The sources used were extracted from heavily irradiated plutonium, the parent isotope of $Am^{241}$ being the $\beta$-emitter $Pu^{241}$.

The energy scale was established by observing the $K$ radiation following $K$ capture in the isotopes $Os^{185}$, $Sn^{113}$, and $Zn^{65}$, giving lines at 60.8 kev, at 27.3 and 24.1 kev, and at 8.05 kev, respectively. Lines attributable to $Am^{241}$ were observed at 59.7±0.3, 26.3±0.2, 20.9±0.2, 17.3±0.2, and 13.5±0.2 kev. There were indications of the presence of a line at 75±2 kev of intensity roughly ½ percent of that of the 60-kev line. The line at 26.3 kev has not previously been reported. A typical spectrum is shown in Fig. 1, as taken with a thirty-channel pulse analyzer.

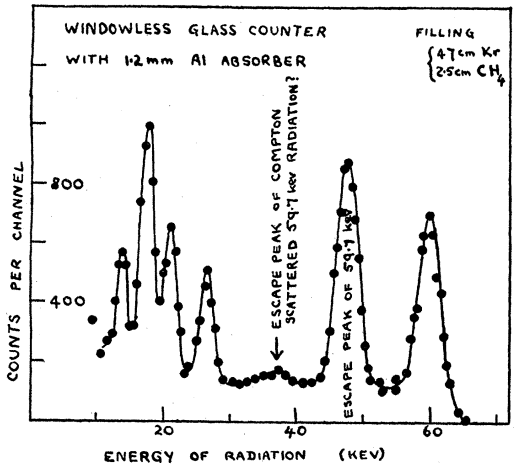


FIG. 1. $\gamma$- and $L$-ray spectrum of $Am^{241}$ observed in a krypton-filled proportional counter.

The relative intensities of the various lines were obtained by collimating the radiation and admitting it to a krypton-filled counter through a thin mica window, the efficiency of the counter being calculated from known mass absorption coefficients. A correction of 14 percent was necessary for the 59.7-kev peak due to wall effect.[1] The intensity of the 13.5-kev peak required correction for two reasons. Firstly, the "escape" peak of the 26.3-kev radiation occurred at 13.6 kev (the difference being the energy of the $K$ radiation of Kr). Secondly, as the 13.5-kev radiation lies below the $K$ absorption edge of Kr and must therefore be detected by absorption in the outer electronic shells of the counter gas, it cannot have a $K$ escape peak, and all absorbed quanta give rise to counts in the "normal" (13.5-kev) peak. The magnitude of these corrections was determined from the observation that the ratio of the counts in the escape peak to counts in the main peak for any energy of radiation was 1.00±0.03. The relative intensities of the principal lines are shown in Table I. Upper limits to the

TABLE I. Relative intensities of $\gamma$- and $L$-rays resulting from the decay of $Am^{241}$.

| Radiation energy (kev) | 59.7 | 26.3 | 20.9 | 17.3 | 13.5 |
|---|---|---|---|---|---|
| Relative intensity | 1 | 0.075±0.008 | 0.177±0.018 | 0.66±0.04 | 0.42±0.04 |

relative intensities of lines in the energy ranges 4–10 kev, 29–40 kev, 40–48 kev, 48–56 kev, and 86–120 kev were 2.5 percent, 0.02 percent, 1 percent, 6 percent, and 0.5 percent, respectively, of the 59.7-kev line.

The three lowest energy lines fit well with the energies 13.9, 17.3, and 20.9 kev to be expected for the $L_\alpha$, $L_\beta$, and $L_\gamma$ x-ray lines of $Np^{237}$, as determined by extrapolation from the published values for U, Pa, and Th.[2]

To demonstrate that the observed lines were not due to fission product contamination, the spectrum of $\gamma$-rays which were in coincidence with $\alpha$-particles was observed. A coincidence resolving time of 2 $\mu$sec was found sufficient to avoid loss of true coincidences, and it was found that the lines appeared in the same relative intensity in the single and coincidence spectra.

The number of 59.7-kev quanta per $\alpha$-particle was measured by the coincidence method, using a 2-mm thick sodium iodide crystal as the gamma-detector. The discriminator in the gamma-ray channel was set to reject all pulses below the peak due to the 59.7-kev radiation. The results required correction for the fraction of pulses lost into the "escape" peak, which is produced by the escape of iodine $K$ radiation from the crystal. The magnitude of this correction was determined by measuring the relative areas of the main and escape peaks when the source was covered with sufficient platinum to absorb the $L$ rays and the 26.3-kev line. Apart from this correction the net efficiency of the $\gamma$-counter was assumed to be equal to the solid angle which it subtended at the source. The absolute intensity of the 59.7 kev $\gamma$-ray was found to be 0.40±0.015 per $\alpha$-particle. This is to be compared with other work,[3] where a value of 0.32 was obtained.

The authors are grateful to Dr. J. Milsted for preparing the sources used and to Mr. D. West for much guidance. One of us (J.K.B.) wishes to express his gratitude to the Director, A.E.R.E., Harwell and to the Officer-in-Charge, ONR Branch Office, London, for permission to work at Harwell and for leave of absence from ONR, London.

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## The Microwave Spectrum and Molecular Constants of Hydrogen Cyanide*

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(Received April 7, 1952)

THE microwave spectra of the $J=0\rightarrow1$ transition of three isotopic species of HCN have been re-examined using a harmonic generator driven by a 2K33 klystron with a fundamental wavelength of about 1.3 cm. The third harmonic was used for $DC^{12}N$ and the fourth harmonic for $HC^{12}N$ and $HC^{13}N$, with all frequency measurements being made at the frequency of the fundamental. The observed line frequencies are given in Table I.

TABLE I. Observed line frequencies.

| Molecule | Frequency (Mc/sec) |
|---|---|
| $HC^{12}N$ | 88,631.4±0.5 |
| $HC^{13}N$ | 86,340.1±0.5 |
| $DC^{12}N$ | 72,415.0±0.5 |

The $HC^{12}N$ and $HC^{13}N$ frequencies differ by approximately 30 Mc from the values previously reported;[1] this difference possibly is due to an error by the earlier workers in the identification of frequency marker pips, which could give an error of exactly 30 Mc.

The errors given are probable errors and are expected to be made smaller by further work.

These measurements form part of a determination of the velocity of light and were undertaken after it was pointed out by Professor D. H. Rank that the previous microwave measurement of the $HC^{12}N$ frequency was inconsistent with his result for the rotational constant. The determination of $c$ is discussed by Rank in his accompanying letter.

The above frequencies lead to slight changes in the previous listed[1] bond distances. The new values for the internuclear distances as determined from the various isotopic combinations are given in Table II. In addition, a computational error seems to have been involved in the bond distances previously derived from

TABLE II. Internuclear distances.

| Isotopic pair | $d_{CH}$ | $d_{CN}$ |
|---|---|---|
| $DC^{12}N-DC^{13}N$ | 1.0657A | 1.1556A |
| $HC^{12}N-HC^{13}N$ | 1.0679A | 1.1557A |
| $HC^{13}N-DC^{12}N$ | 1.0623A | 1.1568A |
| $HC^{13}N-DC^{12}N$ | 1.0626A | 1.1567A |

the $DC^{12}N-DC^{13}N$ pair. Our calculated value for this pair, based on the earlier frequency measurements, is included in Table II. It is seen that the values for the bond distances are now more consistent with each other than formerly. In addition, the D—C distance appears shorter than the H—C distance, rather than longer as previously reported. Variations in the bond distances listed in Table II are primarily due to variation of zero-point vibrations with isotopic substitutions. Since these are particularly large for an H—D substitution, the most accurate distances are probably given by the pairs of isotopes $HC^{12}N-HC^{13}N$ and $DC^{12}N-DC^{13}N$.

The harmonic generator[2] used consists of a pair of crossed guides with a silicon crystal and tungsten cat whisker mounted inside the guide at the junction. One guide is of appropriate size for the fundamental wavelength (1.3 cm), the other guide is of a size suitable for the second harmonic. The use of various sizes of tapered wave guide at the output of the generator allows the separation of the several harmonics produced. The detector used is basically similar to the generator and is described more fully elsewhere.[3] One generator and one detector conveniently operate over a wide range of frequencies and have been used successfully for the second, third, and fourth harmonics. The only changes necessary were adjustments of the tuning plungers in the generator and detector mounts (and replacements of the 2K33 klystron to reach widely different fundamental frequencies).

The authors wish to thank Dr. G. A. Silvey for preparing the chemicals and Mr. George Dousmanis for making the calculations.

* This work was supported jointly by the Signal Corps and the ONR.
[1] Simmons, Anderson, and Gordy, Phys. Rev. **77**, 77 (1950).
[2] The design of the generator is due to Mr. E. Richter, formerly of this laboratory and now with the Sperry Gyroscope Company.
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## The Velocity of Light Determined by the Band Spectrum Method*

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IT is well known that the rotational energy levels of a diatomic or linear polyatomic molecule can be expressed by the relationship $\nu=F(J)=BJ(J+1)-DJ^2(J+1)^2+\cdots$, where $J$ is the rotational quantum number and $\nu$ is the frequency; $B=h/8\pi^2I$, where $h$ is Planck's constant and $I$ is the moment of inertia for the particular vibrational state in question; $B$, $D$ and $\nu$ as given above are expressed in pure frequency units. In the microwave absorption spectrum it is possible to measure with high precision in pure frequency units the 0→1 rotational transition for suitable molecules. The frequency of this transition is equal to $2B-4D$ to the approximation given above. $B$ and $D$ for the ground state can be determined from measurement of infrared rotation vibration bands. The values obtained from the optical spectra will be in $cm^{-1}$ units. It follows directly that the ratio of $B$ microwave to $B$ infrared is identically equal to the velocity of light in vacuum.

Dr. A. E. Douglas of Ottawa pointed out to one of us (D. H. R.) that a precision determination of $B$ infrared, preferably by interferometric means, could yield a significant value for the velocity of light. We have completed such a determination making use of two rotation vibration bands of HCN arising from the ground state. The bands used were the 103 and 004 bands, respectively. The absorption tube was an 8-meter multiple reflection tube of the type invented by White[1] and similar to those used extensively by Bernstein and Herzberg.[2]

The spectrograph consisted of a plane grating mounted between collimating and focusing mirrors of 10-meter focal length. The plane grating has 15,000 lines to the inch and 6.5 inches of ruling. This grating, ruled on speculum metal by Anderson, is exceedingly perfect and shows theoretical resolving power in the fifth order as nearly as can be determined. We are indebted to Dr. A. L. Loomis for his generosity in the donation of this grating to The Johns Hopkins University after his many years of ownership, and to Prof. G. H. Dieke of Johns Hopkins for the loan of the grating.

Photographs of the bands were obtained in the first order by using a Fabry-Perot etalon of 21.35-mm spacer external to and in conjunction with the plane grating spectrograph. Calibration of the etalon was by means of neon standards. Plates were also obtained in the second order of the grating without the auxiliary interferometer, using the fourth-order iron standards. The pressure of the gas varied in different experiments from 35 to 70 mm Hg. After measurements of the plates the molecular constants were determined by least squares methods.

Dr. Douglas kindly communicated the preliminary results which he had obtained for the ground state in his extensive unpublished work on the complete near infrared system of HCN. These values of Douglas for $B$ infrared showed that probably the measurements of $B$ microwave by Simmons, Anderson, and Gordy[3] must be in error by some multiple of ten megacycles in spite of their high precision, since no reasonable value of $c$ could be obtained. One of us (D. H. R.) communicated with Professor Gordy concerning this matter and also later with Professor Townes pointing out the importance of obtaining a check determination in the microwave spectrum. The result obtained by Townes and his collaborators, $B=44{,}315.9\pm0.25$ megacycles per second, after correcting for centrifugal distortion, appears in a companion letter in this issue of *The Physical Review*. Our result for $B$ infrared is $1.47830\ cm^{-1}\pm0.000025$. $D$ was found to be $3.1\times10^{-6}\ cm^{-1}$. The value obtained for the velocity of light $c$ is 299,776±7 km/sec, where the uncertainty stated is the sum of the uncertainties of $B$ microwave and $B$ infrared. From our experience in making these measurements and treating the data we feel that somewhat improved precision of the optical measurements is possible and that systematic error can be discovered if present and materially reduced if found. The precision of measure of this hybrid optical method at present is comparable with previous optical methods and is exceeded only by the very recent pure microwave methods.[4–7] It is certainly too early to say whether any real discrepancy between optical and microwave methods for determining the velocity of light exists. Further, more precise measurements are now in progress. A full account of these experiments will appear elsewhere.

* This research was assisted by support from the ONR.
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## Photoconductivity of Trapped Electrons in KCl Crystals between 24°C and −190°C

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THE photoconductivity of trapped electrons in KCl[1] and KBr[2] crystals at room temperature has been reported previously. The same technique has now been used to study the