current as reported by Cobine[2] for carbon. This has also been observed with a cathode-ray oscillograph for an arc fed with superposed alternating and direct current. Transitions in the reignition voltage have been observed for C, Co, Cr, Fe, Mn, Mo, Ni, W and Zn while Cu, Ag, and Al show only a single state over the range of current investigated (0.8–15 amp.).

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[1] See J. Slepian, J. A. I. E. E. October, 1928; F. C. Todd and T. E. Browne, Phys. Rev. **36**, 732 (1930).
[2] J. D. Cobine, R. B. Power and L. P. Winsor, J. App. Phys. **10**, 420 (1939).

A Rotational Analysis of Some CS_2 Bands in the Near Ultraviolet System

In considering the possible electron configurations of various electronic states of carbon disulphide, Mulliken concluded that the molecule, though linear in the normal state, is bent in the excited electronic state of the λ3200 absorption band system.[1]

Some time ago Jenkins[2] reported that some of the bands in this system resemble those of a linear molecule with a simple P and R branch. However, with the spectrograph used, many of the lines were not resolved. Photographs of the bands taken by the writer in the second order of a 30,000-line-per-inch grating having a practical resolving power of about 300,000, show some of the bands fairly well resolved. Both parallel and perpendicular types are present. It will be shown by Mulliken in a later paper that even if the molecule is bent in the excited electronic state, one may still expect essentially the same types of band structures as if it had remained linear. Let $\Lambda h/2\pi$ be the angular momentum along the axis in the lower state. In the upper electronic state, the angular momentum around an axis parallel to the line joining the S atoms may be characterized approximately by $Kh/2\pi$, because even a considerably bent carbon disulphide molecule approximates surprisingly closely to a symmetric top. Then there exists for practical purposes a selection rule, $(K-\Lambda)=0$ (parallel type), or ± 1 (perpendicular type).

The results obtained from the analysis of four rotational bands may be summarized as follows:

Band at λ3501, type $^1\Sigma_u^+ \leftarrow {}^1\Sigma_g^+$, $B'=0.1122$, $B''=0.1093$
Band at λ3467, type $^1\Pi_g \leftarrow {}^1\Sigma_u^+$,
$B_{PR}'=0.1044$, $B_Q'=0.106_5$, $B''=0.1016$
Band at λ3637, type $^1\Sigma_u^+ \leftarrow {}^1\Sigma_g^+$, $B'=0.1178$, $B''=0.1151$
Band at λ3601, type $^1\Sigma_u^+ \leftarrow {}^1\Sigma_g^+$, $B'=0.1120$, $B''=0.1097$

The B values are in cm^{-1}. The symbols used for the transition type are not strictly applicable to the bent molecule but represent those linear molecule types which the observed bands resemble. However, the capital Greek letters continue to represent the total angular momentum about the figure axis.

The bands at λ3501 and λ3601 have a common upper state whose rotational levels are perturbed. This perturbation has been analyzed indicating that it is of the heterogeneous type ($\Delta\Lambda=\pm 1$), the observed $^1\Sigma_u^+$ being perturbed by a $^1\Pi_u$ state. The perturbation analysis gives sufficient data to determine that the B value of the perturbing state is 0.113 cm^{-1}. The prediction by the theory that the heterogeneous type of perturbation causes a constant shift of all levels whose J values are greater than those of the perturbed levels, has been verified. The intensity distribution among the perturbed lines and the extra lines introduced by the perturbation has been calculated and verified. The lower states of these two bands differ by two quanta of the degenerate vibration ν_2. This would indicate that the value $\nu_2=397$ cm^{-1}, as given by the Raman spectra data for liquid carbon disulphide, is too low for carbon disulphide vapor.

It will be noted that the band at λ3467 has two B values for the upper state. One was obtained from the Q branch, the other from the P and R branches. This may most reasonably be explained by a splitting of the levels due to the removal of K degeneracy by asymmetry. In order for the asymmetry to be sufficiently large to produce the observed splitting, it is necessary that the apex angle be bent to about 120° in the upper state. Calculations show that in spite of this asymmetry, rotational levels in the upper state will still approximately follow a simple $J(J+1)$ formula if J is less than 25.

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June 25, 1940.

[1] R. S. Mulliken, J. Chem. Phys. **3**, 720 (1935).
[2] F. A. Jenkins, Astrophys. J. **70**, 191 (1929).

Gamma-Ray Resonances from the Bombardment of Carbon by Deuterons

Gamma-rays from the bombardment of carbon by deuterons were first reported by Lauritsen and Crane.[1] Later Tuve and Hafstad[2] reported γ-rays of high intensity from carbon bombarded by 1.0-Mev deuterons. We have confirmed this high yield of γ-rays from $C^{12}+H^2$ and have further found that the curve of γ-ray intensity as a function of bombarding energy is not a continuously rising curve but exhibits resonances. This is very interesting in view of the fact that it is the first known case of resonant emission of γ-rays from deuteron bombardment. Furthermore the data on the resonances in the emission of neutrons[3] and protons[4] from $C^{12}+H^2$ indicate that the γ-rays, at least in part, come from a radiative capture of a deuteron by C^{12}.

The experiments on the γ-ray resonances have been carried out with the Rice Institute high pressure Van de Graaff machine. The γ-rays have been detected both by means of coincidences of Geiger counters and by a Wulf type electroscope filled with argon at 70 atmospheres pressure. Most of the data have been taken with the electroscope because of the greater reliability and speed of such measurements. The intensity of the γ-rays from one microampere of 1.5-Mev deuterons on a thick graphite target was found to give the same ionization in the argon-filled chamber as 5 mg of radium (filtered by 1 cm of iron). The γ-ray intensity from $C^{12}+H^2$ was found to be three

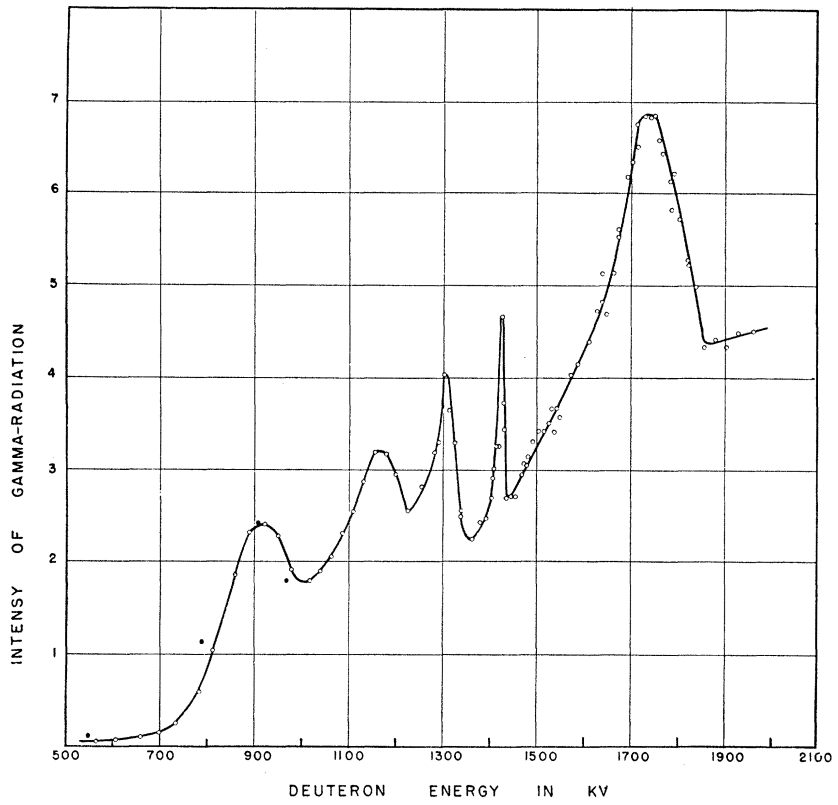

FIG. 1. The excitation curve for the emission of γ-rays from a thin target of carbon bombarded by deuterons. Open circles refer to data taken with an argon-filled ionization chamber and solid circles to data taken with coincidence Geiger counters.

times that obtained from the bombardment under similar circumstances of a thick crystal of CaF_2 by 1.5-Mev protons.

The excitation curves for the γ-rays have been carried out with thin carbon targets made by evaporation of paraffin onto silver disks. These targets were in general only a few thousand volts thick. The deuterons were magnetically analyzed by deflection through 90° before falling on the paraffin targets. Figure 1 gives the yield curve for the γ-rays from 550 kev up to 2000 kev. This curve shows resonances at 920, 1160, 1300, 1430, and 1740 kev. The experimental half-widths of the resonances vary from about 250 kev for the level at 1740 kev to 10 kev for the level at 1430 kev. The 10-kev width of this level is probably due to the spread in energy of the deuteron beam.

The γ-rays from all the resonances are hard, and although differing slightly, show about the same absorption in lead as do the γ-rays from RaTh. With poor geometrical conditions the radiation from the resonance at 1300 kev was reduced to half-value in 2.6 cm of lead.

Gamma-rays might arise from the following reactions:

$$C^{12}+H^2\rightarrow(N^{14*})\rightarrow C^{13*}+H^1+Q_1;$$
$$Q_1=2.71 \text{ Mev for ground state} \quad (1)$$

$$C^{12}+H^2\rightarrow(N^{14*})\rightarrow N^{13*}+n^1+Q_2;$$
$$Q_2=-0.25 \text{ Mev for ground state} \quad (2)$$

$$C^{12}+H^2\rightarrow(N^{14*})\rightarrow N^{14}+\gamma_1+Q_3; \qquad Q_3=10.4 \text{ Mev} \quad (3)$$

$$C^{12}+H^2\rightarrow(N^{14*})\rightarrow N^{14**}+\gamma_2+Q_3;$$
$$Q_3=10.4 \text{ Mev for ground state}$$
$$N^{14**}\rightarrow N^{14}+\gamma_3$$

$$C^{12}+H^2\rightarrow C^{12*}+H^2, \quad (4)$$
$$C^{12*}\rightarrow C^{12}+\gamma.$$

The fact that the yield of N^{13} exhibits some of the same resonances[3] as the γ-rays shows that reactions involving C^{13} could not be responsible. Considerations of the intensity of the γ-rays and of the relative abundance of the carbon isotopes ($C^{12}/C^{13}=90$) leads to the same conclusion. The observed γ-rays cannot come from reactions (2) or (4) because they would then be of very low energy. This would be impossible in view of the Geiger-counter coincidence measurements and of the absorption coefficient in lead.

Since the γ-ray resonances at 1300, 1430, and 1740 kev are not exhibited for proton emission,[4] it seems reasonable to suppose that the γ-rays from these levels are not from reaction (1), and so must be from the only remaining reaction (3). All the γ-rays would not be expected to have the maximum possible energy, but frequently the N^{14*} would return to the ground state of N^{14} in steps, as in the case of the reaction:

$$C^{13}+H^1\rightarrow(N^{14*})\rightarrow N^{14}+\gamma_1+Q_5; \quad Q_5=8.2 \text{ Mev} \quad (5)$$
$$C^{13}+H^1\rightarrow(N^{14*})\rightarrow N^{14**}+\gamma_2$$
$$N^{14**}\rightarrow N^{14}+\gamma_3.$$

Lauritsen and Fowler[5] have found γ-rays with energies of 2.8, 5.4 and 8. 1 Mev from this reaction.

Further work is in progress to investigate the energy of the γ-rays and a more detailed account of these experiments will be given after this work has been completed.

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June 27, 1940.

[1] C. C. Lauritsen and H. R. Crane, Phys. Rev. **45**, 345 (1934).
[2] M. A. Tuve and L. R. Hafstad, Phys. Rev. **48**, 106 (1935).
[3] T. W. Bonner, E. Hudspeth and W. E. Bennett, Phys. Rev., following letter.
[4] M. M. Rogers, W. E. Bennett, T. W. Bonner and E. Hudspeth, Phys. Rev., following letter.
[5] C. C. Lauritsen and W. A. Fowler, this issue, p. 193A.

Resonances in the Emission of Neutrons from the Reaction $C^{12}+H^2$

We have investigated the excitation curve for the reaction

$$C^{12}+H^2\rightarrow(N^{14*})\rightarrow N^{14}+n^1-0.25 \text{ Mev.} \qquad (1)$$

The excitation curve for the neutrons had previously been obtained by Amaldi, Hafstad and Tuve[1] using a thick carbon target. Their measurements showed no resonances because they extended to only 950 kev.

We have found that the excitation curve from a thin carbon target is not a smooth one, but shows resonances at 920, 1160, 1300, and 1825 kev. To detect the neutrons we have used a Wulf electroscope filled with hydrogen at a pressure of 7 atmospheres and we have studied the radioactivity of the N^{13} which is formed whenever a neutron is emitted according to reaction (1). The ionization measurements are much quicker, and so most of the data are of this kind. The measurements of the radioactivity of N^{13} were taken as a check on the ionization chamber data.

The hydrogen-filled electroscope would also detect neutrons from the reaction

$$C^{13}+H^2\rightarrow(N^{15*})\rightarrow N^{14}+n^1+5.2 \text{ Mev.} \qquad (2)$$

However, the yield from this reaction is only 1 percent that from reaction (1) at 800 kev.[2]

The amount of radioactive N^{13} formed in a thin paraffin target was measured by means of a thin-walled Geiger counter placed outside a thin window on the target tube. The procedure was to bombard the target for ten minutes, then shut off the high voltage and follow the activity of the target.

Figure 1 shows the excitation curves obtained from the ionization currents in hydrogen and from the radioactivity of the N^{13}. Since some of the ionization in hydrogen is due to γ-rays, corrections had to be made to compensate for this effect. By using radium filtered by 1.0 cm of lead, we found that the γ-ray sensitivity of the electroscope filled with hydrogen was only 4.75 percent that of the argon-filled chamber which was used in the γ-ray measurements. We used the same target in both experiments, so we were able to calculate that the contribution of the γ rays to the total ionization in hydrogen was 19 percent at 1525 kev. A corresponding correction was made at all other voltages. Curve (3) gives this corrected ionization due to the neutrons alone. Both curves (1) and (3) show resonances at 920, 1160, and 1300 kev. These are the same resonances as those found for the emission of γ-rays.[3] However, the γ-ray resonance at 1430 kev does not show as a resonance for neutron emission.

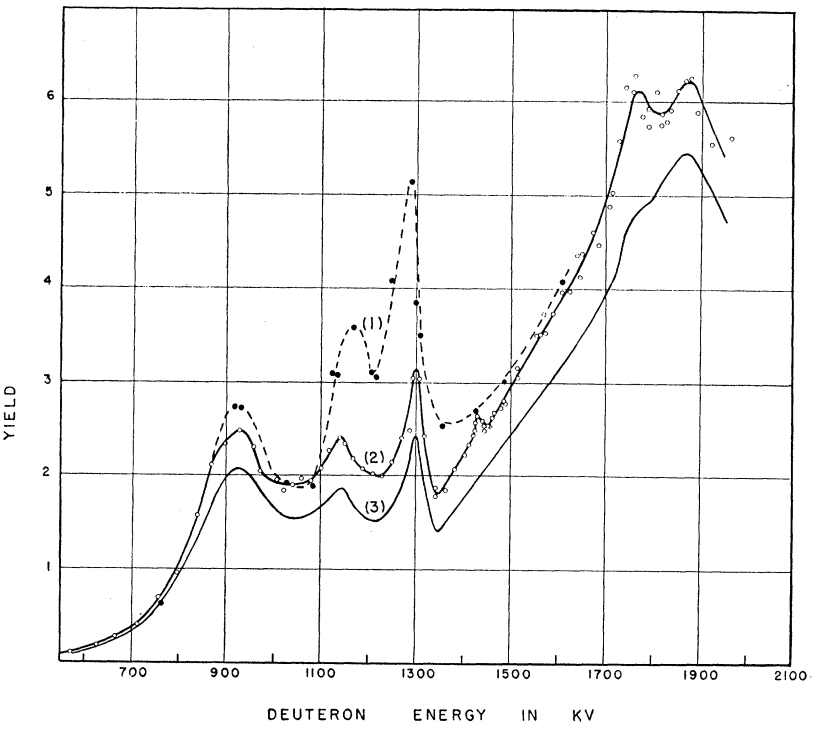

FIG. 1. Excitation curves for the emission of neutrons from a thin target of carbon bombarded by deuterons. Curve (1) gives the yield of N^{13} produced in the reaction. Curve (2) shows the ionization in a hydrogen-filled ionization chamber. Curve (3) is obtained from curve (2) by subtracting the effect produced by the γ-rays from carbon. Hence curve (3) represents the neutron yield.