Band Spectra of the Selenium Isotopes

SUMNER P. DAVIS AND F. A. JENKINS
Department of Physics, University of California, Berkeley, California
(Received July 30, 1951)

AN investigation of the rotation structure of the $^1\Sigma_u^+ \rightarrow {}^1\Sigma_g^+$ band system of Se_2 in the region 3700–3815A has been undertaken in an attempt to resolve the discrepancy[1] that exists between the value of the nuclear spin of $_{34}Se^{77}$ indicated by optical hyperfine structure[2] and by microwave spectra.[3] The former method indicates $I=7/2\pm1$ and the latter $I=\frac{1}{2}$, although with certain reinterpretations[2,4] either value may be reconciled with the other. Under these circumstances it seemed logical to apply the method originally used[5] to establish the value $I=0$ for Se^{80}, namely observation of the alternating intensities in the rotational lines of the electronic band spectrum. For this purpose spectrograms have been obtained of the separated isotopes[6] in which the major components were Se^{77}, Se^{78}, and Se^{80}, respectively. They were taken in the second order of the 21-foot grating, which gives a dispersion of 0.67 A/mm. The source was a small quartz tube containing about 10 mg of selenium and 1–5 mm of argon excited by a 60-Mc oscillator. This source may be scaled down in size to yield band spectra of the nonmetallic elements with much smaller samples. Preliminary studies of the possibility of measuring the spin of P^{32} in this way show that the P_2^{31} spectrum may be obtained with as little as 2 μg of phosphorus.

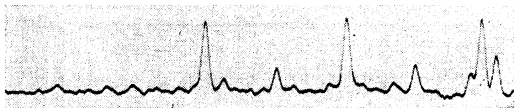

FIG. 1. Tracing of last five lines of 10,5 band of Se_2^{77}, enlarged 40 times from the original plate. The abrupt ending of the P branch due to predissociation is apparent.

$P(45)(44)(43)(42)(41)$

Even though the bands of Se_2 become much simpler when produced by the separated isotopes, only a few at the ultraviolet end are sufficiently free from overlapping to permit an analysis of the rotational structure. Measurements of the 10,4 and 10,5 bands confirm the analysis given by Olsson,[5] who reported on bands due to Se_2^{80} and Se^{78} Se^{80}. The state $v'=10$ shows strong perturbations, while the predissociation occurring in this state at $K'=49$ in Se_2^{80} comes at $K'=44$ in Se_2^{77}. The 9,4 and 9,5 bands appear to be free from such irregularities, and are most suitable for observing the intensity alternation. Our plates of Se_2^{78}, from a sample containing 82.6 percent of Se^{78}, show a very simple structure consisting of singlet P and R branches with alternate lines missing. Hence, as expected, the spin of this isotope is zero.

The first plates with enriched Se^{77} gave evidence of a pronounced alternation,[7] with the lines of odd K stronger since the nucleus obeys Fermi statistics. This sample had a concentration of 58.4 percent Se^{77}, but overlapping by lines due to the next most abundant molecule, Se^{77} Se^{80}, prevented an accurate measurement of the alternation ratio. Hence a special separation was made by the Stable Isotopes Division[6] yielding 50 mg of 91.7 percent Se^{77}. Using 9.5 mg of this material, successful spectrograms were obtained on which the alternation of intensities was essentially free from disturbances. Photographic photometry on the last five lines of the P branch in the 10,5 band, a microphotometer trace of which is shown in Fig. 1, was done by the method previously used by one of the authors[8] in determining the spin of P^{31}. The average ratio obtained was 3.0:1, showing definitely that the nuclear spin of Se^{77} is $\frac{1}{2}$. The band spectrum method, it should be emphasized, is the only way of determining nuclear spins which gives a positive result in cases where $I=0$ or $\frac{1}{2}$. Our value agrees with the conclusion of Canada and Mitchell,[9] based on measurements of the beta-ray spectrum of As^{77}. It also confirms the presumption of Mayer[10] that the odd neutron in Se^{77} is in the $p_{1/2}$ state, rather than in $g_{9/2}$.

In the course of this work, an accidental contamination of air in one tube yielded a well-resolved band system which is evidently that now attributed[11] to SeO, but not as yet studied in detail. By using the separated isotopes, a complete analysis of the rotational structure of these bands will be possible.

[1] J. E. Mack, Revs. Modern Phys. **22**, 64 (1950).
[2] J. E. Mack and O. H. Arroe, Phys. Rev. **76**, 173 (1949).
[3] Strandberg, Wentink, and Hill, Phys. Rev. **75**, 827 (1949); Geschwind, Minden, and Townes, Phys. Rev. **78**, 174 (1950).
[4] Townes, Foley, and Low, Phys. Rev. **76**, 1415 (1949).
[5] E. Olsson, Z. Physik **90**, 138 (1934). A more complete account is given in E. Olsson, Dissertation, Stockholm (1938).
[6] All enriched isotopes were supplied by the Stable Isotopes Research and Production Division, Y-12 Area, Oak Ridge National Laboratory.
[7] S. P. Davis and F. A. Jenkins, Phys. Rev. **83**, 891 (1951). The final result, as reported in the present letter, was given in this paper at the Vancouver meeting.
[8] F. A. Jenkins, Phys. Rev. **47**, 783 (1935).
[9] R. Canada and A. C. G. Mitchell, Phys. Rev. **81**, 485 (1951).
[10] M. G. Mayer, Phys. Rev. **78**, 16 (1950).
[11] Asundi, Jan-Khan, and Samuel, Proc. Roy. Soc. (London) **157**, 28 (1936).

Photodisintegration of He^4

T. S. BENEDICT AND W. M. WOODWARD
*Cornell University, Ithaca, New York**
(Received July 27, 1951)

CROSS sections for the production of protons from He^4 using the 300-Mev bremsstrahlung beam of the Cornell synchrotron have been measured for proton energies ranging from 45 to 120 Mev. The apparatus consists of a pressure vessel (Fig. 1)

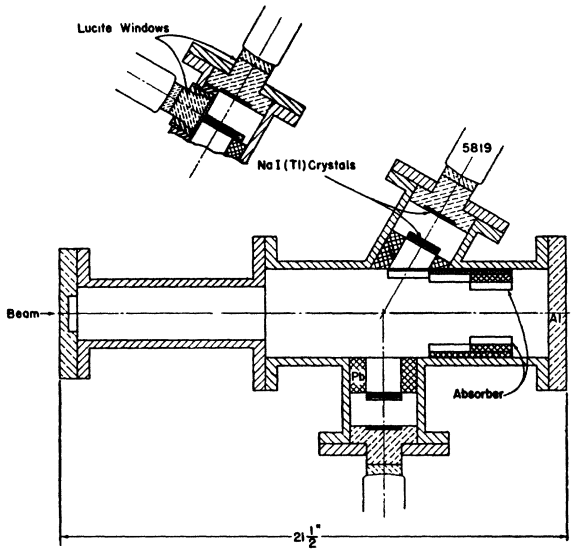

FIG. 1. Schematic diagram of the apparatus.

capable of withstanding pressures up to 2000 lb/in.^{2}, with counting arms mounted at 60° and 90° with respect to the γ-ray beam. Two NaI(Tl) crystals are mounted inside each arm in such a way as to form a proton counter telescope. The light from the crystals is piped out of the vessel through Lucite windows which are about 4 cm thick. The scintillations are detected by RCA 5819 photomultiplier tubes. The front counter, in conjunction with a multi-channel pulse-height discriminator, was used to measure the ionization of those particles which pass through the front crystal and subsequentlv lose >15 Mev in the back crystal.

With this arrangement one observes a pulse-height distribution with a width at half-maximum of 3 Mev corresponding to an energy spread for protons incident on the first crystal of about 20 Mev. This method distinguishes protons from mesons and electrons because, although it is possible for the latter to produce 15-Mev pulses in the back crystal (i.e., stars), they will produce considerably smaller pulses in the front crystal. The energy of those protons counted could be varied by sliding lead absorbers in front of the counting arms as shown in Fig. 1.

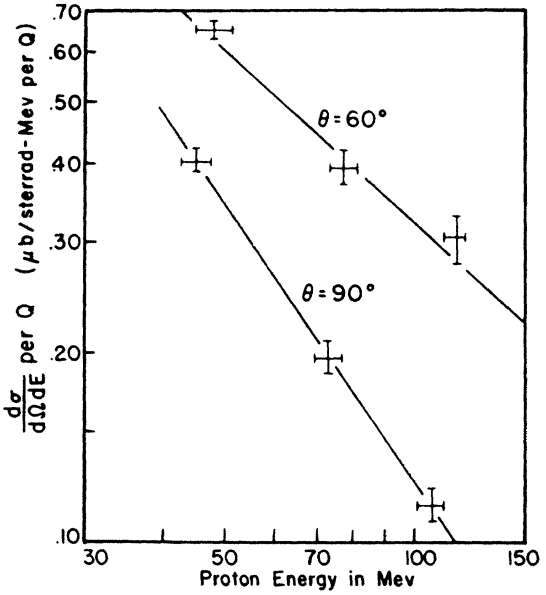

FIG. 2. Cross section *vs* energy for photoprotons from He^4 at 60° and 90° relative to the γ-ray beam.

The counting system was calibrated by observing the number of counts in the proton distribution curve as a function of discriminator bias setting for the back crystal. The number of protons counted should go to zero approximately linearly as the bias setting for the back crystal approaches the value corresponding to the energy thickness of the crystal. This energy was also checked using the ThC″ end point, and the two calibrations agreed. The front crystal was calibrated in a similar manner.

The beam was monitored with an ionization chamber behind one-quarter inch of lead which had previously been calibrated against the pair spectrometer. Measurements were made at 60° and 90° in the laboratory system for three proton energies at a gas pressure of 1800 lb/in.[2] The cross sections given in Fig. 1 are plotted in μb/sterrad-Mev per effective quantum, since there are at least three reactions which yield protons, viz:

(a) $\gamma+He^4 \rightarrow H^3+p$,
(b) $\gamma+He^4 \rightarrow p+n+H^2$,
(c) $\gamma+He^4 \rightarrow p+p+n+n$.

If we assume that the predominant reaction is (a), the cross sections at 101° in the c.m. system per photon are $d\sigma/d\Omega = 25$, 17, and 14μb at γ-ray energies of 78, 112, and 153 Mev, respectively.

It should be noted that the resolution of the arrangement was not sufficient to distinguish between protons, deuterons, and tritons; however, energetic considerations show that the heavier particles should contribute only a small fraction of the observed coincidences.

The errors given in Fig. 2 are relative errors. The error to be assigned to the absolute cross sections is 30 percent.

† Supported by the joint program of the ONR and AEC.

The Nature of the Second-Order Transition in ND_4Br

HENRI A. LEVY AND S. W. PETERSON
*Oak Ridge National Laboratory, Oak Ridge, Tennessee**
(Received July 25, 1951)

SECOND-ORDER phase transitions in the ammonium halides have been interpreted as the onset of free rotation[1] or of orientational disorder[2] of ammonium ions. Recent spectroscopic evidence[3] supports the latter hypothesis. We have obtained direct evidence also favoring the disorder hypothesis from complete crystal structure determinations of two phases of ND_4Br by means of neutron diffraction. A contrary result in ND_4Cl was recently reported by Goldschmidt and Hurst[4] from a neutron diffraction study of that material.

ND_4Br undergoes the following changes[5] as the temperature is lowered:

$$\text{f.c. cubic} \xrightarrow{\sim 125°} \text{simple cubic (CsCl type)} \xrightarrow[\text{second order}]{-58.4°}$$
$$\text{tetragonal} \xrightarrow{-105°} \text{simple cubic (CsCl type).}$$

Neutron diffraction data from all four phases have been collected, and those of the two CsCl-type structures have been analyzed in detail. Scattering cross sections used were those reported by Shull and Wollan.[6] Observed data and comparison with calculation are presented in Table I.

TABLE I. Neutron diffraction data[a] from ammonium bromide.

Indices	Low temperature phase Calc.	Obs.	Uncertainty	Room temperature phase Calc.	Obs.	Uncertainty
100	17.9	17.9	±0.4	17.8	17.7	±0.35
110	72.0	72.3	1.4	67.5	67.3	1.3
111	15.4	16.1	0.8	3.9	3.6	0.4
200	5.4	5.0	0.6	6.2	6.8	0.7
210	0.6	1.7	1.0	0.2	0	1.0
211	84.5	87.1	2.4	32.0	32.1	1.6
220	31.1	30.8	2.0	18.9	19.5	1.4
221–300	79.1	76.0	3.5	8.7	7.8	0.8
310	2.4	4.1	2.1	3.9	3.7	1.8
311	13.1	13.3	3.5	3.0	3.0	1.5
222	43.3	41.5	8	11.3	11.3	1.7
320	8.4	5.8	4	2.0	3.7	1.8
321	159.5	163.2	8	72.8	77.8	5.8
400	0.2	0	1	0.1	0	1.0
410–322	27.2	27.4	3	4.8	6.1	3.0
411–330	124.1	117.5	15	45.9	48.0	4.8
331	27.5	33.4	15	6.8	9.6	4.8
420	77.7	93.2	15	31.3	36.9	5.5
421	23.4	40.9	15	2.5	5.2	2.6
332	32.0	25.0	10	18.8	18.1	2.7

[a] The quantities listed are the square of the structure factor multiplied by the multiplicity of the reflection, jF^2. The calculated values are for the final models and include the effects of temperature motion. Intensities were measured on an absolute scale, so that absolute as well as relative agreement is significant.

The phase at −195°C was found to give a simple cubic pattern with $a_0 = 3.96$A. Peak intensities were satisfactorily matched by calculation from a model conforming to symmetry T_d^1 with deuterium atoms placed in fourfold positions (e),[7] along the body diagonals of the cube. The required temperature factor for deuterium corresponded to a mean amplitude of vibration of about 0.14A. Thus, the lowest temperature phase consists of an ordered structure closely similar to that found for low temperature ND_4Cl.

The room temperature pattern corresponds to a simple cubic unit with $a_0 = 4.05$A. The model which gave satisfactory agreement placed the four deuterium atoms at random in the eightfold positions (g) of space group O_h^1, corresponding to twofold randomness in the orientation of the tetrahedral ammonium ions. The model required anisotropic temperature motion of the deuterium atoms, the distribution being greatly extended in directions near the plane normal to the N−D link. This anisotropy could result from torsional oscillation of the ammonium ion about the two