TABLE I. Tentative assignment of most intense lines in the $J=5\rightarrow 6$ transition of SeCS.

Isotopic species	Ground vibrational state (Mc/sec.)	l-type components (Mc/sec.)	(Mc/sec.)	Moments of inertia (a.m.n.—A^2)
$S^{32}C^{12}Se^{82}$	24,021	24,048	24,075	252.49
$S^{32}C^{12}Se^{80}$	24,203	24,214	24,230	250.59
$S^{32}C^{12}Se^{78}$	24,376	24,386	24,406	248.81
$S^{32}C^{12}Se^{77}$	24,508	24,521	24,527	247.47
$S^{32}C^{12}Se^{76}$	24,602	24,614	24,627	246.53

field was increased to 6000 v/cm, at which point arcing between the Stark electrode and the walls of the guide began.

The preliminary frequency measurements for the most intense lines in the $J=5\rightarrow 6$ transition are given in Table I along with a tentative assignment. Since the Stark pattern was not completely resolved, the frequencies given in Table I may be in error by as much as 4 Mc/sec.; this is especially true in the case of the l-type components. The moments of the inertia are believed to be correct to ± 0.10 a.m.u.—A^2. Although these preliminary values are not sufficiently precise for accurate determination of internuclear distances, they may be valuable for thermodynamic work.

The present investigation is being extended to include the lines associated with the $J=4\rightarrow 5$ and $J=6\rightarrow 7$ transitions, some of which have already been observed. It is hoped that improvements in the absorption cell will permit the use of higher Stark fields and that more accurate frequency measurements can be made. At that time, a report on the less abundant isotopic species will be made.

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[4] We are indebted to Mr. S. R. Smith and Miss T. B. Enzer of the Chemistry Department for the analysis.

Isotopic Constitution of Thulium*

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TO date the only investigation of the isotopic constitution of thulium is that of Aston[1] who reported in 1934 that thulium consists of a single isotope of mass 169. In his report Aston mentioned having difficulty with his apparatus and gave no estimate of upper limits to the existence of other possible isotopes. Recent improvements in mass spectrometry prompted a re-examination of this element.

Our study has verified that thulium is simple to a high degree. The analysis was made with a 60°-type mass spectrometer, described by Leland,[2] incorporating an electron multiplier to give increased sensitivity in ion detection. The sample used was Tm_2O_3, "specure" brand, supplied by Johnson, Matthey and Company, Ltd., London. Ions were obtained by thermionic emission from a tungsten filament coated with a paste made by wetting the sample in distilled water.

A preliminary run at a relatively low emission temperature revealed the presence of ions at all masses in the range 162 to 176. At this temperature all ion intensities were of the same order of magnitude, but with an increase in emission temperature the ratios of all peak heights to that at 169 were found to decrease markedly. This indicated that the presence of peaks other than at 169 was in the main due to impurities rather than to isotopes of thulium. To obtain maximum reduction of the impurity intensities relative to thulium the emitting filament was operated at the highest temperature compatible with stable performance of the spectrometer. The relative ion intensities observed are given in column 2 of Table I.

TABLE I. Ion intensities in the mass range 162 to 176.

		Assumed impurities					
Mass No.	Observed intensity	SmO^+ 0.070 percent	Er^+ 0.48 percent	Yb^+ 0.10 percent	Lu^+ 0.39 percent	Total	Relative abundance of thulium
1	2	3	4	5	6	7	8
162	~0.001		0.0007			~0.001	<0.001
163	0.011	0.011				0.011	<0.002
164	0.016	0.0079	0.0077			0.016	<0.002
165	0.010	0.0097				0.010	<0.002
166	0.166	0.0052	0.160			0.165	<0.02
167	0.115		0.110			0.110	<0.02
168	0.144	0.019	0.130	0.0001		0.149	<0.02
169	100.000						100.00
170	0.087	0.016	0.072	0.003		0.091	<0.01
171	0.015			0.014		0.014	<0.002
172	0.022			0.022		0.022	<0.003
173	0.016			0.016		0.016	<0.002
174	0.032			0.032		0.032	<0.004
175	0.382				0.380	0.380	<0.04
176	0.023			0.013	0.010	0.023	<0.003

Table I also includes a quantitative account which explains the observed intensities in terms of impurities. Assuming the presence of impurity ions, namely SmO^+, Er^+, Yb^+, and Lu^+, in the amounts shown at the heading of columns 3 to 6 respectively and accepting the isotopic constitution of these elements as reported,[3] one arrives at constructed intensities (column 7) which are in good agreement with the observed intensities for all of the small peaks. Consequently it seems reasonable to conclude that the intensities observed at all masses except at 169 can be attributed to impurities. This would then permit isotopes of thulium in amounts not greater than the accuracy with which the observed intensities could be experimentally established. Although the observed and constructed amounts agree everywhere to within five percent, some of the observed intensities may be subject to as much as a 10 percent error. The latter figure was used in arriving at the values in column 8 for the upper limits of possible isotopes of thulium.

We wish to thank Professor A. O. C. Nier for his suggestion of this study and his interest in it. The construction of the apparatus was aided materially by grants from the Graduate School and the Minnesota Technical Research Fund subscribed to by General Mills, Inc., Minneapolis Star-Journal and Tribune, Minnesota Mining and Manufacturing Company, Northern States Power Company, and Minneapolis Honeywell Regulator Company.

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On Nuclear Quadrupole Moments

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IT was pointed out by Rabi that the hyperfine splitting due to the nuclear quadrupole moment includes the effect of an electric quadrupole moment induced in the electron shells. In order to obtain a crude estimate of the moment induced in a core of closed shells we consider the Thomas-Fermi model. For the electrons of maximum energy $E=0$, the momentum p is given by

$$\frac{p^2}{2m}=\frac{Ze^2\chi}{r}+\frac{e^2Q(3\cos^2\theta-1)}{4r^3}, \qquad (1)$$

Table I. Effect of the induced quadrupole moment.*

Element	Z	Orbital	R	$\langle V\rangle a_H{}^3$	$\langle 1/r^3\rangle a_H{}^3$	$Q/(10^{-24}\,\mathrm{cm}^2)$	$Q_{\mathrm{corr}}/(10^{-24}\,\mathrm{cm}^2)$
B	5	$2p$	0.220	0.860	1.18	0.06^a, 0.03^b	0.077^a, 0.038^b
Al	13	$3p$	0.121	1.04	2.57	0.156	0.177
Sc	21	$3d$	0.452	1.89	1.26	——	——
Ga	31	$4p$	0.055	2.21	12.1	0.232^c, 0.146^d	0.245^c, 0.155^d
In	49	$5p$	0.038	1.66	13.2	1.144^e, 1.161^f	1.189^e, 1.207^f
Eu	63	$4f$	0.405	9.29	6.88	1.2^g, 2.5^h	2.0^g, 4.2^h
Lu	71	$5d$	0.125	4.52	10.9	5.9^i, 7.0^j	6.7^i 8.0^j
Ac	89	$6d$	0.116	1.28	3.33	——	——

* In the last two columns of this table the superscripts refer as follows to different sotopes: ^{a} B^{10}, ^{b} B^{11}, ^{c} Ga^{69}. ^{d} Ga^{71}, ^{e} In^{113}, ^{f} In^{115}, ^{g} Eu^{151}, ^{h} Eu^{153}, ^{i} Lu^{175}, ^{j} Lu^{176}.

where χ is the Thomas-Fermi function at a point in the electron cloud, r is the length of the vector from the nucleus to this point, and θ is the angle included by this vector and the axis of the nuclear quadrupole moment Q. The density of electrons ρ is $8\pi p^3/3h^3$. Let $\Delta\rho$ be the density due to the second term of (1). Thus,

$$\Delta\rho=8\pi p_0{}^2\Delta p/h^3, \tag{2}$$

where Δp is the change of momentum associated with the term containing Q, and p_0 would be the maximum momentum, p, for $Q=0$. We have

$$(p_0\Delta p)/m=e^2Q(3\cos^2\theta-1)/4r^3. \tag{3}$$

From (1), (2), (3) we obtain

$$\Delta\rho=\pi(2me^2/h^2r^2)^{\frac{3}{2}}(Z\chi/r)^{\frac{1}{2}}Q(3\cos^2\nu-1). \tag{4}$$

The potential due to $\Delta\rho$ is that of a quadrupole moment ΔQ:

$$\begin{aligned}\Delta Q&=2\pi\int_0^\pi\int_0^\infty r^4(3\cos^2\theta-1)\Delta\rho\,\sin\theta d\theta dr\\&=(16\pi^2/5)(2me^2/h^2)^{\frac{3}{2}}QZ^{\frac{1}{2}}\int_0^\infty(\chi r)^{\frac{1}{2}}dr.\end{aligned} \tag{5}$$

Upon substituting $r=(0.88534a_H/Z^{\frac{1}{3}})x$, where x is the Thomas-Fermi variable ($a_H=$ Bohr radius), we obtain

$$\Delta Q=[2(1.7707)^{\frac{3}{2}}/5\pi]Q\int_0^\infty(\chi x)^{\frac{1}{2}}dx. \tag{5a}$$

We shall consider the case of a single valence electron; its radial wave function times r will be called v. The energy of interaction E_Q with the nuclear moment can be written:

$$E_Q=-AQ\int_0^\infty(v^2/r^3)dr, \tag{6}$$

where A is a constant. For the interaction $E_{\Delta Q}$ with the induced moment, the penetration of the electron inside the core leads to:

$$\begin{aligned}E_{\Delta Q}=\frac{2(1.7707)^{\frac{3}{2}}AQ}{5\pi}\int_0^\infty drv^2\bigg\{\frac{1}{r^3}\int_0^x(\chi x')^{\frac{1}{2}}dx'\\+r^2\int_x^\infty[(\chi x')^{\frac{1}{2}}/r'^5]dx'\bigg\},\end{aligned} \tag{7}$$

where $r'=(0.88534a_H/Z^{\frac{1}{3}})x'$, and the limit x of the x' integrals pertains to r. The difference in sign of E_Q and $E_{\Delta Q}$ reflects the fact that the electrons concentrate in the region where the potential due to the nuclear Q is positive, thus tending to compensate the effect of the nucleus. If we let $R=-E_{\Delta Q}/E_Q$, then Q is $1/(1-R)$ times the value previously obtained without the induced effect. We write

$$R=0.2998\langle V\rangle/\langle 1/r^3\rangle, \tag{8}$$

where

$$\langle V\rangle=\int_0^\infty drv^2\bigg\{\frac{1}{r^3}\int_0^x(\chi x')^{\frac{1}{2}}dx'+r^2\int_x^\infty[(\chi x')^{\frac{1}{2}}/r'^5]dx'\bigg\}, \tag{9}$$

$$\langle 1/r^3\rangle=\int_0^\infty(v^2/r^3)dr, \tag{10}$$

with: $\int_0^\infty v^2dr=1$.

Table I gives the values of R for eight elements. The values of $\langle V\rangle$ and $\langle 1/r^3\rangle$ are also listed, together with the quadrupole moments[1] as determined at present and the corrected values, in the cases where data are available. The valence electron functions were obtained by means of the Thomas-Fermi potential,

$$[(Z-1)\chi+1]e/r.$$

A more detailed discussion will be given in a forthcoming paper.

It is a great pleasure to thank Professor Edward Teller, who suggested this problem, for many helpful discussions. I am also indebted to Drs. H. M. Foley and H. Snyder for stimulating discussions.

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Nuclear Magnetic Resonance for K^{39}

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Nuclear magnetic resonance has been found for K^{39} at 1.59 Mc in a field of 8000 gauss using a recording oscillating-detector spectrometer. The sample was 1 ml of saturated aqueous solution of KNO_2. The frequency of the K^{39} resonance was compared with the frequency of the N^{14} resonance in concentrated nitric acid by repeatedly substituting the samples in the oscillator coil without otherwise disturbing the apparatus. The frequencies repeated within the accuracy of a General Radio Type 620-A frequency meter. The result is

$$\nu(K^{39})/\nu(N^{14})=0.64580\pm0.00006.$$

Using the measurements of Proctor and Yu[1] on N^{14} in nitric acid, we find

$$\mu(K^{39})/\mu(H^1)=0.13999\pm0.00002$$

with no diamagnetic correction or allowance for possible chemical shift. This value agrees with molecular beam measurements.[2]

* Work supported by the National Research Council of Canada.

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Magnetic Moments of Odd Nuclei

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It has been pointed out by Wangsness[1] that a certain regularity seems to be associated with the magnetic moments of odd nuclei differing by two neutrons. There are, however, certain difficulties with the proposed classification. Besides failing to explain the pair $_{47}Ag^{107,109}$ as mentioned by Wangsness, it fails also in the cases of $_{81}Tl^{203,205}$, $_{55}Cs^{133,135}$, and $_{55}Cs^{135,137}$, not to mention the case[2] of $_1H^{1,3}$. Moreover, by using the argument given by Wangsness as to the effect of the increase and decrease of electric charge density in the nucleus one should expect the inverse effect to take place by the addition of a pair of protons or an alpha-particle instead of two neutrons. This is confirmed by the two pairs $_0n^1-{}_2He^3$ and $_{78}Pt^{195}-{}_{80}Hg^{199}$, but stands in contradiction to the known cases of: $_{17}Cl^{37}-{}_{19}K^{39}$, $_{55}Cs^{137}-{}_{57}La^{139}$, $_{48}Cd^{113}-{}_{50}Sn^{115}$, $_{36}Kr^{83}-{}_{38}Sr^{87}$, $_{54}Xe^{131}-{}_{56}Ba^{135}$.

A simple and exclusive rule to summarize these data with the exception of the Cs isotopes is the following. An addition of either two protons or two neutrons to an odd nucleus, provided it leaves its spin unchanged, "pushes" its magnetic moment away from a line intermediate to the Schmidt lines.[3]

Except for the cases of $_1H^3$ and $_2He^3$ this actually means that the magnetic moments are pushed toward a better agreement with the naive one-particle model by the addition of such pairs.

Using the above rules inductively one may argue that the nuclei $(Z+2k,\ N+2m)$ should be closer to the Schmidt lines than the initial $(Z,\ N)$ nucleus, provided that the spins of the initial,