The gamma-ray reported by Swann and Hill at 215 kev must have been based on the assumption that the electron line at 135.5 kev is due to K conversion. It appears more probable that this is an M line for a 139-kev gamma-ray whose rather strong K and L lines are obscured in early exposure by the strong blackening due to the 14-hour activity. Subsequent plates show the lines in their proper ratio.

It is possible to observe some equivalent mathematical combinations of the gamma-energies and thus to suggest a nuclear level scheme as shown in Fig. 3. The three gamma-rays shown in the upper part of this figure could be arranged in alternate plans dependent upon the evaluation of the components of the accompanying beta-radiation. No measurement was made in this investigation of the beta-energies. The electron intensity ratios can be approximately expressed for five of the gamma-rays, as shown in column 3, Table IV. These numbers are based on visual estimates.

Some of the short exposures required to distinguish the electron lines associated with the 14-hour activity from those of 31-hour half-life were taken near the Argonne pile by Mr. W. C. Jordan. This investigation was made possible by the joint support of the U. S. Office of Naval Research and the U. S. Atomic Energy Commission.

PHYSICAL REVIEW VOLUME 90, NUMBER 3 MAY 1, 1953

Relative Abundances and Neutron Capture Cross Sections of the Neodymium Isotopes*

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(Received November 24, 1952)

A double-focusing mass spectrometer has been used to determine the relative isotopic abundances of naturally-occurring neodymium and the relative isotopic neutron capture cross sections. Allowance for isotope fractionation, an effect which is only noticeable under certain experimental conditions, has been accomplished by an averaging technique. The relative abundances are compared with the results previously published.

The relative cross sections are normalized to a value of 48 barns for the capture cross section of normal neodymium. The resulting isotopic cross sections are in satisfactory agreement with the recently published results of Pomerance.

THE neutron capture cross sections of the neodymium isotopes have been studied previously, both by activation methods[1] and with a mass spectrometer.[2] In view of the very high fluxes available with the Chalk River reactor, it was felt that the mass spectrometer studies should be repeated. This work has now been completed and the results, both capture cross sections and relative abundances, are reported below.

In a recent paper[3] Pomerance has reported on the neutron capture cross sections of the isotopes of twenty-four elements, including neodymium, by a pile oscillator method, using separated isotpes. The cross-section data obtained by the two methods are in fair agreement (See Table II).

The mass spectrometer method for determining neutron capture cross sections has been described previously.[2] A sample of neodymium was irradiated in the Chalk River pile for a period of time long enough to effect an appreciable change in the abundances of the isotopes. The relative abundances of the neodymium isotopes in the irradiated and unirradiated samples were measured with a Dempster-type double-focusing mass spectrometer[4] employing a heated crucible ion source.[5]

A comparison of the two sets of results permits the calculation of the relative capture cross sections of the individual isotopes. If the net change in the isotopic abundances is small, it is permissible to use a simple set of equations derived on the assumption that the rate of change in abundance is constant with time. If n, n_2,—n_s, and n_1', n_2',—n_s' are the initial and final abundances, respectively, of the 1st, 2nd, — and sth isotopes of an element, having capture cross sections σ_1, σ_2,—σ_s, then

$$\sigma_1 Nt = (n_1 - n_1')/\tfrac{1}{2}(n_1 + n_1'),$$
$$\sigma_2 Nt = [(n_1 - n_1') + (n_2 - n_2')]/\tfrac{1}{2}(n_2 + n_2'),$$

etc. Here N is the number of neutrons per cm^2 per sec, and t is the total irradiation time in seconds. These equations are sufficiently accurate that, even for Nd^{143}

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* Submitted by one of the authors (W. H. W.) in partial fulfillment of the requirements for the degree of Master of Science at McMaster University.

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[1] W. Bothe, Z. Naturforsch. **1**, 179 (1946).

[2] D. C. Hess and M. G. Inghram, Phys. Rev. **76**, 300 (1949).

[3] H. Pomerance, Phys. Rev. **88**, 412 (1952).

[4] A. J. Dempster, Proc. Am. Phil. Soc. **75**, 755 (1935).

[5] A. E. Shaw, Atomic Energy Commission Report MDDC 308, (unpublished).

TABLE I. Isotopic abundances for naturally occurring neodymium.

Isotopic mass no.	Percent abundances Present work	 Inghram, Hess, and Hayden[a]	 Mattauch and Scheld[b]
142	27.09±0.03[c]	27.13	26.80
143	12.14±0.02	12.20	12.12
144	23.83±0.03	23.87	23.91
145	8.29±0.01	8.30	8.35
146	17.26±0.02	17.18	17.35
148	5.74±0.02	5.72	5.78
150	5.63±0.02	5.60	5.69

[a] See reference 7.
[b] See reference 6.
[c] The quoted error is the standard deviation.

for which the change in abundance was 13 percent, the difference between the result using the appropriate approximate equation and that obtained by using the exact equation was less than one third the quoted standard deviation.

The unirradiated neodymium abundance measurements were obtained using two different chemical forms of the element. The first group comprised seven samples of neodymium metal filings, about two milligrams each. These yielded measurable peaks for only two hours on the average, during which time the effect of mass fractionation in the source was marked, i.e., the abundance of the lighter isotopes decreased relative to the heavier isotopes. The second group of results was obtained from a single 50-microgram sample of neodymium oxalate, which showed no evidence of depletion after running six hours, and only slight isotope fractionation changes. The averages of the two groups were in excellent agreement and are compared in Table I with results published previously by Mattauch and Scheld,[6] and Inghram, Hess, and Hayden.[7]

The irradiated neodymium abundances were obtained using two 50-microgram samples of the oxalate. Each sample was run for six hours, but showed definite abundance changes during the last two. For this reason only the data from the first four hours were used for each sample.

The only contaminant detected which could affect the results was Pr^{141}. An analysis of the neodymium with a twenty-one-foot grating spectrograph showed that the amount of praseodymium present was too small to have any effect.

In order to normalize the isotopic cross sections, it is necessary to assume some definite value for the capture cross section of the element, $\sigma_c(\mathrm{Nd})$. Three somewhat different values have appeared in the last two years: 52 barns,[8] obtained inside the Argonne heavy-water reactor using a pile oscillator technique; 44 barns,[9] obtained using the same method in the graphite reflector of the Oak Ridge graphite-moderated reactor; and 48 barns,[3] also obtained at Oak Ridge. In this latter case, where the isotopic capture cross sections were measured using separated isotopes as absorbers, $\sigma_c(\mathrm{Nd})$ is found by summing the contributions of all the isotopes. Since neodymium shows no strong capture levels above the thermal neutron region,[10] which might explain the discrepancy between the first two values, the mean of these three is used to normalize the relative capture cross sections obtained in this experiment.

TABLE II. Neutron capture cross sections of neodymium isotopes.

Isotopic mass no.	Present work $\sigma_c(\mathrm{Nd})=48$ b	Pomerance[a] $\sigma_c(\mathrm{Au})=95$ b[d]	Hess and Inghram[b] $\sigma_c(\mathrm{Nd})=48$ b[e]	Bothe[c] $\sigma_c(\mathrm{Ho})=64$ b[f]
142	13 ± 5[g]	18.5± 2	<13	
143	334 ±12	292 ±23	256	
144	0 ± 6	4.8± 0.6	<16	
145	37 ± 6	52 ± 4	<32	
146	3.7± 5	9.8± 0.8	<21	1.8
148	3.7± 9	3.3± 1.0	<48	3.7
150	0 ±12	2.9± 1.5	<48	—

[a] See reference 3.
[b] See reference 2.
[c] See reference 1.
[d] Cross sections measured relative to gold, using $\sigma_c(\mathrm{Au})=95$ barns for neutrons having a velocity of 2200 meters per sec. The sum of the contributions of all the isotopes to $\sigma_c(\mathrm{Nd})$ is 48 barns.
[e] Hess and Inghram used a value for $\sigma_c(\mathrm{Nd})$ of 45 barns. The isotopic cross sections listed here have been adjusted to $\sigma_c(\mathrm{Nd})=48$ barns for purpose of comparison.
[f] Bothe's original work used holmium as a standard, using a value for $\sigma_c(\mathrm{Ho})$ of 49 barns. The cross sections listed here have been corrected for $\sigma_c(\mathrm{Ho})=64$ barns, as quoted by Pomerance, reference 9.
[g] The errors quoted are obtained from the standard deviations of the isotope abundance measurements and do not include any allowance for the possible error in the normalization value of 48 barns for $\sigma_c(\mathrm{Nd})$.

The results are compared in Table II with those obtained by Pomerance,[3] the previous mass spectrometric results,[2] and the activation cross sections measured by Bothe.[1]

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[6] J. Mattauch and H. Scheld, Z. Naturforsch **3a**, 105 (1948).
[7] Inghram, Hess, and Hayden, Phys. Rev. **74**, 98 (1948).
[8] Harris, Muehlhause, Rasmussen, Schroeder, and Thomas, Phys. Rev. **80**, 342 (1950).
[9] H. Pomerance, Phys. Rev. **83**, 641 (1951).
[10] R. K. Adair, Revs. Modern Phys. **22**, 249 (1950).