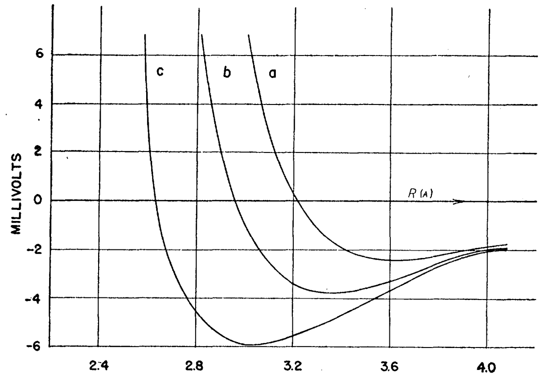

FIG. 1. Interaction energies of two hydrogen molecules, in millivolts, plotted against distance between their centers (in A). Relative orientation of molecules is as follows: (a) — —, (b) — |, (c) | |.

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, Ze, is taken to be 1.166 electronic units.[1] 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 Δ 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,[2] 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[3] from gas kinetic effects, satisfactory agreement is found.

[1] S. C. Wang, Phys. Rev. 31, 579 (1928).

[2] H. S. W. Massey and R. A. Buckingham, Proc. Roy. Ir. Acad. 45, 31 (1938).

[3] R. H. Fowler and E. A. Guggenheim, *Statistical Thermodynamics* (Cambridge University Press).

The Disintegration Scheme of Na^{24}

L. G. ELLIOTT, M. DEUTSCH, AND A. ROBERTS*
Massachusetts Institute of Technology, Cambridge, Massachusetts

April 30, 1943

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[1] 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.[2] Since then these results were again questioned by C. E. Mandeville.[3] We have since repeated the measurements with improved accuracy.

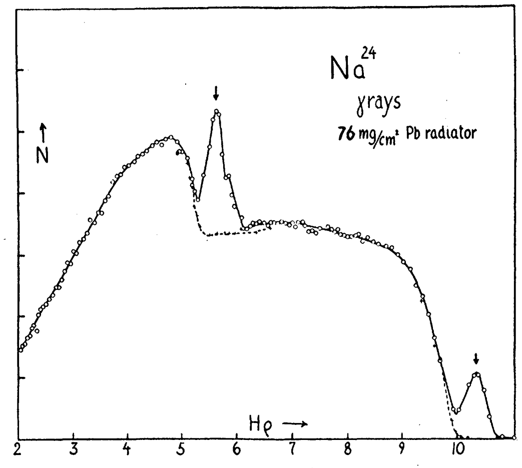

FIG. 1. Secondary electron spectrum showing photoelectron (arrows) and Compton electron (dotted line) groups due to the 1.38 and 2.76 Mev gamma-rays of Na^{24}.

Figure 1 shows the momentum distribution of secondary electrons ejected from a thin lead radiator (and its brass backing) observed in the magnetic lens spectrometer. The observed counting rates were not divided by Hρ as is customary. This procedure was adopted to keep the ordinates of the curve more nearly equal throughout the entire range. Besides, we wish to emphasize the two photoelectron lines (marked by arrows) whose heights should *not* be divided by the transmitted momentum interval since they represent nearly monokinetic electron groups.

The half-width of the transmitted momentum band is about 3.5 percent, but the observed width of the photoelectron lines is slightly greater because of the thickness of the radiator and the presence of the unresolved *L* photoelectron groups. The statistical counting errors are negligible for most of the points. However the probable error, as indicated by the scatter of the points is about two percent, due partly to small errors in correcting for decay of the sources and in normalizing the several runs of which the curve is a composite.

All regions where photoelectron lines were suspected were studied in separate runs, and it seems quite certain that the intensity of any other gamma-ray above 0.34 Mev (if present at all) does not exceed ten percent of the intensity of the two observed lines.

The distribution of Compton recoil electrons from a copper radiator was also studied. Its absolute intensity and shape deviate by several percent from the Compton groups from lead, probably because of the difference in scattering of the secondary electrons in the two radiators. Therefore only the regions near the end points are indicated in Fig. 1 (crosses and dotted line).

The energies of the gamma-rays, obtained both from the photoelectron lines and the Compton end points are 1.38 ±0.03 and 2.76±0.06 Mev. The ratio of the intensities may be obtained by correcting the heights of the lines for the variation in photoelectric cross sections and retardation in the radiator. Details of this correction will be published soon in a paper dealing with spectrometer technique. The ratio thus obtained is $I_{1.4} : I_{2.8} = 0.9 : 1$, uncertain to about fifteen percent.

While some of the divergent results previously obtained by other authors were probably due to misinterpretation of data, others may have been due to impurities. The remote possibility cannot be excluded entirely that there may be *several* gamma-rays of very low intensity in the energy range between the two intense lines.

Coincidence measurements of beta- and gamma-rays and of gamma-rays with each other were also performed, and the results agreed with those of other workers,[1, 4] showing that each beta-ray is followed by a 1.38- and a 2.76-Mev gamma-ray in cascade. Mr. W. C. Peacock of this laboratory has recently repeated these experiments with carefully calibrated gamma-ray counters, and it appears quite certain that the great majority (at least 90 percent) of the disintegrations proceeds by this scheme. As in the case of Y^{86} the fact that the gamma-ray energies are in the ratio 1 : 2 has therefore no evident significance in terms of the disintegration scheme.

Our thanks are due to Professors Evans and Livingston and the cyclotron crew.

* Now at the M. I. T. Radiation Laboratory.

[1] J. Itoh, Proc. Phys. Math. Soc. Japan **23**, 605 (1941).

[2] L. G. Elliott *et al.*, Phys. Rev. **61**, 99A (1942).

[3] C. E. Mandeville, Phys. Rev. **62**, 309 (1942).

[4] Feather and Dunworth, Proc. Camb. Phil. Soc. **34**, 442 (1938).

Gamma-Rays from Na^{24} and La^{140}

C. E. MANDEVILLE
The Rice Institute, Houston, Texas

April 30, 1943

MEASUREMENTS on the energies and relative intensities of the γ-rays from Na^{24} have been repeated with a magnetic spectrograph which has been previously described.[1] Recent measurements[1] seemed to indicate the presence of quanta at 0.84, 1.31, 1.66, and 2.90 Mev. Subsequent improvements and modifications in the operation of the spectrograph and experiments[2, 3] on the γ-rays from Sc^{48} and As^{76} have disclosed that the spectrograph was not satisfactorily designed for the measurement of γ-rays of energy less than 1.0 Mev and with an intensity less than fifty percent of that of any high energy γ-rays present when the first experiments[1] on the gamma-radiation from Na^{24} were performed. In addition to measurements of the energies of the γ-rays from Sc^{48} and As^{76}, observations as yet unpublished, extending over a wide range of energy, have been made upon a considerable number of the radioactive isotopes of other elements. On plotting the distributions in momentum of the Compton recoils of the γ-rays from these various radioactive isotopes, it became apparent

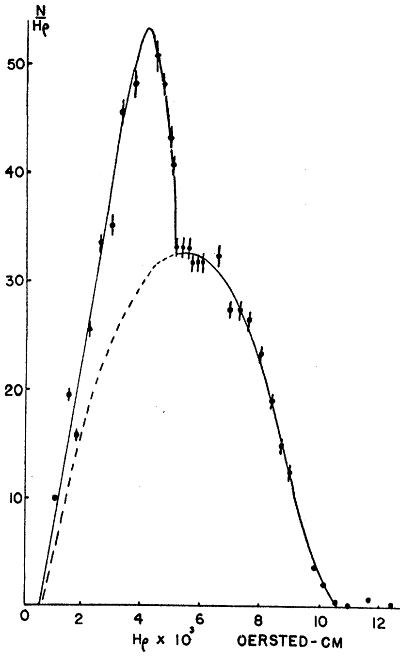

FIG. 1. Momentum distribution of the Compton recoils of the γ-rays from Na^{24}.