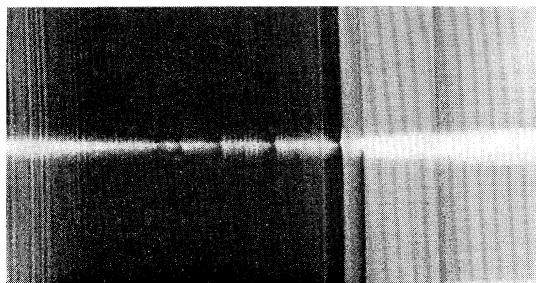

FIG. 1.

more, although precautions were taken to exclude ordinary carbon from the discharge tube, a small amount of it would considerably affect the result.

An interesting confirmation of this determination is the appearance on the spectrogram of a faint head (marked by three dots) in the calculated position for $C^{13}C^{13}$. In ordinary carbon, this has an intensity less than one ten-thousandth of that of the main band, and is not observable in emission. In stellar absorption spectra, however, it has been identified by Sanford.[5] If the above measurement is correct, its intensity for the enriched sample should be one two-hundredth, and this is enough to make it barely visible. There can be no doubt of its identity here, since it does not appear in the spectrum of ordinary carbon.

We wish to express our thanks to Drs. B. H. Sage and W. N. Lacey, of the Chemistry Department of the California Institute of Technology, for kindly supplying us with the very pure methane gas required for this work. To Dr. Wm. R. Smythe of the Physics Department, at whose instigation the separation of isotopes was undertaken here, is due more than an ordinary acknowledgment for the many valuable suggestions he has made in connection with the construction and operation of the diffusion apparatus. We are also indebted to Dr. H. T. Byck for assistance in the spectroscopic work.

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        February 8, 1936.

[1] G. Hertz, Zeits. f. Physik 79, 108 (1932); Naturwiss. 21, 884 (1933).
[2] To be more fully described in a later paper.
[3] F. A. Jenkins and L. S. Ornstein, Proc. Amst. Acad. Sci. 35, 3 (1932).
[4] F. W. Aston, Proc. Roy. Soc. A149, 400 (1935).
[5] R. F. Sanford, Publ. Astronom. Soc. Pacific 41, 271 (1929).

Two-Body Problem in General Relativity Theory

In a recent paper,[1] Silberstein attempts to show the incorrectness of the general theory of relativity. His reasoning is as follows:

a. I set up a static solution of the gravitational equations which has two singular points and is everywhere else free from singularities.

b. The two particles so represented are not accelerated in each other's gravitational field, in contradiction with experience. Hence the gravitational equations of the general relativity theory are incorrect.

We should like to point out the following. Even if (a) were the case the conclusion (b) would not be justified. For in a field theory only a representation of masses which is free from singularities can be accepted, since at a singularity the laws of the field are violated. However the assertion (a) is not correct. We shall show that the solution given by Silberstein has singularities outside of the two points. This we did not notice in our recent paper, where we referred to this solution, which had been previously communicated to one of us.

In order that a line element of the form (1) (cf. Silberstein's paper) represent a regular gravitational field outside

of the two particles, not only must ν and λ and their first derivatives be continuous, but λ must vanish everywhere for $x_1 = 0$ except at the two mass-points. The latter condition is necessary in order that an infinitesimal circle in the plane $x_2 = $const., $x_4 = $const. with center at $x_1 = 0$ shall have the ratio of circumference to diameter, each measured in natural length (integral of ds), equal to π. One can show that the solution in question does not satisfy these conditions as far as the funcion λ is concerned.

For this purpose we put the expression (10) into a more convenient form by introducing the angle α formed by the two radii-vectors r_1 and r_2. This satisfies the relation

$$r_1 r_2 \sin \alpha = D x_1.$$

The bracketed expression in (10) can now be written

$$[\ \ ] = \pm \cos \alpha - 1,$$

where the double sign comes from the square root. According to Silberstein the square root is always to be taken positive, so that one should therefore write

$$[\ \ ] = |\cos \alpha| - 1.$$

This obviously leads to discontinuous derivatives for λ on the surface $\alpha = \pi/2$, in violation of the conditions for regularity.

As a matter of fact, a closer investigation shows that the calculation can be carried through without the introduction of the square root and the resultant ambiguity in sign. One then finds that in the correct solution

$$[\ \ ] = \cos \alpha - 1.$$

This, however, also fails to satisfy the regularity conditions, for λ is nonvanishing on the axis ($x_1 = 0$) between the two mass-points.

We should like to remark that, as shown in a letter to one of us, Professor C. Lanczos of Purdue University has independently recognized the error in Silberstein's paper.

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Princeton, New Jersey,
February 17, 1936.

1 Silberstein, Phys. Rev. 49, 268 (1936).
2 Einstein and Rosen, Phys. Rev. 48, 73 (1935).

A Correction to "On the Structure and Interpretation of the Infrared Absorption of Crystals"[1]

R. B. Barnes, R. R. Brattain and the author would like to express their thanks to Dr. M. A. Durand for calling their attention to a typographical error in their paper of the foregoing title. In Table I on page 590, the columns C_{12} and C_{44} were interchanged. The discussion in the text is not to be altered.

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1 Barnes, Brattain and Seitz, Phys. Rev. 48, 582 (1935).

Infrared Absorption of Hydrogen Chloride in Nonionizing Solvents

The appearance of the interesting paper of E. K. Plyler and D. Williams on the infrared absorption spectrum of hydrogen chloride in benzene at about 3.4μ[1] has suggested to us the propriety of recounting our observations on the infrared absorption of that substance in various solvents, made in continuance of work on the Raman spectra of these solutions.[2] The work has been performed on the harmonic at about 1.76μ by means of a prism-grating spectrometer employing an echelette grating of 3600 lines to the inch. The results are in general agreement with those obtained from Raman spectra—the absorption band is displaced to lower frequencies by an amount increasing with the dipole moment of the solvent, the displacement reaching a limiting value beyond which further increase in moment is without effect. As is perhaps to be expected, there is no trace of rotational structure, though solutions in PCl_3, $POCl_3$, CCl_4, SO_2, show either very distinctly, or at least clear signs of a division into two bands with maxima separated by an amount, in PCl_3 and CCl_4, about the same as the P-R doublet separation in the incompletely resolved gaseous absorption, while in $POCl_3$ and in SO_2 the separation is distinctly greater than in the gas (about 220 cm^{-1} in SO_2, solution, against 120 cm^{-1} for the gas). Moreover the intensity of the low frequency branch is much greater than that of the other, in contradistinction to the intensity relations in the P and R branches in the gas. Diminishing the temperature in PCl_3 solutions makes the division into two bands less pronounced and also causes a relatively small diminution in the frequency of maximum absorption.

The absorption coefficient in these solutions, judged from a comparison of cell lengths required for about the same absorption in the gas and in solution, seems to be only slightly greater than in the gas.

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February 8, 1936.

1 Plyler and Williams, Phys. Rev. 49, 215 (1936).
2 West and Arthur, J. Chem. Phys. 2, 215 (1934).

Ultraviolet Absorption in Hydrogen Fluoride. A Correction

An ultraviolet absorption spectrum in hydrogen fluoride was recently reported in a letter by K. Siga and H. Plumley.[1] It has since been demonstrated by the second author that the observed spectrum must be attributed to the presence in the hydrogen fluoride of a trace of sulfur dioxide as an impurity. It is concluded that hydrogen fluoride at atmospheric pressure, and with a path length of 30 cm, shows no absorption in the ultraviolet region above 2000A.

H. J. PLUMLEY

Ryerson Physical Laboratory,
University of Chicago,
February 4, 1936.

1 K. Siga and H. Plumley, Phys. Rev. 48, 105 (1935).