related; though as indicated, they generally fall about 6 Mev apart.

It is to be noted that $_{26}Fe^{54}$ has the "magic" number of 28 neutrons and $_{28}Ni^{58}$ the "magic" number of 28 protons. The neutron yield per mole per roentgen for the 6 percent Fe^{54} isotope is found to be about 3/5 of that obtained by Price and Kerst[8] (Table III). Nickel, on the other hand, which is "magic" in all

TABLE III. Photoneutron yields.

Isotope	Neutrons/mole/roentgen: Present work indicated isotope only	Price and Kerst natural element
Fe^{54}	1.01×10^6	1.64×10^6
Ni^{58}	1.12×10^6	1.04×10^6
Zn^{64}	2.82×10^6	2.35×10^6

isotopes, is found to give the same yield, within experimental error, for the 68 percent isotope Ni^{58} as for the natural element. We find about 20 percent more neutron yield from the 50 percent isotope Zn^{64} than Price and Kerst found for the natural element. This difference may still be within the combined experimental error. These measurements substantiate the neutron yield from nickel found by Price and Kerst, which was about one-half of that from the other elements in this region of the periodic table.

The absolute neutron yields are based on a maximum cross section for Cu^{63} of 0.10 barn. This value is 10 percent less than our previously published result[1] and is believed to be more accurate.

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Interpretation of Photoneutron Yields

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"RESONANCE" cross-section curves for several (γ, n) reactions have recently been determined by activation measurements in this laboratory.[1-3] These resonances are of the type predicted for nuclear dipole transitions by Goldhaber and Teller[4] and by Levinger and Bethe.[5] The curves are so similar in relative shape (except for Fe^{54} and C^{12}, which rise steeply owing to high (γ, n) thresholds) that it is possible to use their average cross-section shape in an analysis of the photoneutron yields obtained for 53 elements by Price and Kerst.[6]

TABLE I. Characteristics of (γ, n) cross-section curves.

Reaction	Energy of maximum Mev	E_m-Q Mev[a]	Maximum σ barn	Half-width Mev	Integrated cross section, Mev-barn
$P^{31}(\gamma, n)P^{30}$	17.0	4.6	0.017	7.6	0.13
$Ni^{58}(\gamma, n)Ni^{57}$	18.5	6.8	0.060	4.5	0.33
$Cu^{63}(\gamma, n)Cu^{62}$	17.5	6.6	0.10[b]	5.8	0.63[b]
$Zn^{64}(\gamma, n)Zn^{63}$	18.5	6.7	0.12	7.2	0.83
$Sb^{121}(\gamma, n)Sb^{120}$	14.5	5.2	>0.21	5.4	>1.2
$Sb^{123}(\gamma, n)Sb^{122}$	14.5	5.2	0.34	5.5	2.0
$Ta^{181}(\gamma, n)Ta^{180}$	13.5	5.5	>0.078	4.5	>0.39
Average	—	6.0	—	5.5[c]	—

[a] Energy of peak maximum above threshold.
[b] A 10 percent correction has been applied to the values of reference 1.
[c] This is not the mean of the above values, because the shape averaging was carried out vertically rather than horizontally.

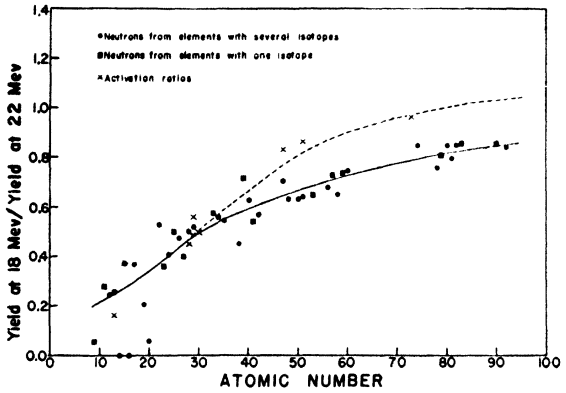

FIG. 1. Ratio of photoneutron yields with 18- and 22-Mev x-rays.

The essential characteristics of the cross-section curves are shown in Table I. An average of the curves was obtained by normalizing them at their peaks in arbitrary cross-section and energy position.

Steinwedel *et al.*[7] predict that the resonance peak energies should vary as $A^{-1/3}$, whereas Goldhaber and Teller predict a variation as $A^{-1/6}$. With the peak position data of Table I and the values for (γ, n) reactions in Cu^{65} (19.0 Mev), Fe^{54} (18.5 Mev),[3] Ag^{109} (16.5 Mev),[8] Al^{27} (19.6 Mev),[9] and C^{12} (22.4 Mev),[10] the best fit to the above type of relationship is

$$E_m=36A^{-0.18}, \tag{1}$$

where E_m is the peak energy in Mev. This favors the prediction of Goldhaber and Teller. However, the empirical relationship

$$E_m=21.5\exp(-0.00274A) \tag{2}$$

fits the data much better and has been used in the following considerations.

With the peak energies as calculated from Eq. (2), the average cross-section shape as determined above, and the Schiff x-ray spectrum,[1] the ratio of photoneutron yields for 18 and 22 Mev x-rays was calculated as a function of atomic number. This is plotted as the broken line in Fig. 1. The crosses are the activation ratios which fundamentally determine the curve. The data of Price and Kerst are also plotted in this figure, and the solid curve is the empirical fit to their points. Elements with one or many isotopes are represented, respectively, by solid squares or solid circles. Both types of points fit the empirical curve equally well, indicating that the resonance peak energies for the isotopes in a given element are not appreciably different.

Figure 1 shows that above $Z=30$ there are more neutrons at 22 Mev than can be accounted for from (γ, n) reactions. From threshold considerations these neutrons can only arise from $(\gamma, 2n)$ and (γ, pn) reactions. The ratio of the broken to the solid curve diverges from unity at $Z=30$ and reaches a fairly constant value of 1.22 at $Z=50$. This indicates that the resonance peak energy for $(\gamma, 2n)$ and (γ, pn) reactions falls below 22 Mev at about $Z=40$. Since there are fewer photons at this peak than at the (γ, n) peak, it may be estimated that the sum of the $(\gamma, 2n)$ and (γ, pn) integrated cross sections is of the order of 30 percent of that for (γ, n) reactions (assuming equal contributions from each multiple reaction).

With the above assumptions as to peak shape and energy, the maximum and integrated (γ, n) cross sections were computed directly from the photoneutron yield data. The 22-Mev data were used up to $Z=30$; beyond that, the 18-Mev data were used so as to minimize the contribution from multiple reactions. For the average resonance curve, the integrated cross section (Mev-barns) is related to the peak cross section σ_m (barns) by the expression

$$\int \sigma_{\gamma n}dW=6.05\sigma_m. \tag{3}$$

These quantities are plotted to relative scales in Fig. 2 as a func-

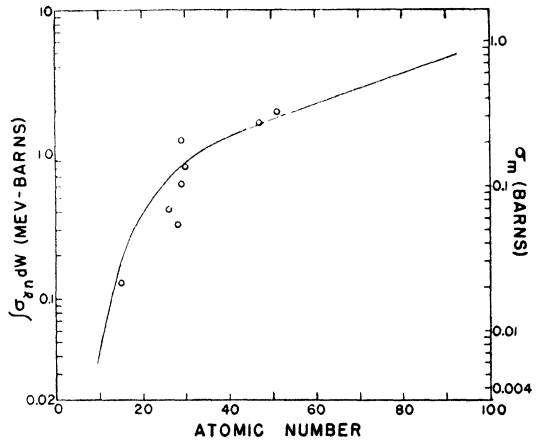

FIG. 2. Maximum and integrated (γ,n) cross sections as a function of atomic number. The curve is derived from photoneutron yields; the points are independent activation measurements of the integrated cross section.

tion of atomic number. Since the absolute cross-section values of Table I were not used in the computation of the average shape, these points and the other values from references 1, 3, and 8 are plotted in Fig. 2 and constitute a satisfactory independent check on the general curve.

Only one (γ, pn) and no $(\gamma, 2n)$ reactions have yet been investigated in detail. The integrated cross section for $S^{32}(\gamma, pn)P^{30}$ is 0.003 Mev-barns,[2] or 2 percent of the integrated (γ, n) cross sections in that region of the periodic table. This may indicate that $(\gamma, 2n)$ reactions are more important than (γ, pn) reactions, or that the extra neutron yields are much less in light elements.

I am indebted to Dr. L. Katz for valuable discussions.

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New Superconducting Borides and Nitrides

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THE pronounced metallic character of many borides, carbides, and nitrides of the transition metals is evident from the fact that the electrical resistivity of these compounds has a positive temperature coefficient in the neighborhood of room temperature and is, in several cases, less than the resistivity of the constituent metal.[1] Meissner[2] found that many of these compounds show superconducting behavior, the carbides of molybdenum and tungsten being of special interest in this respect, since the metals themselves appear to be nonsuperconducting down to very low temperatures (<1°K). A knowledge of the extent to which such apparently nonsuperconducting elements form superconducting compounds is obviously important for a satisfactory theory of superconductivity; but, on reviewing the available data against the general background of the periodic system, one is struck by the large number of interesting compounds which have so far not been tested, little having been done since the pioneer work of Meissner. This situation led us to embark some time ago on an experimental survey of metallic compounds, the object being to throw more light on the chemical and structural conditions governing the occurrence of superconductivity. We have adopted a magnetic detection method, which, as pointed out by Shoenberg,[3] provides a direct measure of the amount of superconducting material present, and avoids the difficulty occurring in electrical resistance measurements that a small quantity of superconducting impurity may shunt the bulk of the specimen, thus producing a large but spurious effect. Although we have so far examined only about 60 semimetallic and intermetallic compounds down to 1.3°K, it seems worthwhile to describe 4 new superconductors which have recently been found in the boride and nitride groups.

TABLE I. Experimental results. Superconducting compounds are shown in boldface type together with their transition temperatures. The numbers in parentheses represent the lowest temperatures of measurement for those compounds which did not become superconducting.

	Nb	Ta	Mo
B	**NbB 6°** Nb_3B_4 (1.27°) NbB_2 (1.27°)	TaB (1.29°) Ta_3B_4 (1.30°) TaB_2 (1.32°)	**MoB 4.4°** Mo_2B_5 (1.32°)
N	**NbN 14.7°**[a] Nb_2N (9.5°)[a]	TaN (1.88°)[a] Ta_2N (9.5°)[a]	**Mo_2N 5°** **MoN 12.0°**

[a] See reference 7.

Superconductivity was observed in the monoborides of *niobium* and *molybdenum*, with the transition temperatures[4] shown in the first row of Table I. X-ray analyses for these compounds and also for other borides which did not become superconducting down to the lowest temperatures of measurement (shown in parentheses in Table I) were in good agreement with the recent structural data of Kiessling,[5] who found NbB orthorhombic and MoB tetragonal. It is interesting to note that the only other previously reported superconducting boride, ZrB, tested by Meissner[2] in electrical resistance measurements, is, according to Kiessling,[5] nonexistent. The latter evidence, coupled with the uncertainty of the resistance method, throws considerable doubt on the superconductivity of ZrB, so that NbB and MoB must be regarded as the only borides at present definitely known to be superconducting.

Superconductivity was also observed in two nitrides of *molybdenum*, with the transition temperatures shown in the lower part of Table I. The x-ray analyses were in these cases in agreement with the results of Hägg,[6] who assigns a face-centered cubic structure (with N/2 missing) to Mo_2N and a hexagonal lattice to MoN. In the preparation of Mo_2N by nitriding molybdenum metal, the formation of some mononitride can hardly be avoided. The magnetization of a mixed specimen of about 85 percent Mo_2N, 10 percent MoN, and 5 percent Mo is plotted against temperature in Fig. 1; and from the relative heights of the two plateau regions we conclude that while Mo_2N becomes normal at about 5°K, MoN remains superconducting up to 12.0°K. In the latter, remarkably high transition temperature, which was studied in detail by surrounding the specimen with solid hydrogen, MoN is second only to NbN,[7] a situation seen to be even more striking

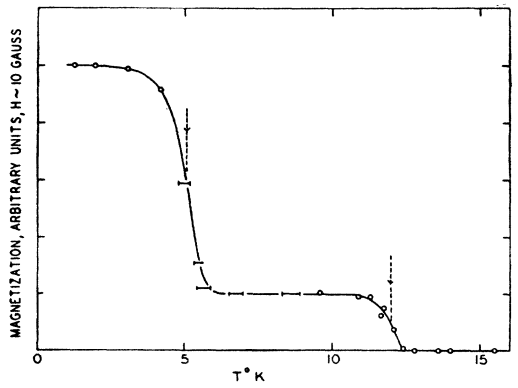

FIG. 1. Temperature variation of low field-strength magnetization of mixed molybdenum nitride specimen.