

Plates taken on the spectrograph described by Ekefors<sup>1</sup> with 400 sparks at  $7 \cdot 10^4$  volts and  $0.63 \cdot 10^{-6}$  farads between aluminum electrodes cored with rubidium halide salts, show the principal doublet of the copper-like spectrum of rubidium ( $Z=37$ ):

Rb IX  $4s^2S_{1/2}-4p^2P_{3/2}$  583.37A 171417  $\text{cm}^{-1}$   
 $4s^2S_{1/2}-4p^2P_{1/2}$  628.62A 159078  $\text{cm}^{-1}$

with about the same intensity as the strongest lines of the 833A group of oxygen. They are present in three orders. With a self inductance of  $6 \cdot 10^{-6}$  henrys in series with the gap, the stronger (583A) is perceptible, but the weaker is entirely cut out, while neighboring lines of lower excitation energy are little affected. With only  $8 \cdot 10^{-6}$  henrys in series, however, the intensity of the Rb IX lines is but slightly less than with none, whereas some still unidentified fairly intense lines are cut out, indicating that they require considerably more energy for excitation. A crude preliminary estimate gives for the energy required to remove eight electrons from rubidium:

Rb I  $4s^24p^65s^2S$  - Rb IX  $4s^2S=5 \cdot 10^2$  electron volts.

The corresponding Br VII lines are among the most intense on the plates.

Complete details will be given later with a more general study of the ultraviolet spark spectra of the heavier halogens and alkali metals, in collaboration with Mr. J. C. Betz, to whom I am indebted for aid in the measurements and calculations.

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 Madison, June 6, 1931.

<sup>1</sup> B. Edlén and A. Ericson, *Zeits. f. Physik* **64**, 64 (1930); E. Ekefors, *Phys. Zeits.* **15**, 737 (1930). The circuit used here differs from that of these investigators in that the air gap in series with the vacuum spark gap is here omitted.

#### The Scattering of X-rays from Polyatomic Gases

P. Debye<sup>1,2</sup> has recently discussed the interference pattern of the x-rays scattered by gases such as  $\text{CH}_2\text{Cl}_2$  and  $\text{CCl}_4$ . These gases can be considered approximately as diatomic and tetraatomic gases respectively, because such a great proportion of the intensity of the scattered rays comes from the chlorine atoms. According to Debye, the intensity per electron of the x-rays scattered by a gas consisting of molecules made up of point atoms of the same kind is

$$S = \frac{Z}{n} \sum_{r=1}^n \sum_{s=1}^n \frac{\sin kl_{rs}}{kl_{rs}} \quad (1)$$

where

$$k = 4\pi \sin(\phi/2)\lambda \quad (2)$$

and  $Z$  is the number of electrons massed together into each point atom,  $n$  is the number of atoms in each molecule, and  $l_{rs}$  is the distance between the  $r$ th and  $s$ th atoms of a molecule.

More recently, Jauncey<sup>3</sup> has investigated the theory of the scattering of x-rays by a solid consisting of atoms of one kind. This theory can also be applied to a single molecule of gas, the atoms having size and the molecule a given orientation. The formula for this case is

$$S = 1 + (Z-1)f'^2/Z^2 + (f^2/nZ) \sum_{r=1}^n \sum_{s=1}^n \cos k(z_r - z_s) \quad (3)$$

where the symbol  $\sum' \sum'$  indicates that in the summation  $r \neq s$ ,  $f$  is the atomic structure factor of an atom and  $f'$ , which is nearly equal to but less than  $f$ , has been discussed by Jauncey.<sup>4</sup> Eq. (3) is valid for a particular orientation of the molecule. For random orientation, it can easily be shown that

$$S = 1 + (Z-1)f'^2/Z^2 + (f^2/nZ) \sum_{r=1}^n \sum_{s=1}^n \frac{\sin kl_{rs}}{kl_{rs}} \quad (4)$$

For point atoms,  $f'=f=Z$  and the right side of Eq. (4) becomes identical with Debye's Eq. (1). For diatomic atoms, Eq. (4) becomes

$$S = 1 + (Z-1)f'^2/Z^2 + (f^2/Z) \frac{\sin kl}{kl} \quad (5)$$

where  $l$  is the separation of the centers of the two atoms. For a molecule consisting of atoms whose centers are at the corners of a regular tetrahedron, Eq. (4) becomes

$$S = 1 + (Z - 1)f'^2/Z^2 + (f^2/Z) \frac{3 \sin kl}{kl} \quad (6)$$

where  $l$  is the length of a side of the tetrahedron. Debye gives an experimental curve for  $\text{CCl}_4$ , whose humps are flatter than required by Eq. (1). According to Debye, this flatness is due partly to the size of the atoms of Cl. We see that the size can be taken account of by Eq. (6). However, when Wollan's<sup>5</sup>  $f'$  values for argon are put in Eq. (6), the humps are somewhat but not sufficiently flattened.

Eqs. (3) and (4) are based on the assumption of no thermal vibrations of the atoms within a molecule of the gas and Debye has suggested that part of the flatness of the experimental curve is due to thermal vibration of the atoms. If there is thermal vibration of the atoms, it is only the double summation of Eq. (4) which is affected. Let us find the average value of  $(\sin kl)/kl$  as  $l$  varies. If we suppose that  $l = l_0 + x$  where  $l_0$  is the average separation and also that the fraction  $x/l_0$  is small and that the probability of  $x$  being between  $x$  and  $x + dx$  is  $\exp(-x^2/\alpha^2)dx$ , we find

neglecting squares and higher powers of  $\alpha/l_0$ , that

$$\text{Ave} \frac{\sin kl}{kl} = \frac{\sin kl_0}{kl_0} \exp(-k^2\alpha^2/4). \quad (7)$$

Hence to take care of the thermal vibration of the atoms we multiply the double summation term in Eq. (6) by  $\exp(-k^2\alpha^2/4)$ , where  $\alpha$  is the most probable change in the separation of any pair of atoms from the value  $l_0$ . This has the effect of further reducing the humps at large angles as has been noted by Bewilogua.<sup>6</sup>

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June 12, 1931.

<sup>1</sup> P. Debye, Phys. Zeits. **31**, 419 (1930).

<sup>2</sup> P. Debye, Proc. Phys. Soc. Lond. **42**, 340 (1930).

<sup>3</sup> G. E. M. Jauncey, Phys. Rev. **37**, 1193 (1931).

<sup>4</sup> G. E. M. Jauncey, Phys. Rev. July 1, (1931).

<sup>5</sup> E. O. Wollan, Phys. Rev. **37**, 862 (1931).

<sup>6</sup> L. Bewilogua, Phys. Zeits. **32**, 265 (1931).

#### The Effect of Internal Stress on Magnetic Susceptibility

Honda and Shimizu have found (Nature **126**, 990, 1930) that copper and silver when severely cold worked suffer a decrease of diamagnetic susceptibility. Subsequent annealing restores the susceptibility (and the density, which is decreased by cold working) to the original value. Copper may even be made paramagnetic, but when heated in a vacuum the original diamagnetism is completely restored at about 350°C.

These experiments seem to corroborate the previous work of Francis Bitter (Phys. Rev. **36**, 978, 1930) who found that stretching copper and silver wires beyond the elastic limit altered their susceptibilities. H. E. Banta, (Phys. Rev. **37**, 634, 1931) has repeated Bitter's work but failed to find any effect of stretching on the susceptibility. Since there was a possibility that Banta's wires were not given sufficiently large internal stresses to produce the desired effect some further measurements have been made of the density change caused by stretching annealed copper wires. These wires were cut from the same piece which had furnished samples for the susceptibility measurements and were stretched by practically the same amount as those sam-

ples. A density decrease was produced which was adequate to cause an easily measurable susceptibility change, assuming the curve given by Honda and Shimizu to hold. However, no susceptibility change was found. The negative result of Banta cannot, therefore, be due to insufficient strains.

In a private communication to one of the writers Francis Bitter has pointed out that the equation  $dI/dp = de/dH$ , expressing the reciprocal relationship between intensity of magnetization  $I$ , pressure  $p$ , strain  $e$ , and field  $H$ , does not necessarily imply a value of  $dI/dp$  too small to measure even though  $de/dH$  cannot be observed. In Banta's paper this equation and the absence of magnetostriction in copper was adduced as an argument against an effect of strain on susceptibility. Bitter, however, states that in a piece of copper stretched to the breaking point the pressures may be a good deal larger than 5000 kg/cm<sup>2</sup>. This is a surprisingly large value, since the International Critical Tables give 2277 kg/cm<sup>2</sup> as the ultimate tensile strength of electrolytic copper. Using  $dp > 5 \times 10^9$  dynes/cm<sup>2</sup> and  $dI < 2 \times 10^{-2}$  as reasonable values for his own experiments, Bitter gets