where F and G are similar to A, B, C. This formula can also be obtained directly from the condition that for $\mathbf{P}\|[111]$ the degeneracy of $x^2+\omega y^2+\omega^2 z^2$ and $x^2+\omega^2 y^2+\omega z^2$ ($\omega^3=1$) is not removed.

In the event that the minimum energy occurs at a lower symmetry point in the Brillouin zone, similar procedures can be adopted; however, more parameters may be involved.

Experimental results of G. L. Pearson[5] and H. Suhl[6] of the magneto-resistance of germanium indicate strongly that isotropic scattering and spherical energy surfaces cannot explain the data. It is to be hoped that the method of "deformation potentials"[7] can be extended to the case of degenerate energy bands so as to give a not more than three parameter (A, B, C) theory which may be compared with experiment to determine the band shapes.

I am indebted to J. Bardeen, C. Herring, and F. Seitz for helpful discussions of group-theoretical aspects of this problem, and to P. M. Morse for suitable perspective.

[1] A. Sommerfeld and H. Bethe, *Handbuch. der Physik* 24/2 (Julius Springer, Berlin, 1933).
[2] For a classification of Kubic Harmonics see F. C. Von der Lage and H. A. Bethe, Phys. Rev. **71**, 612 (1947).
[3] J. H. Van Vleck, Phys. Rev. **33**, 467 (1929); see L. I. Schiff, *Quantum Mechanics* (McGraw-Hill Book Company, Inc., New York, 1949), p. 155.
[4] W. Shockley, Phys. Rev. **50**, 754 (1936).
[5] G. L. Pearson, Bull. Am. Phys. Soc. **25**, No. 2, I13 (1950).
[6] H. Suhl, Bull. Am. Phys. Soc. **25**, No. 2, I14 (1950).
[7] W. Shockley and J. Bardeen, Phys. Rev. **77**, 407 (1950).

Microwave Measurements on the Stable Selenium Isotopes in OCSe*

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From a re-examination of the $J=2\rightarrow 3$ transition in OCSe (previously studied by Strandberg[1]), the relative masses of the stable Se isotopes have been determined, and an upper limit of 0.002×10^{-24} cm^2 assigned to the quadrupole moments.

A balanced bridge superheterodyne spectrometer[2] was used to obtain OCSe rotational lines (which occur near 24,000 Mc) as narrow as 60 kc. This high resolution allowed very accurate frequency measurements to be made by the usual comparison with harmonics of a quartz crystal. The differences between isotopic lines and their statistical errors resulting from approximately seven measurements of each are given in Table I. Allowing for possible systematic errors, these separations are probably accurate to 0.015 Mc. They differ appreciably—in one case as much as 0.5 Mc—from an earlier measurement,[1] and hence modify considerably the isotopic masses previously obtained.

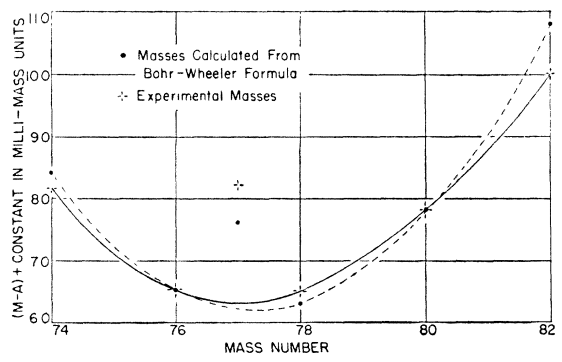

FIG. 1. Variation of masses of the stable Se isotopes as a function of mass number. The experimental masses are determined after assuming Se^{76} and Se^{80} are correctly given by the semi-empirical Bohr-Wheeler formula.

TABLE I. Observed frequency differences between the $O^{16}C^{12}Se$ lines.

	$\Delta\nu$(Mc/sec.)
$O^{16}C^{12}Se^{78}\rightarrow OCSe^{74}$	320.43 ±0.013
$O^{16}C^{12}Se^{78}\rightarrow OCSe^{76}$	156.15 ±0.006
$O^{16}C^{12}Se^{78}\rightarrow OCSe^{77}$	76.95 ±0.008
$O^{16}C^{12}Se^{78}\rightarrow OCSe^{80}$	148.58 ±0.008
$O^{16}C^{12}Se^{78}\rightarrow OCSe^{82}$	290.10 ±0.004
$O^{16}C^{12}S^{32}\rightarrow OCSe^{77}$*	5.458 ±0.007

* The absolute frequency of the $OCSe^{77}$ line is 29,331.38 assuming the $O^{16}C^{12}S^{32}$ frequency as previously measured to be 24,325.92.

TABLE II. Experimentally determined masses of stable Se isotopes compared with masses calculated from semi-empirical mass formula.

A (mass number)	Experimental masses	Masses calculated from Bohr-Wheeler mass formula
74	73.9481 ±0.0006	73.9484
76	75.9465*	75.9465
77	76.9482 ±0.0004	76.9476
78	77.9465 ±0.0004	77.9463
80	79.9478*	79.9478
82	81.9500 ±0.0006	81.9508

* These masses are assumed to be given exactly by the Bohr-Wheeler formula.

If zero-point vibrations were not present, the rotational frequencies of OCSe and a known mass of one Se isotope would give the other five Se masses to an accuracy limited only by the errors of measurement. The 0.015 Mc frequency uncertainty would then correspond to an error of 0.00018 mass unit. Zero-point vibrations are of course unavoidable, but if two isotopic Se masses are taken to be known, the errors due to zero-point vibrations can be largely eliminated and the other four Se masses determined with rather good accuracy.[2,3] Table II lists the masses and the maximum errors expected due to a combination of experimental uncertainty and the residual errors due to zero-point vibrations. These latter will be discussed more fully in a subsequent paper.

The experimental masses (assuming values of Se^{76} and Se^{80} given by the Bohr-Wheeler formula) are plotted in Fig. 1 and compared with predictions of the Bohr-Wheeler formula.[4] It may be seen that agreement between the curvature of the mass defect and the odd-even mass difference is rather good, although there are some discrepancies larger than the errors allowed in Table II. This method of mass measurement is especially good for determination of the odd-even mass difference since the distance which the odd isotope, Se^{77}, lies off the curve of the even masses is unaffected by errors in the assumed Se^{76} and Se^{80} masses or by uncertainties due to zero-point vibrations. The odd-even mass difference is found to be 0.0018 mass units, rather than $\delta=0.036/A^{\frac{3}{4}}=0.0014$ from the Bohr-Wheeler formula.

Although the OCSe lines were obtained as narrow as 60 kc, no noticeable asymmetry or splitting suggestive of hyperfine structure was observed in Se^{77} or in any other Se isotopes. In addition, the Se^{77} line-width was measured to be the same, within 5 kc, as that of Se^{76}. This agrees with previous observations,[1] and is a rather strong indication that the spins of the even isotopes are zero, and that of Se^{77} one-half, since then no quadrupole hyperfine structure could be observed. If the Se^{77} spin is not $\frac{1}{2}$, examination of the theoretical quadrupole coupling patterns for various spins gives an upper limit of 1 Mc to the quadrupole coupling constant $eQ\partial^2V/\partial z^2$. In comparison, S^{33} shows a coupling constant of -28.5 Mc in the very similar molecule OCS. Estimating $\partial^2v/\partial z^2$ for Se in OCSe by the same method[5] as was used for OCS, an upper limit of 0.002×10^{-24} cm^2 may be assigned to the Se^{77} quadrupole moment. Such a small quadrupole moment is puzzling in view of measurements on the optical hyperfine structure which indicate a spin for Se^{77} of 5/2 or greater.[6] It may be connected, however, with closure of a proton shell[7] at Se^{77}.

Since the Se^{79} is still unknown, Mr. William Low searched for a line due to $OCSe^{79}$, using a recording Stark modulation spectrometer and with the OCSe gas at dry ice temperatures. If the Se^{79} occurred naturally, it should produce a line very near that due to the $OCSe^{80}$, $v_2=2$, $l=0$ transition. No absorption attributable to Se^{79} was found, however, and since the nearby OCSe, $v_2=2$, $l=0$ line strength was about seven times noise background (at -78°C), an upper limit of one part in 10,000 may be set on the natural abundance of Se^{79}.

The design of the heterodyne spectrometer has benefited from the advice of Professor Yardley Beers. In addition, the authors appreciate the considerable help of Mr. R. H. Ellis, Jr. in construction of the spectrometer, and the interest of Mr. Paul Kisliuk who some time ago initiated work on these measurements but was not able to carry them through with the equipment then available.

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[1] Strandberg, Wentink, and Hill, Phys. Rev. **75**, 827 (1949).
[2] Columbia Radiation Laboratory Quarterly Report (June 30, 1949).
[3] Townes, Holden, and Merritt, Phys. Rev. **74**, 113 (1948).
[4] Quoted by M. G. Mayer and E. Teller, Phys. Rev. **76**, 1227 (1949).
[5] C. H. Townes and B. P. Dailey, J. Chem. Phys. **17**, 796 (1949).
[6] J. E. Mack and O. V. Arroe, Phys. Rev. **76**, 173 (1949), and private communication.
[7] Townes, Foley, and Low, Phys. Rev. **76**, 1415 (1949).

Resonance and Thermal Neutron Scattering in V^{51}

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A LITERAL application of the Breit-Wigner scattering theory enables one to correlate the experimental values of the resonance and thermal cross sections of V^{51}

Harris, Hibdon, and Muehlhause[1] have reported a prominent neutron scattering resonance ($\Gamma_n \gg \Gamma_\gamma$) in V^{51} at $\sim$2700 ev with a scattering resonance integral, Σ_s, of 192b. This quantity yields the coherent thermal scattering amplitude, a, via the following relations:

$$a=g(\lambda\!\!\!^{-}_0\Gamma_n/2E_0), \quad \Sigma_s=\tfrac{1}{2}\pi g\sigma_0\Gamma_n/E_0,$$

and

$$\sigma_0=4\pi\lambda\!\!\!^{-}_0{}^2=2.60\times10^6/E_0,$$

where $\lambda\!\!\!^{-}_0$=neutron wave-length at the resonance energy, Γ_n=neutron width, E_0=resonance energy, and $g=\frac{1}{2}(1\pm1/2i+1)$ is the statistical weight factor ($i=7/2$, spin of V^{51}). These relations yield the formula

$$a=\lambda\!\!\!^{-}_0\Sigma_s/\pi\sigma_0=0.555b^{\frac{1}{2}} \text{ (units of } 10^{-12} \text{ cm)}.$$

Shull and Wollan[2] have reported the coherent thermal scattering cross section, σ_{coh}, to be less than 0.1b (units of 10^{-24} cm^2). This quantity, according to the one-level Breit-Wigner formula, is given by:

$$\sigma_{coh}=4\pi|R-(g\lambda\!\!\!^{-}_0\Gamma_n/2E_0)|^2=4\pi|R-a|^2;$$

where $R=0.137A^{\frac{1}{3}}$ is the nuclear radius. For V^{51} we have $R=0.508b^{\frac{1}{2}}$ and therefore:

$$\sigma_{coh}=4\pi|0.508-0.555|^2\simeq0.03b \text{ (negative phase)}.$$

The resonance data are also in good agreement with the total thermal scattering cross section, σ_s, given by Hibdon[3] as 5.02b. This quantity can be used to determine the total angular momentum, J, of the compound state at 2700 ev. Again the one-level Breit-Wigner expression for σ_s yields:

$$\sigma_s=4\pi g|R-(a/g)|^2+4\pi(1-g)R^2,$$

from which

$$\sigma_s=5.02b \ (g=7/16 \text{ for } J=3),$$

or

$$\sigma_s=3.04b \ (g=9/16 \text{ for } J=4).$$

Preference is therefore indicated for $J=3$. One may also conclude that

$$\sigma_{max}\simeq420b \quad \text{and} \quad \Gamma\simeq780 \text{ ev}.$$

Since one resonance level determines the thermal scattering cross section so completely it appears that the next closest level, ϵ_2, from zero energy is such that $|\epsilon_2|\gg2700$ ev. Other cases of light odd-Z, even-n, isotopes which display this same level pattern are:[4-6] Na, Cl, Co, and Mn.

[1] Harris, Hibdon, and Muehlhause (unpublished work).
[2] C. G. Shull and E. O. Wollan, Naturwiss. **10**, 291 (1949).
[3] C. T. Hibdon (unpublished work).
[4] Hibdon, Muehlhause, Selove, and Woolf, Phys. Rev. **77**, 730 (1950).
[5] C. T. Hibdon and C. O. Muehlhause, Phys. Rev. **76**, 188 (A) (1949); S. Harris and C. O. Muehlhause, Phys. Rev. **76**, 189 (A) (1949).
[6] Harris, Hibdon, and Muehlhause (unpublished work).

Observations of the Rapid Withdrawal of Stored Holes from Germanium Transistors and Varistors

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IN the course of a study of transistor response to square pulses of applied voltage and current, the behavior illustrated in Fig. 1 was found to be typical of units employing N-type germanium. The collector current I_c is there shown as a function of time for different pulsed values of I_ϵ (emitter current) and V_c (collector voltage), applied as independent parameters. For each of the curves except the ones marked "steady state," V_c was pulsed from zero to 10 volts in the "reverse" direction (for which the point contact normally has a high resistance) for a period of one microsecond.

The bursts of collector current provoked by preceding emitter current appeared to be explainable most reasonably on the basis of a rapid gathering-in of holes[1] produced by the forward emitter current and existing within the germanium at the time of application of collector potential. This explanation suggested that the same electrode might be used first to inject holes as an emitter and then to withdraw them as a collector. When this was tried, bursts of reverse current exceeding 24 milliamperes and overloading the pulser were obtained for the same voltage pulses, which interrupted a normal forward current of only 1 milliampere. With the forward current reduced to zero, the reverse current pulses became square and only a fraction of a milliampere in height.

Using a more powerful pulse generator for examining conventional germanium varistors (diodes) of various types, we found that the response curves could be classified into several dis-

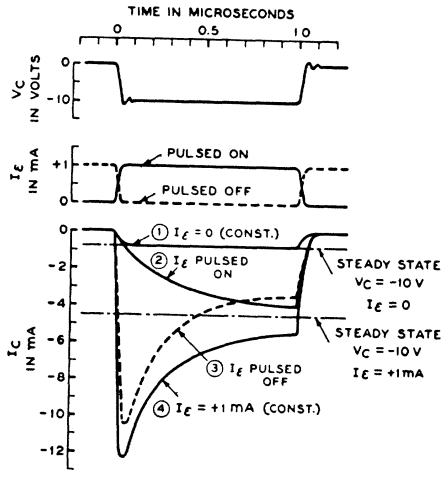

FIG. 1. Pulse study of transistors—typical wave forms.