

FIG. 1. Range-energy relationship for  $C^{12}$  ions in E1 emulsion. Experimental points show  $E_r(\alpha)$  vs. range. Solid curve shows  $E_r(R)$  vs. range for  $Z_{eff}(C^{12})=3.62$ .

A few  $\alpha$ -particle tracks having a short, heavy stub at the origin were attributed to photo-alpha-reactions in light nuclei, in which the recoil fragment had small charge and sufficient energy to leave a measurable track. The only elements of this kind present in the emulsion are carbon, nitrogen, and oxygen; since carbon normally disintegrates into a three-pronged  $\alpha$ -particle star, it was suspected that these events might be due to the reactions  $N^{14}(\gamma, \alpha)B^{10}$  and  $O^{16}(\gamma, \alpha)C^{12}$ . These assignments were confirmed by the following analysis.

The energy of each recoil fragment,  $E_r(\alpha)$ , was calculated from the momenta and energies of its associated  $\alpha$ -particle and  $\gamma$ -ray

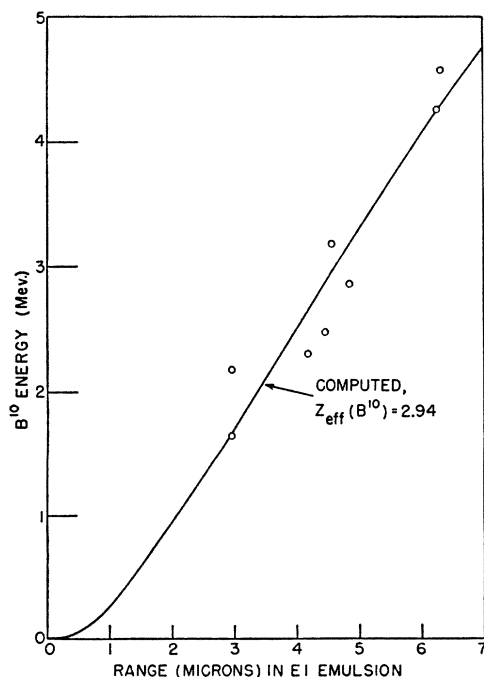


FIG. 2. Range-energy relationship for  $B^{10}$  ions in E1 emulsion. Experimental points show  $E_r(\alpha)$  vs. range. Solid curve shows  $E_r(R)$  vs. range for  $Z_{eff}(B^{10})=2.94$ .

on the assumptions that it was either (1)  $B^{10}$  or (2)  $C^{12}$ . On these same assumptions it was also possible to calculate two values for the energy of the recoil nucleus,  $E_r(R)$ , from the functional form of the general range-energy relationship:  $E/M=f(Z_{eff}^2 R/M)$ , by making use of the known range-energy relationship for  $\alpha$ -particles for which a value  $Z_{eff}=2$  was used. For the recoil fragment,  $Z_{eff}$ , the ionic charge, is less than the nuclear charge since at low energies not all the atomic electrons are stripped from their orbits;<sup>4</sup> and it will vary from point to point along the track. However, by applying this method of analysis to the experimental range-energy points for light nuclei used in Knipp and Teller's paper,<sup>4</sup> we are convinced that over the limited range of energy in our experiment a constant value of  $Z_{eff}$  for the recoil nuclei is a satisfactory approximation in each case. A preliminary study of our data indicated that a value of  $Z_{eff}=0.6Z$  was sufficiently accurate to identify the reactions.

For each event the recoil energies as calculated by the above two methods were compared and in most cases it was found that  $|E_r(\alpha)-E_r(R)|$  was less than 0.5 Mev on one assumption as to the identity of the recoil nucleus which served to identify the reaction, and was considerably greater for the alternative assumption. In this manner, of the 32 events studied, 23 were identified as the  $O^{16}(\gamma, \alpha)C^{12}$  reaction and 8 as the  $N^{14}(\gamma, \alpha)B^{10}$  reaction. One event, which disagreed with both of the above assumed reactions, agreed with the assumption that it was the photo-disintegration of  $C^{12}$  via the ground state of  $Be^8$ .

Figure 1 shows the range-energy relationship for  $C^{12}$  ions in E1 emulsion thus obtained. From the individual points a mean  $Z_{eff}(C^{12})=3.62$  was calculated, and the solid line is the curve obtained from the functional equation using this value. Wrenshall<sup>5</sup> studied recoiling  $C^{12}$  ions in two gas mixtures and reduced the range-energy relationships thus found to standard air. By applying to these de Carvalho's stopping power formula,<sup>6</sup> reduced in range by 3 percent to convert from C2 to E1 emulsions, the curves W1 and W2 were obtained. The agreement with our data is satisfactory.

Figure 2 shows the range-energy relationship for  $B^{10}$  ions obtained in the same way with  $Z_{eff}(B^{10})=2.94$  giving the best fit.

We should like to thank Dr. R. N. H. Haslam and his co-workers at the University of Saskatchewan for making the betatron irradiations, Dr. B. W. Sargent for his interest and advice on the experiment, and Mr. R. G. Hayman for his assistance in searching the plates.

<sup>1</sup> H. Yagoda, *Radioactive Measurements with Nuclear Emulsions* (John Wiley and Sons, Inc., New York, 1949), p. 62.

<sup>2</sup> Hänni, Telegdi, and Zúnti, *Helv. Phys. Acta* **21**, 203 (1948).

<sup>3</sup> Goward, Titterton, and Wilkins, *Proc. Phys. Soc. (London)* **A62**, 460 (1949).

<sup>4</sup> J. K. Knipp and E. Teller, *Phys. Rev.* **59**, 659 (1941).

<sup>5</sup> G. A. Wrenshall, *Phys. Rev.* **57**, 1095 (1940).

<sup>6</sup> H. G. de Carvalho, *Phys. Rev.* **76**, 1729 (1949).

## The Raman Spectrum of Bromine

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**I**n collaboration with Oswaldo Sala we have developed recently an experimental technique for obtaining Raman spectra excited by He 5875.6Å. Details concerning the construction of intense He-lamps and a luminous Raman arrangement will be given elsewhere.

With this arrangement we have attempted to measure the Raman spectrum of gaseous bromine using a 50-cm long Raman tube; the first 10 cm were illuminated by the exciting radiation. The tube contained pure  $Br_2$ ; the pressure was about 900 mm at

85°C. We employed a Lane-Wells three-prism Raman spectrograph with a reciprocal dispersion of 63A/mm in the region of the exciting line.

Most unexpectedly we obtained by an exposure of 15 hours not only the fundamental Raman frequency, but also the shifts corresponding to the first and second overtones with comparable intensity. The reproduction shown in Fig. 1 is an enlargement of the original spectrum.

The frequencies and relative intensities of the Raman shifts are given in Table I.

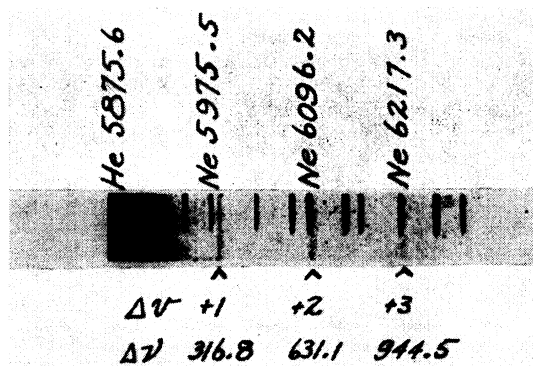


FIG. 1. Raman spectrum of bromine.

From observations on band spectra<sup>1</sup> we have  $\omega_e = 323.86 \text{ cm}^{-1}$  and  $\omega_e x_e = 1.15 \text{ cm}^{-1}$ . From these data we should expect in first approximation a fundamental Raman frequency of  $320.4 \text{ cm}^{-1}$  as compared with the observed value of  $316.8 \text{ cm}^{-1}$ . This difference is 3 or 4 times larger than our measuring error. On the other hand, the small anharmonicity of the three observed frequencies agrees very satisfactorily with the above value of  $\omega_e x_e$  and confirms our value.

From  $316.8 \text{ cm}^{-1}$  we calculate for the molecule  $\text{Br}^{79}\text{-Br}^{81}$  the uncorrected force constant

$$f = 2.35 \times 10^6 \text{ dynes/cm.}$$

The appearance of the intense overtones is the more surprising when one considers that of all Raman-investigated diatomic molecules the  $\text{Br}_2$  molecule approximates best to the simple model of the harmonic oscillator. It seems that even first overtones have never been observed in the Raman spectra of diatomic molecules; in polyatomic molecules they appear in rare cases very weakly. Their intensities compare with the intensities of the fundamental frequencies roughly as the square of the ratio of nuclear distance to displacement. Applying this general rule we should expect in the case of bromine an intensity ratio of nearly  $10^6:10^3:1$  between the fundamental frequency and the first and second overtones.

The relative intensities given above were measured by comparing the density of the lines with intensity marks. They do not

TABLE I. Raman lines of bromine.

$\Delta\nu$	$\Delta\nu(\text{cm}^{-1})$	Rel. int.
+1	316.8	1
+2	631.1	0.85
+3	944.5	0.47

represent the true intensity ratio. Reabsorption of the scattered radiation in the bromine gas weakens the fundamental frequency; on the other hand, the spectral sensitivity of the photographic plate employed is somewhat lower in the region of the second overtone. In any case, the true intensities are not very far from those indicated.

There is no doubt that we have here true overtones corresponding to transitions  $v = +2, +3$ , and not a case of multiple scattering. This results obviously from the relative intensities and also from the observed anharmonicity.

We hope to investigate with a spectrograph of greater dispersion and resolving power the finer vibrational details of the observed frequencies. Besides the isotope effect, we have to expect a structure coming from the participation of the different initial vibrational states. For our temperature conditions the statistical weights of the fundamental and of the first and second excited vibrational states correspond approximately to the ratio 100:45:13. Unfortunately, the absorption of shorter wave-lengths in the bromine gas prohibits the observation of anti-Stokes shifts.

<sup>1</sup> H. Sponer, *Molekülspektren I* (Tabellen, Berlin, 1935).

### Decay Time of Stilbene Scintillations as a Function of Temperature

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USING 931-A photo-multipliers and a pulsed-counter technique described in the accompanying letter we have photographed scintillation pulses from trans-stilbene and have used these to obtain decay time data at isolated temperatures down to that of liquid nitrogen. The observed pulse rise times were about  $10^{-9}$  second. Since this time is considerably shorter than the measured decay times, the data were analyzed simply by comparison of the photographed pulses (smoothed by tracing) with plotted exponentials. The trans-stilbene was used in crystalline form, and was of high purity. In an attempt to obtain a rough comparison with the work of Kelley and Goodrich<sup>1</sup> we have also analyzed a few counts from a crystal of anthracene of unknown purity, at the same temperatures at which the stilbene data were taken. Our value for the decay constant of anthracene at liquid nitrogen temperature agrees with theirs and also with the value obtained by Collins.<sup>2</sup> However, at the higher temperatures our values are noticeably lower than those found by Kelley and Goodrich. The explanation of the discrepancy is not known, but it should be noted that the anthracene pulses consistently showed a very ragged structure at room temperature, making the drawing of the exponentials a matter of individual judgment. The stilbene data, on the other hand, were satisfactorily smooth at all of the temperatures. Our results for stilbene and anthracene are given in Table I, together with their r.m.s. deviations from the mean.

In the experimental set-up, the last 2 dynodes of the photo-multiplier were bypassed with 0.0005 microfarad condensers to prevent dynode voltage variations. Further voltage stabilization during the pulses was achieved by using 100-ohm resistors in the dynode divider network, connected by fairly short leads to the tube socket. Two different tubes were used in obtaining the stilbene data, and no appreciable differences were noted in the data obtained from either at the same temperature. No saturation effects were noted in the performance of the photo-multipliers at even the highest scintillation pulse amplitudes. Because of the rapid rise time of the count pulse, delivered from a low impedance source (a terminated 100-ohm coaxial lead) directly to the plates of the oscilloscope tube, it was necessary to use a 100-ohm damping resistor in series with the connection from the coax center con-

TABLE I. Decay time (to  $1/e$ ) in microseconds.

Temp.	-196°C	-78°	27°
Trans-Stilbene	$0.0044 \pm 0.0005$	$0.0049 \pm 0.0006$	$0.006 \pm 0.001$
Anthracene	$0.010 \pm 0.002$	$0.018 \pm 0.002$	$0.023 \pm 0.005$

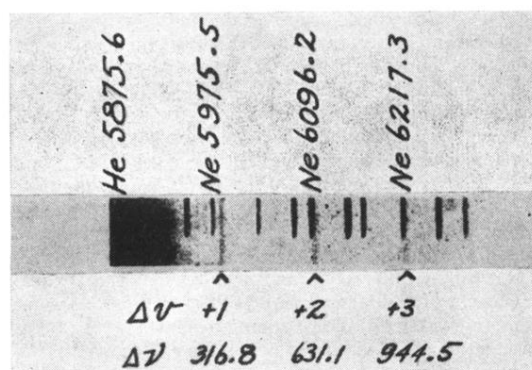


FIG. 1. Raman spectrum of bromine.