energy thresholds of the detector are interpreted as in the 1-Mev analysis. In certain cases below it will be necessary to combine the cross sections for exciting two states because of a lack of sufficient energy resolution in the neutron detector. To increase the statistical accuracy of the calculation, the cross section for exciting a particular level is computed for both 4.0- and 4.5-Mev neutrons and the value given below is the average of these two numbers. The cross section for exciting the 0.84-Mev level, plus that for exciting the 1.02-Mev level in Al^{27}, is 0.19±0.12 barn. The 840-kev level in Fe^{56} is excited with a cross section of 0.50±0.20 barn by inelastic neutron scattering. The sum of the cross sections for exciting the 0.96-Mev level in Cu^{63} and the 1.12-Mev level in Cu^{65} is 0.49±0.20 barn per copper atom. The 0.90-Mev level in Bi^{209} is excited with a cross section of 0.28±0.15 barn by inelastic neutron scattering.

The 4.0-Mev cross sections are compared in Table II with those obtained from reference 16. The agreement between measurements done by the two methods is very good. In Table III the cross sections measured at 4.5 Mev are compared with those obtained from another sphere transmission experiment.[3] A fission neutron source and an $Al^{27}(n,p)Mg^{27}$ threshold detector were used in this experiment. The average neutron energy was 6 Mev and the half-width of the energy spectrum detected was about 3 Mev. This set of measurements is also in agreement with the present results.

Theoretical predictions of the cross section for formation of the compound nucleus have been carried out for 4.0-Mev neutron energy recently,[16] using the complex square-well potential of Feshbach, Porter, and Weisskopf. The calculated cross sections are considerably lower than the observed inelastic cross sections given in Table II. This is the same difficulty which was observed for silver and gold at 1-Mev neutron energy.

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Spin, Quadrupole Moment, and Mass of Selenium-75*

L. C. AAMODT† AND P. C. FLETCHER
Columbia University, New York, New York

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The microwave spectrum of $OCSe^{75}$ has been observed and from it the spin, quadrupole moment, and mass of Se^{75} were measured. Frequencies of the six observed lines of the $J=2\rightarrow 3$ rotational transition give a nuclear spin of 5/2, a quadrupole coupling constant $eqQ=946.0$ Mc/sec, and a rotational constant $B_0=4081.926$ Mc/sec. From these and other known properties of the OCSe molecule, one obtains the quadrupole moment of Se^{75} as $Q=1.1\times 10^{-24}$ cm$^2\pm 20$ percent, and the mass ratio $(M_{Se^{75}}-M_{Se^{76}})/(M_{Se^{75}}-M_{Se^{80}})=0.199566\pm 0.000030$. The odd-even mass difference for Se^{75} is 1.5±0.2 mMU. The observed spin disagrees with that expected from the shell model which predicts a spin of 1/2 or 9/2. Three possible nuclear configurations which agree with the observed spin and also indicate a positive quadrupole moment are $[p_{1/2}(g_{9/2})^2]_{5/2}$, $(g_{9/2})^3{}_{5/2}$, and $(f_{5/2})^5{}_{5/2}$. Magnetic moment measurements are needed to clearly distinguish between configurations. The sample material was obtained by bombarding arsenic with deuterons. Approximately $1\frac{1}{2}$ micrograms of sample material were produced but only 0.07 microgram could be used in each spectroscopic run because of difficulties in synthesizing OCSe.

INTRODUCTION

THE stable selenium isotopes Se^{74}, Se^{76}, Se^{77}, Se^{80}, and Se^{82} have sufficient natural abundance to make them available for microwave spectroscopy. Their nuclear properties have been determined or in the case of the even-even nuclei, confirmed by previous investigators.[1–3] Of the radioactive isotopes, Se^{79}, with a half-life of 6.5×10^4 years, has had its nuclear properties determined by Hardy *et al.*[4] Another selenium isotope which is amenable to microwave spectroscopy, because of a sufficiently long half-life (128 days[5]), is Se^{75}. Since this atom cannot be obtained with sufficient specific activity from pile bombardment to make measurements by microwave techniques possible, the sample material was produced by cyclotron bombardment. This is the first case where cyclotron bombard-

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* Work supported by the U. S. Atomic Energy Commission.

† Now at Brigham Young University, Provo, Utah.

[1] Strandberg, Wentink, and Hill, Phys. Rev. **75**, 827 (1949).

[2] Geschwind, Minden, and Townes, Phys. Rev. **78**, 174 (1950).

[3] W. Low, thesis, Columbia University, 1950 (unpublished).

[4] W. A. Hardy *et al.*, Phys. Rev. **92**, 1532 (1953).

[5] Cork, Rutledge, Branyan, Stoddard, and Le Blanc, Phys. Rev. **79**, 889 (1950).

ment has been used as a source of sample material for microwave spectroscopy, and indicates that a number of additional radioactive nuclei can be studied by similar methods. The amount of Se^{75} obtained was small (approximately $1\frac{1}{2}$ micrograms) and required the use of a spectrometer of very high sensitivity.[6]

The spectrum measured indicates the following regarding the nuclear properties of the Se^{75} nucleus: (1) The spin of the nucleus is 5/2; (2) the quadrupole coupling constant for Se^{75} in OCSe is 946.0 ± 0.4 Mc/sec; (3) it possesses an electrical quadrupole moment of 1.1×10^{-24} $\text{cm}^2\pm20$ percent; (4) the mass ratio $M_{Se^{75}}/M_{Se^{76}}$ is 0.98686 ± 0.00001; and (5) the odd-even mass difference is 1.5 ± 0.2 mMU.

The observed spin does not agree with the individual particle model following the Mayer[7] and Jensen[8] scheme. This model predicts a spin of 1/2 or 9/2. Three possible nuclear configurations agree with the observed spin and also indicate a positive quadrupole moment. These are $[p_{1/2}(g_{9/2})^2]_{5/2}$, $(g_{9/2})^3{}_{5/2}$, and $(f_{5/2})^5{}_{5/2}$. Parity considerations appear to favor the second configuration. On the other hand the large positive quadrupole moment that was observed agrees better with the estimate of the quadrupole moment for the first configuration rather than the second. Magnetic moment measurements should resolve the ambiguity.

PREPARATION OF THE TARGET

Se^{75} may be produced by two processes: $Se^{74}(n,\gamma)Se^{75}$ and $As^{75}(d,2n)Se^{75}$. In the first process the stable selenium cannot be chemically separated from the Se^{75} so that only a low specific activity can be obtained. Samples available from pile bombardment using this process have specific activities of 1300 mC/g.[9] This corresponds to 0.009 percent abundance. This is not sufficient abundance for microwave spectroscopy; for example, the spectrometer used required an abundance of the order of 0.1 percent to measure the lines observed.

The second process allowed easy chemical separation of the arsenic but it had certain disadvantages. Various factors make arsenic a very unfavorable target material. Arsenic sublimes, having a vapor pressure of 1 mm at 372°C. In addition it oxidizes forming AsO_2 which also sublimes. Experimentally, the heat of bombardment readily evaporated the target surface, even with the best possible cooling of the target holder, unless good thermal conductivity was obtained throughout the target volume. This made it desirable to have a target of solid arsenic. Several methods or producing such a target were attempted. Arsenic which was plated electrolytically proved to be too flaky and porous. Melting the arsenic proved difficult because of its high vapor pressure, 36 atmospheres, at its melting point of 814°C. A bomb was constructed to melt the arsenic but a satisfactory surface upon which to melt it was not readily obtainable. The arsenic was found to alloy with gold and iron and react with platinum. A quartz container was not satisfactory because the arsenic solidified in small spherical balls on the quartz surface. However, it was found possible to press arsenic powder under high pressure into wafers having a density of 90 percent of that of solid arsenic. These wafers had sufficient thermal conductivity to withstand the heat of bombardment.

Chemical considerations dictated a small target volume. The dimensions of the cyclotron beam and the depth of penetration determined the minimum cross-sectional area and the minimum thickness, respectively, and required a thin wafer-like target. For mechanical strength the wafers had to be considerably thicker than the minimum set by the penetration and could not be formed with as large a cross-sectional area as desired, therefore making it necessary to use several wafers in each target. The wafers were $\frac{1}{2}$ mm thick and were originally pressed in a circular shape and trimmed to size with a razor blade. The pressure used in pressing wafers was 85 tons per square inch.

In order to assure a good thermal contact with the target holder, which was made of copper, the arsenic wafers were heated, tinned with pure tin using ammonium chloride as a flux, and soldered into the target holder. The target holder was a water-cooled block with dimensions 6 inches by 1 inch by 1 inch. The target was placed in a shallow rectangular cavity cut into one of the sides of the copper block and covered with a one-mil aluminum foil which prevented the loss of any evaporated arsenic.

BOMBARDMENT DETAILS AND IDENTIFICATION OF THE Se^{75}

Since the cross section of the $As^{75}(d,2n)Se^{75}$ reaction was not known initially and estimates obtained varied quite widely, several preliminary bombardments were made to determine the yield. The earliest targets were badly evaporated but gave sufficient information to determine the approximate bombardment time for the later perfected targets. The final bombardment used a maximum cyclotron current of 75 microamperes and 500 microampere hours of bombardment. The bombardments were made in the Brookhaven cyclotron which has a 22-Mev deuteron beam.

The Se^{75} was identified by measuring the lines grouped around the 124-kev and the 269-kev lines[5] in its decay spectrum. The measurements were sufficiently quantitative to indicate the yield for monitoring purposes although no attempt was made to resolve the individual lines of the spectrum. The measurements were made with a sodium iodide scintillation counter. The yield measured for the bombardment conditions listed above was $1\frac{1}{2}$ micrograms. This indicated an average cross section of the order of 2.7 barns (assuming

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[6] W. A. Hardy and G. Silvey, Phys. Rev. **95**, 385 (1954).

[7] Maria Goeppert Mayer, Phys. Rev. **78**, 16 (1950).

[8] Haxel, Jensen, and Suess, Phys. Rev. **75**, 1766 (1949).

[9] *Radioactive Isotope Bulletin* (Isotope Division, U. S. Atomic Energy Commission, Washington, D. C., 1955).

a 50-mg/cm^2 range). Additional confirmation of the identity of the Se^{75} was made by observing that the radioactivity followed the expected position of the selenium during chemical manipulations.

CHEMISTRY

After bombardment the target was freed from the target holder by heating the target holder on an electric hotplate. In addition to $1\frac{1}{2}$ micrograms of Se^{75} it consisted of 7 grams of arsenic, 1 gram of tin, and traces of copper and aluminum. (The selenium was probably in the form of As_2Se_3 or $AsSe_5$.) The target material was then dissolved in aqua regia; 50 micrograms of normal selenium carrier added; and the Se^{75} reduced to elemental selenium by adding the reducing agent hydrazine hydrochloride. At this point the selenium was precipitated and the arsenic and other solubles were filtered out. After rinsing, the selenium was combined with a large excess of CO and heated at 500°C for 15 minutes. This produced the molecule OCSe—carbonyl selenide—which was the molecule used in the absorption cell.

(1) Partial Molecular Synthesis

The $1\frac{1}{2}$ micrograms of Se^{75} obtained from cyclotron bombardment could not all be synthesized into the carbonyl selenide molecule at the same time. Each time the Se was heated with CO and the OCSe removed, only about 10 to 15 percent of the Se atoms were found to have formed carbonyl selenide molecules. This process could be repeated several times but the presence of diluting gases prevented the combining of these separate yields. The partial synthesis was determined by measuring the ratio of the radioactivity in the OCSe sample material to the radioactivity remaining in the reaction vessel. In order to rule out the possibility that some of the activity in the reaction vessel was coming from extraneous sources, the intensity of the decay spectrum of Se^{75} was measured in both the reaction vessel and in the molecular sample material by using the sodium iodide scintillation counter. These measurements agreed well with those originally made using a proportional counter. This partial synthesis reduced the total amount of Se^{75} available for spectroscopy to about 0.2 micrograms per run.

(2) Dilution of the Sample

At least two foreign gases, OCS and CO_2, were present in the sample material. The OCS was due to sulfur that was present in the target material or in the reagents used. Sulfur follows the same chemistry as selenium, and forms OCS rather than OCSe. The carbon dioxide may have entered as an impurity in the carbon monoxide, or it may have been formed by the carbon monoxide reacting with oxygen that was either present in the reaction vessel or that entered as an impurity in the carbon monoxide. The presence of these gases reduced the intensity of the OCSe^{75} absorption lines by not allowing all of the sample material to be put into the absorption cell. Only about 0.07 micrograms of Se^{75} could be put into the cell per run.

The OCS was minimized by reducing the sulfur content in the target material and reagents used. The CO_2 was minimized by a method of fractional distillation (which will be described under spectroscopic procedure) and purification of the carbon monoxide.

Since the ratio of arsenic and tin to Se^{75} was large (approximately 4.6×10^6 and 6×10^5 respectively) sulfur impurities in either of these materials in even small percentages were troublesome. To test the amount of sulfur present in the aresnic and tin, a "blank" chemical run was made using 7 grams of arsenic, 1 gram of tin, and 50 micrograms of ordinary selenium. Since the sulfur in the arsenic formed OCS and the selenium formed OCSe, the amount of sulfur present was measured by observing the relative intensities of the carbonyl selenide and carbonyl sulfide absorption lines with the microwave spectrometer. The amount of sulfur present in commercially available chemically pure arsenic was found to vary considerably from lot to lot. A source was finally found that contained less than 10 micrograms of sulfur in 7 grams of arsenic. This proved satisfactory. Purification of the arsenic by electrolysis was not successful since the physical form of the purified arsenic was such that it was impossible to press it into suitable wafers for the target. The tin proved to contain a negligible amount of sulfur.

Carbon dioxide was difficult to remove because its vapor pressure was approximately the same as that of carbonyl selenide. To insure a dilution of less than 50 percent (equal amount of diluting gas and OCSe) the CO used had to contain less than 0.0004 percent CO_2. Since the gas available was only 99.97 percent pure, it was necessary to purify it. The purification process consisted of sealing off a volume of CO and heating it to 500°C. The oxygen in the CO reacted to give CO_2, and this gas along with the CO_2 originally present was removed by freezing it out with liquid nitrogen. Purification by this method gave good results; it allowed the effective sensitivity to be increased by a factor of two in later runs.

SPECTROSCOPIC PROCEDURE

(1) Admittance of the Sample into the Absorption Cell

The large dilution of the carbonyl selenide made it desirable to preferentially admit it to the absorption cell. The method of fractional distillation used was the following. A carbon disulfide bath was prepared by using a liquid nitrogen cold finger. The first portion of the diluted sample was admitted to the absorption cell while the spectrometer was adjusted to observe the $J=2\rightarrow3$ rotational transition of the OCSe^{74} molecule. This line was used as a monitoring line. The sample material was admitted until this absorption line first began to appear. Then the material that had entered the absorption cell (the material consisting mainly of CO_2) was discarded; the carbon disulfide bath was then replaced by a dry ice-acetone bath, and the remainder of the sample admitted.

Definite improvement resulted from this procedure. During the manipulations the radioactivity always moved in a manner consistent with the carbonyl selenide, and the radioactivity in the absorption cell agreed semiquantitatively with the carbonyl selenide spectral intensities.

(2) Molecular Dissociation

Each molecular synthesis produced sufficient sample material to fill the absorption cell only once, and each cyclotron bombardment enough material to allow about four good molecular syntheses. This made it desirable to keep the sample material in the spectrometer for long periods of time to facilitate measurements with the minimum of sample preparation.

Carbonyl selenide is unstable at room temperature. At dry ice temperature, which was the temperature at which the spectrometer was operated, dissociation was inhibited sufficiently to allow 12-hour runs to be made before noticeable decrease in intensity occurred. (Other factors in addition to molecular dissociation were partially responsible for this decrease in intensity.) To preserve the sample material for this length of time it was necessary to keep the temperature below −60°C at all times. Any increase in temperature immediately decreased the line intensity, and also increased the amount of radioactivity left in the absorption cell after the sample material had been removed. This gave a semiquantitative means of monitoring the amount of molecular dissociation in the absorption cell.

(3) Sensitivity Tests and Requirements

The spectrometer sensitivity was tested by observing the $F=3/2\rightarrow 1/2$ quadrupole component of the $J=2\rightarrow 3$ rotational transition of OCS^{33}. This absorption line has an intensity (absorption coefficient) of 7.2×10^{-9} cm^{-1} at room temperature. The spectrometer was adjusted until this line was observed 20 to 30 times noise (at room temperature) giving an ultimate sensitivity (detectable absorption coefficient) of approximately 3 or 4×10^{-10} cm^{-1}. Based on the signal-to-noise ratio of this test line, the absorption coefficient of the observed $OCSe^{75}$ lines ranged from 3×10^{-9} cm^{-1} for the $F=9/2\rightarrow 11/2$ transition to 6×10^{-10} cm^{-1} for the $F=3/2\rightarrow 3/2$ transition. These values agree well with those estimated from the data on the nuclear bombardment, molecular synthesis, and dilution in the absorption cell.

ENERGY LEVELS

The Hamiltonian for a molecule with a single nucleus possessing an electrical quadrupole moment may be written as $H=H_0+H_Q$, where H_0 is the Hamiltonian for the rotating-vibrating molecule and H_Q consists of the additional energy terms due to the interaction between the molecular electric field and the nuclear quadrupole moment. Since no vibrational transition is involved and since the rotational-vibrational interactions are small, the Hamiltonian H_0 may be considered to be H_R, the pure rotational component of the Hamiltonian. Thus we may write $H=H_R+H_Q$.

The most convenient representation is the $IJFM$ representation which $\mathbf{F}=\mathbf{I}+\mathbf{J}$ and M is the component of $\mathbf{F}$ along a space fixed axis. In this representation the quadrupole energy matrix is diagonal in F and M but not in J. The first-order energies are given by the expression (for a linear molecule)[10]:

$$(IJFM|H_Q|IJF'M')=-eqQ\frac{\frac{3}{4}C(C+1)-I(I+1)J(J+1)}{2I(2I-1)(2J-1)(2J+3)},$$

where $C=F(F+1)-I(I+1)-J(J+1)$, e = electronic charge, Q = quadrupole moment of the nucleus, $q=\partial^2V/\partial z^2$, at the nucleus with the quadrupole moment. Here V is the electrostatic potential due to all charges outside the nucleus, and z is the coordinate along the molecular axis.

The large quadrupole coupling in the $OCSe^{75}$ molecule made it necessary to correct the first-order energies by second-order perturbation theory involving different rotational levels. Since the second-order corrections were small, however, the identification of the nuclear spin could be made by using first-order theory. The main lines in the characteristic quadrupole hyperfine patterns for spins of 3/2, 5/2, 7/2, 9/2, and 11/2 and

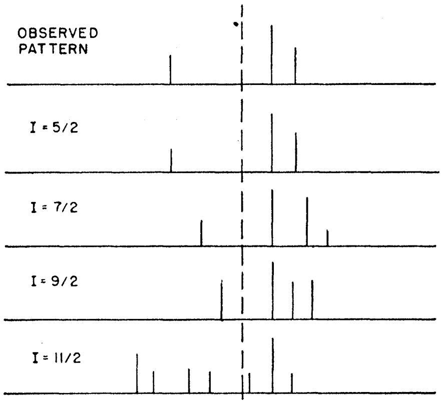

Fig. 1. The comparison of the main lines in the quadrupole hyperfine patterns for various spins ($J=2\rightarrow 3$ transition). The dashed line indicates the frequency of the $J=2\rightarrow 3$ rotational transition, assuming no quadrupole coupling coefficients have been adjusted so that the major components of the various patterns fall in line.

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[10] J. Bardeen and C. H. Townes, Phys. Rev. 73, 627 (1948).

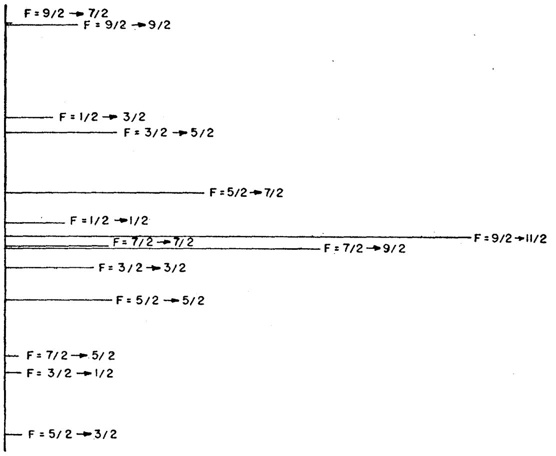

FIG. 2. Quadrupole hyperfine pattern for $J=2\rightarrow 3$ transition, $I=5/2$.

for $J=2\rightarrow 3$ are shown in Fig. 1. The observed lines are shown for comparison. The complete quadrupole pattern for a spin of 5/2 is shown in Fig. 2.

OBSERVED LINES OF OCSe^{75}

Six lines were observed and their frequencies measured. Table I lists these lines with their identification. In Fig. 1 the three strongest observed lines are shown along with the various theoretical patterns. It can easily be seen to agree with the pattern for a spin of 5/2 and to disagree with the others. The theoretical frequencies are listed in column three of Table I. These were computed using the values of eqQ and ν_0 indicated. These frequencies agree within experimental error with the observed values.

Determination of relative intensities of the observed lines was difficult because of unresolved Stark components. Even so, there is general agreement between theory and observation as can be seen in columns four and five of Table I. Column five lists the theoretical relative intensities with the intensity of the strongest line set equal to one. Column four was obtained by listing the signal-to-noise ratio of each line and then dividing by the signal-to-noise ratio of the strongest line. These calculations disregarded unresolved Stark components and also the fact that slightly different operating conditions existed in the different measurements. Even so, agreement is seen to be qualitatively good.

STARK PATTERN

Additional confirmation of the identification of individual lines in the quadrupole hyperfine pattern was made by observing their line shapes. These line shapes were altered by unresolved Stark components. If the dipole moment of the carbonyl selenide molecule had been larger, the separate Stark components could have been individually observed and used for identification. The dipole moment was small enough however, to make it impossible to completely resolve them with the modulating voltages available. A theoretical calculation was made of the Stark pattern for each of the lines in the quadrupole hyperfine pattern for a spin of 5/2. Then, by assuming a reasonable line width, a composite line was drawn including the line and its Stark components. (The Stark components were plotted negatively since in the spectrometer the phase detector inverts the Stark components.) The resulting lines are shown in Fig. 3 (for the three strongest lines in the pattern). As can be seen, the agreement between the observed and theoretical patterns is very good.

NUCLEAR CONSTANTS

The spin of Se^{75} and the quadrupole coupling constant in the OCSe^{75} molecule were determined by the frequency separations of the components of the quadrupole hyperfine pattern. (These are listed in Table I.) The quadrupole coupling constant doesn't allow the quadrupole moment to be calculated directly. The value of q must first be estimated. Even without doing this, however, the ratio of quadrupole moments for two selenium isotopes may be obtained from the experimental data. The value of q is approximately the same for all of the selenium isotopes; consequently a ratio of quadrupole coupling constants represents the ratio of quadrupole moments. Considering the molecule OCSe^{79} which has a quadrupole coupling constant[4] of 752.09 ± 0.05 Mc/sec, we find the ratio $Q_{\mathrm{Se}^{75}}/Q_{\mathrm{Se}^{79}}$ to be 1.25783 ± 0.00062. An estimate of q has been made by Bird and Townes[11] for the molecule OCS, by using the methods of Townes and Dailey.[12] By using this value of q, and assuming that the molecules of OCS and OCSe have similar bonding structures, which is a reasonable assumption, the quadrupole moment of Se^{75} becomes 1.1×10^{-24} cm^2$\pm$20 percent.

The frequency of the rotational transition (assuming no hyperfine structure) allows a determination of the molecular B_0 value for the OCSe^{75} molecule as 4081.925

TABLE I. Comparison of the observed frequencies and relative intensities of the OCSe^{75} electric quadrupole hyperfine pattern with the corresponding theoretical values (for the $J=2\rightarrow 3$ rotational transition and for $I=5/2$).

Line		Observed frequency (Mc/sec)	Theoretical frequency[a] (Mc/sec)	Relative intensities	
F'	F''			Observed	Theoretical
9/2	11/2	24480.45±0.05	24480.407	1.0	1.000
7/2	9/2	24471.31±0.05	24471.354	0.6±0.1	0.678
5/2	7/2	24517.93±0.05	24517.935	0.5±0.1	0.430
3/2	5/2	24565.87±0.03	24565.871	0.2±0.05	0.240
5/2	5/2	24429.58±0.05	24429.600	0.2±0.05	0.230
3/2	3/2	24455.21±0.05	24455.226	0.2±0.05	0.190

[a] The theoretical frequencies were computed by using $eqQ=946$ Mc/sec and $\nu_0=24491.553$ Mc/sec. Second-order corrections were included. (ν_0 is the frequency of the $J=2\rightarrow 3$ rotational transition, assuming no hyperfine pattern.)

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[11] G. Bird and C. H. Townes, Phys. Rev. **94**, 1203 (1954).

[12] C. H. Townes and B. P. Dailey, J. Chem. Phys. **17**, 796 (1949).

± 0.002 Mc/sec. From this, following Geschwind, Minden, and Townes,[2] one obtains the ratio of mass differences $(M_{\mathrm{Se}^{75}}-M_{\mathrm{Se}^{76}})/(M_{\mathrm{Se}^{75}}-M_{\mathrm{Se}^{80}})=0.199566 \pm 0.000030$ and an odd-even mass difference for Se^{75} of 1.5 ± 0.2 mMU.

DISCUSSION

According to the nuclear shell model proposed by Mayer[7] and by Haxel, Jensen, and Suess,[8] the nuclear spin is determined by the last added odd nucleon, the other nucleons pairing off to give zero spin and zero magnetic moment. Levels in the fourth shell are supposed to occur in the order $p_{3/2}$, $f_{5/2}$, $p_{1/2}$, and $g_{9/2}$, which would make the last odd neutron in the $_{34}\mathrm{Se}^{75}{}_{41}$ nucleus (which has 13 particles in this shell), in the $g_{9/2}$ state. According to the nuclear shell model the spin of the nucleus should then be 9/2. Pairing energy however, might favor the situation where two neutrons pair in the $g_{9/2}$ state, leaving the odd neutron in the $p_{1/2}$ state and giving the nucleus a spin of 1/2. Neither of these spins agrees with the experimentally observed spin of 5/2, and the Se^{75} nucleus can be considered to be another definite exception to the individual-particle nuclear shell model. Other exceptions[13–15] are Na^{23}, Mn^{55}, Se^{79}, Eu^{153}, and Yb^{173}. These other exceptions however, all show a spin one less than that which would be predicted by shell theory while Se^{75} differs by 2 from the two spins that might be expected, 9/2 or 1/2.

If one still uses the individual-particle model, but assumes that the nuclear configuration involves the coupling of several neutrons in the fourth shell, several possible configurations suggest themselves. The three most plausible configurations are the following $[(p_{1/2})(g_{9/2})^2]_{5/2}$, $(g_{9/2})^3{}_{5/2}$, and $(f_{5/2})^5{}_{5/2}$ (the remaining neutrons pairing off to give zero spin). Each of these configurations is possible, i.e., they do not violate the Pauli exclusion principle, and they all predict a positive quadrupole moment in agreement with experiment.

In order to distinguish between configurations, several criteria can be used. The exceptionally large positive quadrupole moment agrees with the estimate of quadrupole moment for the first configuration rather than the second, while parity considerations[14] on the other hand seem to favor the second over the first. This ambiguity can be probably resolved by a measurement of the magnetic moment. It is interesting to note that Townes and Moszkowski[15] have pointed out that all exceptions to the individual-particle shell model have large positive quadrupole moments.

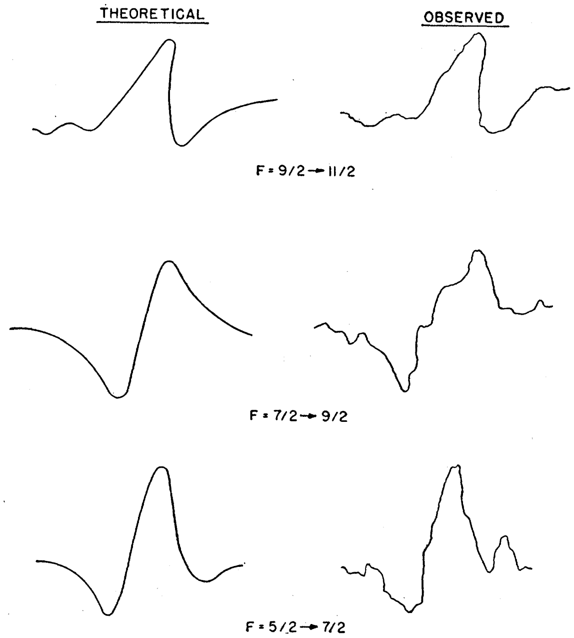

Fig. 3. Comparison of the theoretical and observed line shapes of the three main lines in the quadrupole hyperfine patterns of OCse^{75} ($J=2\rightarrow 3$ transition).

To make magnetic moment measurements, considerably more sample material must be available than that used in the present measurements. The spectral lines involving large F values are the most intense lines, and these in turn possess too many Zeeman components to make them practical for magnetic moment measurements. In this experiment lines involving low values of F were barely observable and an increase in abundance by a factor of five or ten would be necessary to make magnetic moment measurements feasible. The estimated magnetic moments for the three configurations are as follows: $[(p_{1/2})(g_{9/2})^2]_{5/2}$, -0.212; $(g_{9/2})^3{}_{5/2}$, -1.06; and $(f_{5/2})^5{}_{5/2}$, 0.546. The units are nuclear magnetons. As can be seen, a magnetic moment measurement could clearly distinguish between these three configurations.

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[13] J. M. Blatt and V. F. Weisskoff, *Theoretical Nuclear Physics* (John Wiley and Sons, Inc., New York, 1952), p. 770.

[14] J. P. Welker (private communication).

[15] S. A. Moszkowski and C. H. Townes, Phys. Rev. **93**, 306 (1954).