

FIG. 1. Section of mesotron track 6949, enlarged to about three times its size in the cloud chamber. Ion pairs are separated into positive and negative columns, with the positive on the left side. At the top a sharp electron track crosses the picture.

they are quite conspicuous it is probable that not many more will be found by additional study of the pictures. Most of the heavy tracks thus do not represent slow mesotrons;<sup>6</sup> in fact, the fraction of slow mesotrons may not greatly exceed the figure of 0.001 found by E. J. Williams at sea level.

Four of these slow mesotrons yield mass values as follows:

Track	Ionization	$H\rho$	Mass: C. & B.	Mass: Williams <sup>8</sup>
8-21, 2	$2.5 \times I_0$	$2.26 \times 10^5$	$210 \pm 20$	$230 \pm 20$
1621	6.0	1.08	$180 \pm 20$	$225 \pm 20$
6941	6.2	1.11	$190 \pm 15$	$240 \pm 15$
6949	2.4	1.6	$145 \pm 30$	$155 \pm 30$

The probable errors are estimated to include chamber distortion of curvature and statistical uncertainty deriving from the finite number of droplets counted. Curvature was measured by plotting micrometer readings of coordinates along the track and fitting a curve to the points by the method of least squares. The curvature of the first track, for example, was determined from 13 points, with a probable error in fitting of 3.5 percent. The ionization of this track was determined by a count of 335 droplets, hence the statistical error is  $\sim 5$  percent (or more, since each ion is not the result of a single independent event).

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\* Guggenheim Fellow at the time of preparing and assembling the apparatus.

<sup>1</sup> J. A. Wheeler and R. Ladenburg, Phys. Rev. **60**, 754 (1941).

<sup>2</sup> R. B. Brode and G. D. Bagley, Phys. Rev. **56**, 209A (1939).

<sup>3</sup> C. E. Nielsen, Phys. Rev. **61**, 202A (1942).

<sup>4</sup> D. R. Corson and R. B. Brode, Phys. Rev. **53**, 773 (1938).

<sup>5</sup> E. J. Williams, Proc. Roy. Soc. **A172**, 194 (1939).

<sup>6</sup> Compare results of W. M. Powell, Phys. Rev. **61**, 670 (1942).

### X-Ray Line Broadening by Cold-Working Alpha-Brass

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NIEMANN and Stephenson have reported<sup>1</sup> that the x-ray diffraction line broadening produced by small amounts of cold-working of alpha-brass is enhanced by speed of working, while the internal friction thus introduced is not. The first of these facts, which might be of great importance to practical metal forming, is not confirmed by our observations.

Three like-tensile specimens of cartridge brass having sections 6.3 by 0.53 mm, sealed in nitrogen, were annealed for ninety minutes at 400°C, and showed fine-grained strain-free diffraction by back-reflection. Each was then cold-stretched about 7.5 percent, one by a falling weight at a speed exceeding 30 ft./sec., one by a hammer-blow of somewhat less speed, and one slowly in a small tensile stressing frame. The back-reflection patterns from these three strained specimens show no significant difference of line broadening. In each the Ni  $K\alpha$  doublet has become nearly irresolvable visually. If any difference can be found it is that both fast-worked specimens gave traces of coarse-grain irregularity in the photographs, as the other did not.

These observations seem to remove the disparity between line broadening and internal friction effects of cold work. The earlier observations may have been effected by initial differences between the specimens.

<sup>1</sup> F. Niemann and S. T. Stephenson, Phys. Rev. **62**, 330 (1942).

### The Forces Between Hydrogen Molecules

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THE difficult part in an *a priori* calculation of intermolecular forces is the determination of the repulsive exchange forces. For this reason, complete interaction curves have hitherto been obtained for a few simple spherical atoms only. Yet to understand even the most elementary properties of molecules, such as their size and shape, and also to locate the position of the minimum of their van der Waals forces, a knowledge of the exchange forces is required. Attracted by the fundamental nature of the problem, I have undertaken to calculate them for the simplest molecule and herewith report the results.

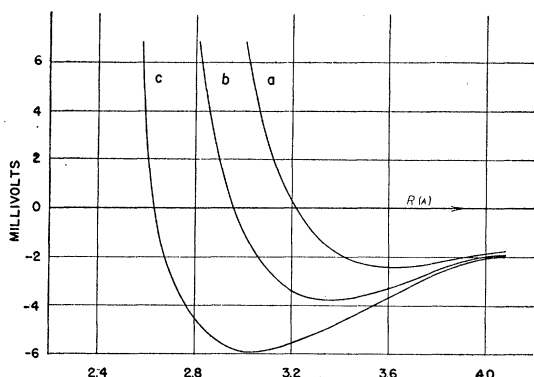


FIG. 1. Interaction energies of two hydrogen molecules, in millivolts, plotted against distance between their centers (in Å). Relative orientation of molecules is as follows: (a) —, (b) - - -, (c) ···.

A function of the Heitler-London-Wang type was chosen to represent the electronic charge distribution of a single molecule. As is well known, this function yields the best molecular energy when the effective nuclear charge,  $Z$ , is taken to be 1.166 electronic units.<sup>1</sup> In the present calculation,  $Z$  was at first left undetermined.

The interaction was investigated for three relative positions of the molecules: (a) both molecular axes are parallel to the line connecting the centers; (b) one molecule is parallel, one perpendicular; (c) both molecules are perpendicular to the center line. The customary approximation of neglecting double exchange integrals leads to results which are entirely erroneous in this problem, and it is necessary to retain all terms. Unwieldy four-particle integrals, however, can be reduced with good validity to known three- and even two-particle integrals.

One feature emerging from the calculation is the following. When  $Z$  is taken to be 1.166 (Wang's value), the exchange forces are *attractive*. This emphasizes the fact that the effective nuclear charge does not have a unique physical significance and that its constancy may not be assumed in molecular problems where the charge symmetry is far from spherical. On further consideration it turned out that in the other two-electron problem, the interaction of He atoms, there is a limiting value of  $Z$ , namely  $(11/8)e$ , below which the exchange forces are also attractive in the interesting range of atomic separations. But in this case the normal value of  $Z$  is great enough to cause no difficulty. The physical reason for the inadequacy of the customary value of  $Z$  in the intermolecular problem is to be found in the circumstance that the electronic charge is strongly concentrated between the two nuclei of a molecule, leaving the nuclei bare to an abnormal degree.

The calculations were therefore carried out for several different values of  $Z$ . Various considerations lead to  $Z \approx 1.4$  as the most reasonable choice. Hence the results will here be given for that case only.

An  $H_2$ -molecule represents a static quadrupole. The part of the interaction arising from this fact is almost negligibly small throughout. It can be expressed in the simple form

$$\Delta E_Q = \frac{3}{25} \left( \frac{\Delta^2}{1 + \Delta^2} \right)^2 \frac{e^2 d^4}{R^5} \cdot f$$

where  $\Delta$  is the usual overlap integral between the atoms of a single molecule and  $d$  the distance between these atoms. The function  $f$  expresses the characteristic angular variation for forces between linear quadrupoles.

Finally the attractive van der Waals energy must be included. This may be taken from the work of Massey and Buckingham,<sup>2</sup> whose result, however, is larger than can be obtained from dispersion data on  $H_2$  vapor. When the dipole-quadrupole forces are added, the result is in fair agreement with that derived by the latter authors.

Composition of all these effects yields the interaction curves (drawn for cases (a), (b), and (c) as defined above) which are given in Fig. 1. As would be expected, collinear molecules repel at larger distances and produce a shallower minimum than parallel ones. When the distances at which the minima occur, and also their depths, are compared with the empirical curves derived by Lennard-Jones and others<sup>3</sup> from gas kinetic effects, satisfactory agreement is found.

<sup>1</sup> S. C. Wang, *Phys. Rev.* **31**, 579 (1928).

<sup>2</sup> H. S. W. Massey and R. A. Buckingham, *Proc. Roy. Soc. London*, **45**, 31 (1938).

<sup>3</sup> R. H. Fowler and E. A. Guggenheim, *Statistical Thermodynamics* (Cambridge University Press).

## The Disintegration Scheme of $Na^{24}$

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THE gamma-rays of  $Na^{24}$  have been studied by several authors. Various energies between 0.8 and 3 Mev were announced at different times. In 1941 Itoh<sup>1</sup> reported finding only two gamma-rays of 1.38- and 2.8-Mev energy respectively and equal intensity. Our experiments, completed before we received Itoh's paper, confirmed his results and therefore were reported only briefly at a section meeting of the Physical Society.<sup>2</sup> Since then these results were again questioned by C. E. Mandeville.<sup>3</sup> We have since repeated the measurements with improved accuracy.

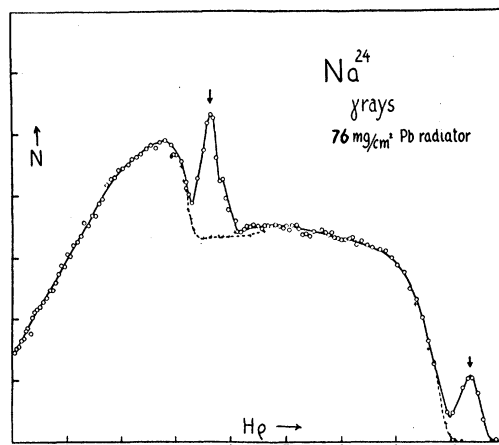


FIG. 1. Secondary electron spectrum showing photoelectron (arrows) and Compton electron (dotted line) groups due to the 1.38 and 2.76 Mev gamma-rays of  $Na^{24}$ .