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The Isotopic Constitution of Scandium, Gadolinium, Dysprosium, Holmium, Erbium, and Ytterbium

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The relative abundances of the isotopes of scandium, gadolinium, dysprosium, holmium, erbium, and ytterbium have been redetermined with a mass spectrometer incorporating an electron multiplier to give increased sensitivity. No new isotopes were found although special attention was devoted to this problem and low upper limits were set for nearly all possible isotopes.

ALTHOUGH the isotopic constitution of all the elements has been investigated heretofore, the data on several of the heavier elements are incomplete insofar as no search has been made for very rare isotopes, and in some cases the abundances need revision or confirmation. With these points in mind, several elements were examined with a mass spectrometer which was particularly well suited for the detection of rare isotopes and the measurement of natural isotopic abundances in relatively heavy elements.

APPARATUS AND PROCEDURE

The mass spectrometer employed in this investigation is essentially a modification of one already described in detail by Nier.[1] Figure 1 is a schematic diagram showing the general features of the major parts of the apparatus. Figure 2 gives a more detailed schematic of the source and source end of the spectrometer tube. Ions are obtained by thermionic emission from an appropriate compound with which the under side of the filament is coated. For the elements reported in this paper an oxide of the element in question was used. Adjustment of the current through the filament provided control over the temperature of the oxide coating and the rate of ion emission. In Fig. 2, S refers to a rectangular chamber which surrounds the filament and, along with one side of the filament, is connected to a source of high potential. J_1-J_2 and J_3 are essentially two slotted round plates connected to somewhat lower potentials and serve to draw the ions emitted by the filament down through a slit in S and to form a beam directed in the proper direction. Actually, J_1 and J_2 are a pair of half plates which, if connected to different potentials, provide a cross field capable of deflecting the ion beam to one side or the other. G_1 and G_2 are two grounded plates with fairly small slits, their function being to limit the beam as to size and angular divergence. The nearly monoenergetic beam of ions leaving the source passes through the sector magnet, is bent and dispersed in a spectrum according to the mass to charge ratio of the constituent ions. To measure the intensity of a particular type of ion the ratio of the magnetic field strength to ion energy is adjusted until the trajectory of the ions in question is such that they pass through the adjustable slit in front of the electron multiplier. The slit width is so adjusted that nearly all the ions in question will pass through to the exclusion of those having different mass or charge to mass ratios. The electron multiplier converts the ion current passing through the slit to a considerably larger, but nevertheless proportional, electron current which is then fed to a conventional feedback current amplifier. The design of the electron multiplier corresponds essentially to a scaled down version of one described by Allen.[2] The dynodes are made of a 2 percent beryllium copper alloy and are stacked up and mounted on a flange with a construction similar to that used on the ion source. Potentials and currents for operating the tube were supplied by electronically regulated supplies, a 2500-volt supply for the ion source, a 4500-volt supply for the multiplier and a 0–300 ma supply for the magnet. At 300 ma the magnet produced a field of about 8000 gauss in the air gap of $\frac{5}{8}$ inch. An ionization gauge not shown in the drawings was attached to the vacuum system to indicate the pressure.

The procedure in analyzing an element was quite simple. A clean new filament was prepared and moistened with a drop of pure water. A small amount of powdered oxide was then added to the drop of water so as to form a paste covering one side of the filament. When dry, the filament and source were inserted into the spectrometer tube and the vacuum pump started. After the ionization gauge pressure reading fell below 10^{-6} mm of Hg, the filament was turned on and its temperature raised slowly until adequate ion emission was obtained. Ion currents were metered by feeding the output of the current amplifier to a Brown Strip Chart recording potentiometer. By varying the magnetic field at an appropriate rate a mass spectrum was then traced by the recorder, and by measuring the heights of the various peaks the isotopic abundances could be determined. In order to maintain the desired accuracy over large ranges in intensity the current amplifier was provided with an accurately calibrated divider enabling step-wise changes in sensitivity up to a factor of 500. The usual procedure was to sweep over two or, at most, three adjacent peaks first in one

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* A.E.C. Fellow.

[1] A. O. Nier, Rev. Sci. Inst. 18, 398 (1947).

[2] J. S. Allen, Rev. Sci. Inst. 18, 739 (1947).

direction and then the other, the amplifier sensitivity being adjusted for each peak so that the recorder registered almost full scale. Generally twenty or more sweeps were made on a given set of peaks, and in some cases the procedure repeated on different days or at different intensities. The multiplicity of the data permits elimination of errors due to short term fluctuations in the ion current simply by an averaging process while reversing of the sweep direction on successive spectra tends to eliminate errors due to slow drifts in ion current intensity.

ACCURACY OF ABUNDANCE MEASUREMENTS

Obviously the problem of making accurate abundance measurements with a mass spectrometer involves both the production of separated ion beams having intensities of known relation to the isotopic abundances and the subsequent accurate measurement of the individual separated ion currents.

This later problem of measuring small ion currents has been fairly well solved by the development of accurate electrical methods to replace the older and inaccurate photographic plate techniques. The problem of quantitative production of separated ion currents, however, is still subject to many uncertainties which are difficult to detect, since they normally lead to systematic errors and do not affect the consistency or reproducibility of the results. If for the present study it is assumed that the chemicals used as ion sources have not suffered an alteration in isotopic constitution during their preparation, there is still the question of whether there is preferential emission of ions from the source or whether discriminating effects on ions of different mass occurs between the source and ion collector. This latter factor is believed to be negligible in the present experiments. By keeping all potentials fixed and varying only the magnetic field, the trajectories of ions of different mass should be identical in every respect at the time they are metered. Variation of ion source efficiency with voltage is not involved and effects due to initial energies of the emitted ions should be similar for all masses, provided the initial energies are independent of mass. The problem of preferential emission, however, is open to question. Such effects have, for example, been observed by Cook[3] in the case of potassium. A check of potassium with the present apparatus showed similar variations which could not be otherwise understood. Presumably the effect is contingent on the uneven transport of ions or atoms to or from the emitting surface, since if there were no mixing or other means of removing matter from the surface of the emitter, the emission would necessarily reach an equilibrium value giving the proper proportions of each isotope. In this respect, the rare earth oxides should be fairly good sources, since the emission does occur from the solid state at temperature not greatly exceeding 1000°C. Furthermore, the relatively high mass of the ions involved make for small fractional mass differences and less pronounced diffusion effects. To obtain an estimate of the reliability of this type of source, measurements were made on gadolinium on successive days and with different ion intensities. Small variations not exceeding one percent were observed, and it is believed that in the present study this type of error did not exceed one percent.

Errors introduced by the current measuring apparatus should not exceed 0.2 percent. The linearity of the electron multiplier was checked by measuring known isotope ratios such as the K^{40} to K^{39} ratio and found to be adequately linear. The input resistor used in the current amplifier when making abundance

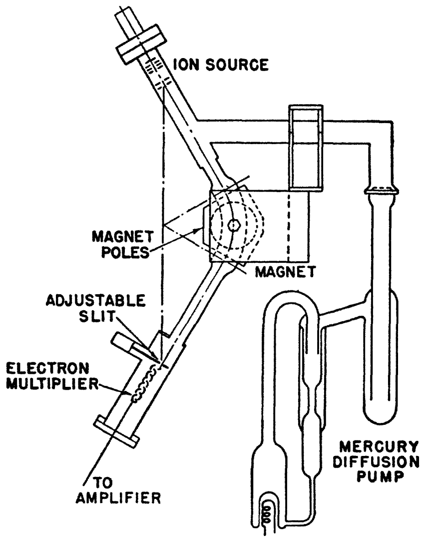

FIG. 1. Schematic drawing showing mass spectrometer tube and auxilliary apparatus,

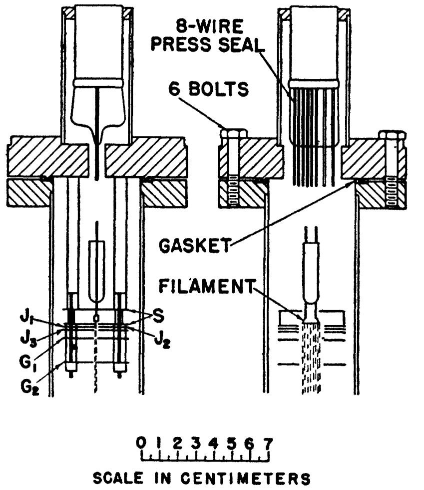

FIG. 2. Schematic drawing of ion sources. The filament is a 0.001-in. tungsten ribbon having a width of 0.030-in. and an overall extended length of about 0.5 inch. Slits in G_1 and G_2 are 0.010 inch by 0.56 inch.

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[3] Kenneth L. Cook, Phys. Rev. 64, 278 (1943).

TABLE I. Isotopic constitution of gadolinium.

Isotope	Atomic percentage This study	Hess	Wahl	Dempster	Aston
149	<0.001	<0.005			
150	<0.0005	<0.005			
151	<0.0003	<0.005			
152	0.20±0.005	0.20	0.2	0.2	
153	<0.0005	<0.005			
154	2.16±0.02	2.15	2.86	1.5	
155	14.68±0.15	14.78	15.61		21
156	20.36±0.20	20.59	20.59		23
157	15.64±0.16	15.71	16.42		17
158	24.96±0.25	24.78	23.45		23
159	<0.002	<0.01			
160	22.01±0.22	21.79	20.87		16
161	<0.001	<0.02			
162	<0.002	<0.02			

measurements had a nominal resistance of 2×10^{10} ohms. By placing a charged air condenser in parallel with this resistor and watching the decay in voltage as a function of time, it was ascertained that for the range of voltages used in making abundance measurements, the resistance was independent of voltage to the extent of the 0.1 percent which could have been detected in the test. Response of the amplifier and recorder were checked and the divider used to change amplifier sensitivity carefully calibrated.

The error limits assigned to the measured abundances reported in this paper are estimated maximum errors. They are taken as one percent of the measured value except in special cases where special uncertainties entered.

DETECTION OF RARE ISOTOPES

The detection of rare isotopes poses altogether different problems. Not only is it necessary to measure ion currents having a ratio of say 10^4 to 10^6 in magnitudes, but it is also necessary to produce such well-defined and separated ion beams that the stragglers in the large beams do not mask the presence of the small one. In addition there is the problem of eliminating impurities to a very high degree. If one considers that there is a smallest ion current which can be detected, then there likewise is a minimum total ion current commensurate with measuring a given ratio of ion currents. The higher this ratio is the higher must be the total ion current. Unfortunately, the production of larger ion currents is generally in opposition to the problem of obtaining well-resolved ion beams. Increasing the size of slits to accept a larger and more diverse beam obviously will give more intensity and poorer resolution. Attempts to increase the rate of ion production in the source usually result in an increase in pressure in the spectrometer tube, and an intolerable amount of scattering occurs. In the present apparatus noticeable scattering occurred even at pressures as low as 10^{-6} mm of Hg. It is clear then that there are definite advantages to be gained by using an electron multiplier and working with smaller ion currents. There is, however, no guarantee that the addition of an electron multiplier will enable one to immediately detect rarer isotopes. In the not too unusual cases where there are certain small but relatively fixed impurity peaks already present, one is forced to work at high intensities in an effort to drown out the impurities. Also there are cases wherein resolution is inadequate by virtue of factors fairly independent of the ion intensity or where the samples used contain impurities which remain pretty much in proportion to the element studied. This latter situation proved to be the biggest difficulty in the elements studied in this investigation. All samples used in this work were procured from Johnson, Matthey, and Company, Limited and were of their "specpure" brand. Each

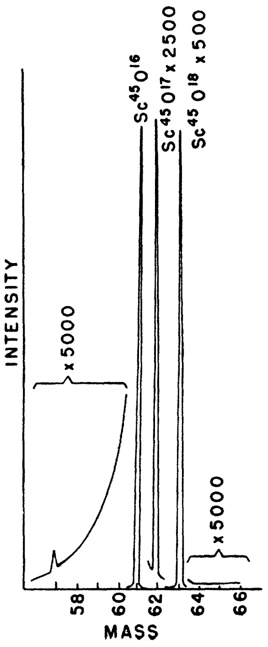

FIG. 3. Mass spectrum of ScO^+ ions. The mass 62 and 63 peaks are due to oxygen isotopes. The mass 57 peak is attributed to an unidentified impurity.

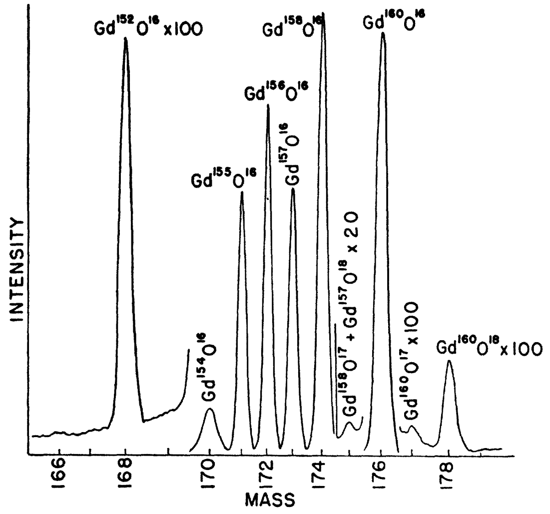

FIG. 4. Mass spectrum of GdO^+ ions showing seven gadolinium isotopes and two oxygen isotopes.

sample had been analyzed spectroscopically by the supplier and detectable traces of impurities reported. Although the spectroscopic analysis generally did not show the presence of troublesome impurities, they invariably turned up in unfortunate amounts. The multiplier used had a gain of about 1000 which is far below its capabilities. In view of the impurity difficulties, however, there was nothing to be gained by taking steps to increase the gain. Also the slits used were larger than would be desirable for best resolution. The lowest upper limits reported in this article occur for scandium and correspond to two parts in 10^6. A better idea of the ultimate capabilities of the apparatus is discerned by the one part in 3×10^6 limit placed on I^{129} as reported in a previous article[4] (erroneously reported one place in the article as three parts in 10^6).

SCANDIUM

Scandium has been examined by Aston[5] who reported the single isotope Sc^{45}. In this investigation heated Sc_2O_3 was used as a source of thermionic ions. ScO^+ ions were by far the most abundant and, consequently, most suited for the analysis in spite of interference from oxygen isotopes. Figure 3 shows a spectrum of the mass region 57 to 66. Peaks at masses 62 and 63 are accounted for by oxygen isotopes as indicated in the figure. The small peak at mass 57 apparently is due at least in part to an impurity of some sort, since its size relative to the 61 peak did not remain constant with time or with variations in the size of the 61 peak. Upper limits obtained for possible scandium isotopes are as follows: Sc^{41} less than 0.001 percent; Sc^{42}, Sc^{43}, Sc^{48}, and Sc^{49} less than 0.0002 percent; Sc^{44} less than 0.0005 percent; Sc^{46} less than 0.002 percent; Sc^{47} less than 0.01 percent. Limits on Sc^{46} and Sc^{47} are taken to be 5 percent of the abundance of the oxygen isotopes which interfered with these measurements. Actually an analysis of the observed mass 62 and mass 63 peak indicated that they were about 5 percent smaller than would be expected on the basis of the abundances of the oxygen isotopes as given by Thode and Smith.[6] However, comparison of data taken at different times and under different source conditions indicated that, in spite of good internal consistency obtainable for a given analysis for fixed conditions, the result of any one analysis might well be in error to the extent of 5 percent, and no special significance could be attached to lower values obtained for the abundance of the oxygen isotopes. The difficulty probably lies with the type of source used as was discussed earlier in this article.

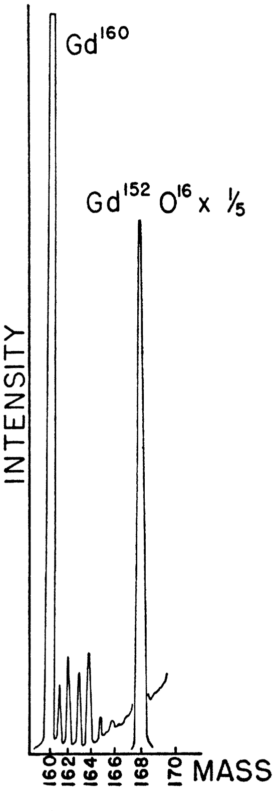

FIG. 5. Expanded view of mass spectrum in region just below lightest known isotope of gadolinium. Unlabeled peaks can be accounted for by rare earth impurities. The flat top in the Gd^{160} peak signifies that it exceeded the maximum travel of the recorder.

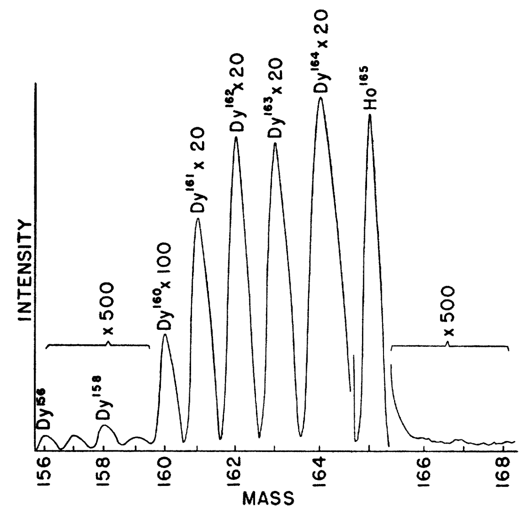

FIG. 6. Mass spectrum of Ho^+ and Dy^+ ions. Peaks at masses 157 and 159 are attributed to impurities.

With the exception of Sc^{41}, limits on other scandium isotopes are computed on the basis of the estimated size of peak which could have been detected. The size of the mass 57 peak under the most favorable circumstances was used to compute an upper limit for Sc^{41}.

GADOLINIUM

The isotopic constitution of gadolinium has been studied by several investigators, first by Aston,[7] who discovered the five isotopes Gd^{155}, Gd^{156}, Gd^{157}, Gd^{158},

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[4] W. T. Leland, Phys. Rev. **76**, 992 (1949).

[5] F. W. Aston, Proc. Roy. Soc. **A134**, 571 (1932).

[6] H. G. Thode and S. R. Smith, National Research Council of Canada, Atomic Energy Project, Report MC-57 (revised) (May, 1949).

[7] F. W. Aston, Proc. Roy. Soc. **A146**, 46 (1934).

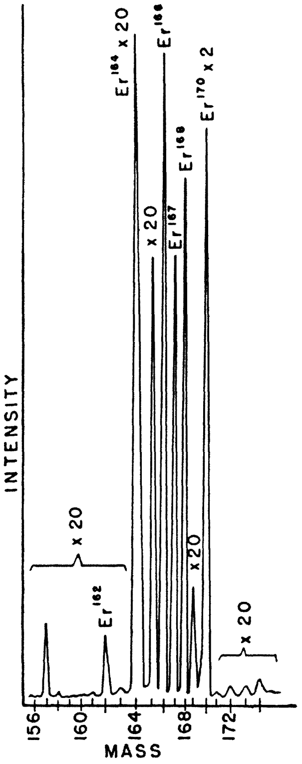

FIG. 7. Mass spectrum of Er^+ ions. Unlabeled peaks are attributed to impurities.

and Gd^{160}, then by Dempster,[8] who also observed the additional less abundant isotopes Gd^{152} and Gd^{154}. Wahl[9] and Hess[10] have since made more precise measurements of the natural isotope abundances but with some disagreement. Further interest in gadolinium centers on the isotope Gd^{150} whose existence in nature has been suggested on the basis of regularities in the isotopic constitution of the heavier elements.[11] Thermionic GdO^+ ions obtained from heated Gd_2O_3 were used in this investigation. The results corrected for the presence of oxygen isotopes are listed in Table I along with those of previous investigations for the sake of comparison. The agreement with Hess' results is quite satisfactory. Actually, if the abundance ratios of adjoining isotopes were compared, the results would be in even better agreement with the exception of the 157/156 ratio. Figure 4 shows a typical mass spectrum of the gadolinium isotopes. The peaks at mass 175, 177, and 178 can be accounted for by oxygen isotopes as indicated in the figure. Computation of the O^{17} and O^{18} abundances on the basis of these peaks gives results agreeing with those of Thode and Smith[6] within 5 percent. The limits placed on Gd^{159}, Gd^{161}, Gd^{162} are consequently computed on the basis of a maximum error in the abundance measurements, namely 10 percent for the peaks of mass 175 and mass 177 and 5 percent for the mass 178 peak.

As is seen in Fig. 5 several peaks occur on the mass range 160 to 169, and in particular a small peak is evident at mass 166 which could be due to $Gd^{150}O^{16}$ in the event Gd^{150} actually existed. However, the 166 peak did not show proper correlation to the other gadolinium peaks, and it is unlikely that more than a small fraction of this peak is due to Gd^{150}. Actually these observed peaks together with their relative abundances are well accounted for by a mixture of NdO^+, Dy^+, and Ho^+ ions which are likely impurities.

The limits placed on the abundances of Gd^{149} and Gd^{150} nevertheless are taken as the size of the corresponding observed impurity peak.

DYSPROSIUM AND HOLMIUM

The holmium oxide secured for the analysis of holmium contained considerable amounts of dysprosia (about 15 percent according to supplier). Because dysprosium has isotopes of mass numbers equal to those of possible holmium isotopes, it was necessary to make an analysis of the dysprosium peaks and compare the results with its previously measured isotopic constitution[12] in order to determine whether or not any holmium peaks were superimposed on those of dysprosium. Although the dysprosium analysis suffered to some extent from the fact that dysprosium occurred in the sample merely as an impurity, the results are nevertheless of interest in that they confirm for the most part the results of Inghram, Hayden, and Hess[12] which do not agree entirely with those of Wahl.[13] In the case of holmium on the other hand, the existence of rare isotopes is still in question. Aston[7] reported a single isotope Ho^{165} but gave no estimate of the sensitivity of his apparatus. Although radioactivities have been reported for most possible holmium isotopes,[14] the isotope assignment in most cases is uncertain. A typical spectrum obtained with Dy^+ and Ho^+ thermionic ions

TABLE II. Isotopic constitution of dysprosium.

	Atomic percentage				
Isotope	This study	Inghram, Hayden, Hess	Wahl	Dempster	Aston
156	$0.064{+0.001 \atop -0.064}$	0.0524			
158	$0.105{+0.001 \atop -0.105}$	0.0902	0.1	0.1	
160	$2.36\ {+0.02 \atop -0.10}$	2.294		1.5	
161	18.73 ±0.19	18.88	21.1		22
162	25.36 ±0.25	25.53	26.6		25
163	24.91 ±0.25	24.97	24.8		25
164	$28.47\ {+0.28 \atop -0.56}$	28.18	27.3		28

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[8] A. J. Dempster, Phys. Rev. **53**, 727 (1938).

[9] W. Wahl, Soc. Sci. Fenn., Comment-Physics-Mathematics U, 1 (1941).

[10] D. C. Hess, Jr., Phys. Rev. **74**, 773 (1948).

[11] H. E. Duckworth, Phys. Rev. **75**, 1438 (1949).

[12] M. G. Inghram, R. J. Hayden, and D. C. Hess, Jr., Phys. Rev. **75**, 693 (1949).

[13] W. Wahl, Suomen Kemistiseuran Tiedonatoja **51**, 64 (1942).

[14] G. T. Seaborg and E. Perlman, Rev. Mod. Phys. **20**, 623 (1948).

is shown in Fig. 6. Upper limits obtained for possible holmium isotopes are as follows: Ho^{161}, Ho^{162}, Ho^{163}, and Ho^{164} less than 0.04 percent; Ho^{166}, Ho^{167}, and Ho^{168} less than 0.001 percent; Ho^{169} less than 0.004 percent. The results for dysprosium are given in Table II but must be qualified to some extent due to the presence of impurities as indicated in Fig. 6 by the presence of peaks of mass 157 and mass 159. Assuming the impurities to be rare earths or other common thermionic ion emitters, it is possible to account for all the peaks. Unfortunately, however, it was not possible to make positive identification, and the abundances for the lighter dysprosium isotopes are correspondingly uncertain. Gd$^+$ ions were pretty much ruled out by noting the inconsequential size of peaks corresponding to GdO$^+$ ions which are normally the most abundant from a gadolinium oxide source. However, various combinations of CeO$^+$, NdO$^+$, PrO$^+$, Dy$^+$, and Tb$^+$ ions giving good account of the peaks in the mass range 156 to 159 could not be ruled out. Actually, it is necessary to assume the presence of only PrO$^+$, Tb$^+$, and Dy$^+$ in which case there would be no interference with the analysis. Taking this last assumption the computed abundances for Dy^{156}, Dy^{158}, and Dy^{160} as given in Table II are higher than those reported by Inghram *et al.*[12] It should be pointed out that since it was not possible to rule out the presence of cerium, this work could not be considered as definite confirmation of the existence of Dy^{156}. The measurement of the Dy^{164} abundance is subject to some error due to imperfect resolution of the mass 164 and mass 165 peaks. This error which is normally negligible is enhanced by the fact the 165 peak is about 20 times as large as the 164 peak. If, for example, in this case the 165 peak has fallen off by a factor of 2000 at the mass 164 position, the 164 peak will still be too high by about one percent. Although it was not possible to ascertain the exact amount of error present on this account, it should not exceed one percent.

The upper limits placed on holmium isotopes lighter than mass 165 are taken as one percent of the corresponding dysprosium peak, while for the heavier isotopes the size of observed impurity peaks is listed.

TABLE III. Isotopic constitution of erbium.

Isotope	Atomic percentage This work	Wahl	Dempster	Aston
160	<0.005		<0.03	
161	<0.01		<0.03	
162	0.154±0.007	0.1	0.25	
163	<0.01		<0.03	
164	1.60±0.02	1.5	2.0	
165			<0.03	
166	33.36±0.33	32.9		36
167	22.82±0.23	24.4		24
168	27.02±0.27	26.9		30
169	<0.15			
170	15.04±0.15	14.2		10
171	<0.01		<0.03	
172	<0.01		<0.03	

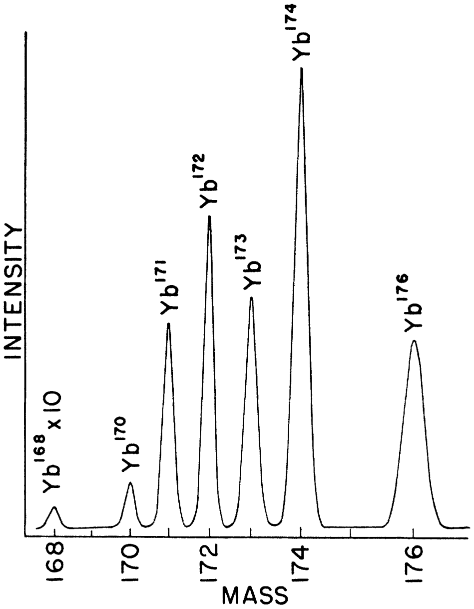

FIG. 8. Mass spectrum of Yb$^+$ ions showing the seven isotopes of ytterbium.

ERBIUM

Erbium was first studied by Aston[7] who reported the isotopes Er^{166}, Er^{167}, Er^{168}, and Er^{170}. Dempster[8] later found Er^{162} and Er^{164}. More recently Wahl[15] has remeasured the abundances of the natural isotopes. The data obtained by these investigations, however, is based on the photographic plate method of ion detection, and it is of interest to redetermine the abundances using more accurate electrical methods of ion current measurements.

Er$^+$ ions obtained from heated Er$_2$O$_3$ gave the results listed in Table III. A typical spectrum is shown in Fig. 7. As is evident from Fig. 7, there are sizeable peaks at mass 165 and mass 169. However, neither of these peaks maintained a constant ratio to the other erbium peaks with time and with variations in source

TABLE IV. Isotopic constitution of ytterbium.

Isotope	Atomic percentage This study	Hayden, Hess, Inghram	Wahl	Dempster	Aston
166	<0.001	0.002			
167	<0.0005	0.002			
168	0.13±0.005	0.140		0.06	
169	<0.0005	0.01			
170	3.03±0.03	3.034	4.21	2.0	
171	14.27±0.14	14.34	14.26		9
172	21.77±0.22	21.88	21.49		24
173	16.08±0.16	16.18	17.02		17
174	31.91±0.32	31.77	29.58		38
175	<0.005	0.01			
176	12.80±0.13	12.65	13.38		12
177	<0.001	0.01			
178	<0.0005	0.002			

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[15] W. Wahl, Suomen Kemist. Tied. **50**, 10 (1941).

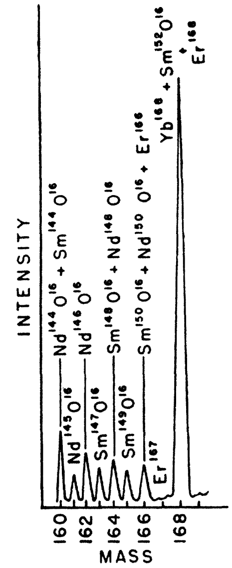

FIG. 9. Mass spectrum showing impurity peaks in mass region below Yb^{168}.

temperature, so they are definitely due, at least in part, to impurities. The corresponding peaks also appeared in the ErO^+ spectrum, but the amounts were significantly different. The most probable impurities are holmium and thulium. SmO^+ ions by virtue of the small mass 163 peak cannot account for the mass 165 peak, while EuO^+ ions are rendered an unlikely source of the 169 peak due to the absence of Eu^+ ions in consequential amounts. Since holmium and thulium have but one isotope, they do not interfere with the analysis other than by making it impossible to detect a small amount of Er^{165} or Er^{169} should they exist. Other peaks in the spectrum indicate the possibility of small amounts of gadolinium, samarium, ytterbium, or dysprosium being present. Allowances for these possibilities have been made by increasing the error limits on abundances in the appropriate direction.

YTTERBIUM

Ytterbium is known to have at least seven naturally occurring isotopes of masses 168, 170, 171, 172, 173, 174, and 176. The five heaviest ones were discovered by Aston,[7] who was the first to investigate the isotopic constitution of ytterbium. Dempster[8] later found the two lighter and rarer isotopes. The relative abundances of the natural isotopes have since been redetermined by Wahl[16] and by Hayden, Hess, and Inghram.[17]

This investigation employed thermionic Yb^+ ions from heated Yb_2O_3. A typical spectrum is shown in Fig. 8, and the results are tabulated in Table IV along with those of other investigators. The measurement of the Yb^{168} abundance was made difficult to some extent by the presence of impurities. Figure 9 shows a typical spectrum of the mass region 160–168. If one makes the very probable assumption that the peaks are due to rare earth ions of the RO^+ or R^+ variety, it is possible to make reasonably positive identification of the impurities by comparing the relative heights of the impurity peaks with the known isotopic abundances of the rare earths. Table V, for example, gives an analysis of the impurity peaks shown in Fig. 9. Examination of the spectrum for lighter masses further substantiates the assignments made. Admitting the presence of samarium of course necessitates a correction in the ytterbium peaks of mass 168 and 170 due to interference from $Sm^{152}O^{16}$ and $Sm^{154}O^{16}$. Under conditions prevalent when the data of Table IV was taken, the correction amounted to 11 percent in the measured abundance of Yb^{168} and 0.4 percent for Yb^{170}. Assignment of upper limits to possible rare ytterbium isotopes has been made on the basis of the heights of observed impurity peaks with the exception of Yb^{175} and Yb^{166} limits. Resolution proved to be a limiting factor in the case of Yb^{175}, while for Yb^{166} allowance has been made for the presence of $Sm^{150}O^{16}$ and $Nd^{150}O^{16}$, the amounts of which are assumed known on the basis of other peaks with an accuracy of 25 percent. Presence of significant amounts of other likely rare earth impurity peaks which might interfere with the analysis has been ruled out. For example, a troublesome amount of gadolinium which would yield GdO^+ ions and give a spectrum coinciding with that of the Yb^+ ions is ruled out by the extreme scarcity of peaks corresponding to Gd^+ ions and to $Gd^{150}O^{18}$.

TABLE V. Analysis of impurity peaks in ytterbium.

Mass	Assumed ions NdO^+	SmO^+	Er^+	Yb^+	Total	Observed peak
160	9.2	0.9			10.1	10.0
161	3.2				3.2	3.4
162	6.6				6.6	6.6
163		4.5			4.5	4.5
164	2.2	3.4			5.6	5.7
165		4.1			4.1	4.1
166	2.2	2.2	0.6		5.0	5.0
167			0.4		0.4	0.5
168		7.9	0.5	52.6	61.0	61.0

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