is $1+\alpha(v/c)\cos\theta$, where

$$\alpha=(\tfrac{1}{3}\sigma^2\pm 1)/(\sigma^2+1). \quad (1)$$

The sign in Eq. (1) is + for V and − for S. From an experimental point of view it is desirable to have a minimum value for σ^2, in order to maximize the difference between α_+ and α_-.

Table I accordingly lists σ^2 for radioactive gases that undergo mirror image β-decays. The values of σ^2(calc) are computed for the configurations listed, and σ^2(obs) are taken from the *ft* values fitted to the empirical[1] constant $1+\sigma^2=5.2\times10^3$ sec/*ft*. For $Ne^{19}-F^{19}$ we adopt the independent suggestions of E. Feenberg and M. Umezawa that the configuration is $(d_{5/2}{}^2d_{5/2})_{1/2}$, which gives the best agreement between σ^2(calc) and σ^2(obs).

TABLE I. Mirror image β-decays.

Gas	Configuration	σ^2(calc)	*ft*.	σ^2(obs)
N^{13}	$p_{1/2}$	0.33	4.7×10^3 sec	0.11
O^{15}	$p_{1/2}{}^{-1}$	0.33	3.8	0.37
F^{17}	$d_{5/2}$	1.4	2.3	1.3
Ne^{19}	$(d_{5/2}{}^2d_{5/2})_{1/2}$	1.6	2.0	1.6
Cl^{33}	$d_{3/2}$	0.60	3.4	0.53
A^{35}	$(d_{3/2}{}^2d_{3/2})_{3/2}$	0.32	3.4	0.53

The average recoil energies of the nuclei, neglecting $\beta-\nu$ correlation, are on the order of 60 ev for N^{13}, 100 ev for O^{15}, F^{17}, Ne^{19}, and 200 ev for Cl^{33}, A^{35}. Simple gaseous molecules containing N, O, or C have exceptionally high binding energies on the order of 10 ev, which might seriously interfere with the recoil ions in at least the case of N^{13}. The situation is much more favorable for Cl^{33}, with a molecular binding energy of order 10^{-2} times the recoil energy. The discrepancy between σ^2(calc) and σ^2(obs) for A^{35} is commensurate with the rather large probable error in the *ft* value. If both chemical binding and the values of σ^2 are considered, the isotopes of Table I are roughly in order of increasing suitability for a $\beta-\nu$ correlation measurement of the Fermi term.

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[1] O. Kofoed-Hansen and A. Winther, Phys. Rev. **86**, 428 (1952); G. L. Trigg, Phys. Rev. **86**, 506 (1952); R. Bouchez and R. Nataf, Compt. rend. **234**, 86 (1952).
[2] M. Fierz, Z. Physik **104**, 553 (1937).
[3] B. M. Rustad and S. L. Ruby, Bull. Am. Phys. Soc. **28**, No. 1, 41 (1953); J. S. Allen and W. K. Jentschke, Bull. Am. Phys. Soc. **27**, No. 5, 17 (1952).

Molybdenum 90

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IN observing the high energy spallation products of niobium,[1] evidence for the existence of a new isotope of molybdenum was obtained. In order to identify this activity, niobium metal foils were bombarded with 55–60-Mev protons in the Harvard 95-inch synchrocyclotron for periods of an hour, and the molybdenum activities were isolated by ether extraction from 6*N* hydrochloric acid. Gross decay curves taken with an end-window Geiger counter on aliquots of such fractions showed a 5.5–6.0-hour and a 14.5–15.0-hour activity; neither half-life corresponds to known molybdenum periods. The decay curve of a sample separated quickly after the end of the bombardment exhibited an additional 15–20-minute activity ascribable to Mo^{91} (15.5 minutes[2]).

Since Nb^{90} is reported to have a half-life of 15 hours,[3,4] it was considered likely that the observed activities were due to a new nucleide, Mo^{90}, decaying with a 5.5–6.0-hour period into the longer lived Nb^{90}. To check this, niobium carrier was added and separated at twelve hour intervals from purified molybdenum fractions and then counted. One such series of separations was done by precipitating the niobium away from the molybdenum with ammonia, and two more series were done by repeated ether extractions of the molybdenum away from the niobium in 6*N* hydrochloric acid. The separated samples were then ignited to the oxide, weighed, and counted. In all three series a plot of the yield of the niobium daughter activity *vs* time showed a slope of 5.7±0.2 hours. One series is shown in Fig. 1. All of the separated samples showed a decay period of 14.7±0.2 hours; some were followed through eight half-lives and showed no sign of turning over.

Comparison of the activity of Mo^{90} and its daughter on an end-window (3.5 mg/cm²) Geiger counter indicated a counting efficiency for the molybdenum activity of 75–80 percent of that of the Nb^{90}. Since the latter is known to have a considerable amount of particulate radiation,[5] then Mo^{90} must also. In fact, aluminum absorption measurements indicate a considerable amount of ~100-kev conversion electrons, some ~240-kev conversion electrons, and either *K* x-rays or positrons of about 1.4-Mev maximum energy, or both, as is most likely the case. Unfortunately, no beryllium absorbers were available to differentiate these last two types of radiation, but positrons must be

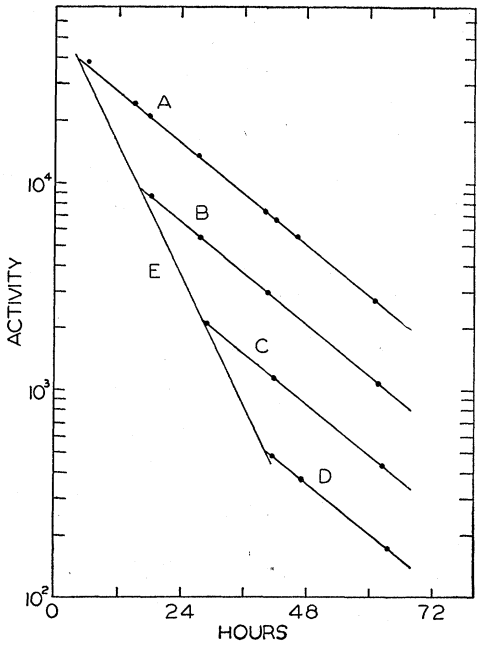

FIG. 1. Yield of Nb^{90} as a function of time of separation from Mo^{90}, curve *E*. Curves *A* to *D* show the decay of the individual Nb^{90} samples.

present to an appreciable extent, as there would be too many *K* x-rays involved for all of the radiation to be electromagnetic.

The value of the positron energy, 1.4 Mev, is an estimate from the extrapolated range in aluminum, and is certainly not a very reliable figure. However, similar aluminum absorption measurements on a sample of Nb^{90} gave a curve with a comparable section due to *K* x-rays and positrons, and the extrapolated range of the positrons corresponds to an energy of 1.2 Mev. This agrees with the value of 1.2 Mev reported by Kundu and Pool,[4] but not so well with the value of ~1.7 Mev given by Boyd.[3]

Lead absorption measurements on a sample of Mo^{90} exhibited a 1.1-Mev gamma-ray, and 240–260 kev and 100–125 kev gamma-rays; aluminum absorption data indicate that both of these last two are partially electron converted, the lower energy ray to the greater extent. Positron annihilation radiation was not resolvable in the lead absorption curve, but a small amount would not show up among the other electromagnetic radiation observed.

In summary, it may be said that from this work Mo^{90} appears to have (1) a half-life of 5.7 ± 0.2 hours; (2) a disintegration scheme involving predominantly three gamma-rays, with energies of approximately 1.1, 0.24–0.26, 0.10–0.13 Mev, of which the second gamma-ray is electron converted to a small extent, and the third to a much larger degree; (3) positrons of roughly 1.4-Mev maximum energy (or of an energy slightly greater than the maximum energy of those from Nb^{90}), and a greater amount of electron capture relative to positron emission than is the case with Nb^{90}.

I wish to state my gratitude to Dr. J. Meadows and Mr. R. Wharton of the Harvard Cyclotron Group for their invaluable help with the bombardments, and to Mr. Rodman Sharp of this laboratory for his assistance with counting.

[1] This preliminary work was performed at the University of California Radiation Laboratory, and the author desires to express his thanks for the guidance and interest of Professor G. T. Seaborg.
[2] R. B. Duffield and J. D. Knight, Phys. Rev. **76**, 573 (1949).
[3] G. E. Boyd, Oak Ridge National Laboratory Report ORNL-229, February, 1949 (unpublished) as reported by Hollander, Perlman, and Seaborg, *Table of Isotopes*, University of California Radiation Laboratory Report UCRL-1928, August, 1952 (unpublished).
[4] D. N. Kundu and M. L. Pool, Phys. Rev. **76**, 183 (1949).
[5] L. Jacobson and R. Overstreet, *Radiochemical Studies: The Fission Products* (McGraw-Hill Book Company, Inc., New York, 1951), Paper No. 91, National Nuclear Energy Series, Plutonium Project Record, Vol. 9, Div. IV.

Systematic Calculations of Gamma-Ray Penetration*

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A NUMBER of methods[1] of varying degrees of rigor have been proposed for finding the intensity and spectrum of Compton-scattered photons arising in the penetration of gamma-rays through a medium. Recently, Spencer and Fano[2] have indicated a seminumerical technique of solving the Boltzmann transport equation for an infinite medium, which is well adapted for use with high speed automatic calculators. In essence the procedure reduces the original transport equation to a set of integral equations for the spatial moments of the gamma-ray flux. These equations now involve only one independent variable, the energy, and are so interlinked that any given number of spatial moments can be found by the numerical integration of a *finite* number of the equations, without any need for analytical approximations. The required flux distribution function can be approximated in various ways from a knowledge of a finite number of its moments, one of the most suitable being an expansion in terms of an appropriate system of polynomials.

Study of the rate of convergence in the polynomial expansion and comparison of the results with experiment[3] indicated that the method could provide answers of adequate accuracy for a wide range of problems of interest.[4] Accordingly, with the support and encouragement of the U. S. Atomic Energy Commission, especially the Oak Ridge National Laboratory, an extensive calculational program has been undertaken to exploit the method, making use of the SEAC, the National Bureau of Standards calculating machine. The materials investigated have covered the complete periodic table, including pure Compton-scattering medium, H_2O, Al, Fe, Sn, W, Pb, and U. For most of these substances calculations have been made for both point isotropic and plane monodirectional sources. In addition, for Pb, Fe, and pure Compton scatterer (which are the most important materials in practice), calculations have been made for infinite plane source geometries in which the photons leave the source with angular distributions corresponding to the Legendre polynomials $P_n(\cos\theta)$, $n=1, 2, 3$.[5] It is hoped that any source angular distribution with symmetry about the normal that does not vary too rapidly can be approximated well enough out of the first four Legendre polynomials. The range of initial energies considered, 0.5 to 10 Mev, was chosen so as to cover the problems of interest in the shielding of reactors. The calculations reported here include the range of penetrations from 1 to 20 mean free paths from the source. For deep penetrations, greater than 15–20 mean free paths, it is not practical to calculate enough terms to obtain adequate convergence.[6]

In the computations it has been assumed that the only scattering process is incoherent Compton scattering of unpolarized gamma-rays. For the energies involved coherent scattering is so nearly forward as to be no collision at all, and it has therefore been omitted from both the total cross section and the scattering kernel. The only other processes considered have been pair production and photoelectric effect, both of which have been treated as completely absorptive. All cross-sectional data were taken from the National Bureau of Standards compilation.[7]

At the present time all machine work has been completed, and final computations are now in progress. Full details of the calculations will be issued later this year.[8] Complete tables of build-up factors and differential spectra will be included in the report, along with examples of angular distributions. These results will not exhaust the calculations which can be made with the raw output from the SEAC. To make these more generally available it is intended to place annotated microfilm copies of the output tapes at each of the U. S. Atomic Energy Commission Depositary Libraries.

We should like to acknowledge the assistance of the Mathematics Division of the National Bureau of Standards, which did the actual coding of the problem and operating of the SEAC, and of the Computing Section of Nuclear Development Associates, which is calculating the finished results from the machine computations.

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[1] See, for example, Hirschfelder, Magee, and Hull, Phys. Rev. **73**, 852 (1948); Bethe, Fano, and Karr, Phys. Rev. **76**, 538 (1949); L. L. Foldy, Phys. Rev. **81**, 395 (1951); G. H. Peebles and M. S. Plesset, Phys. Rev. **81**, 430 (1951).
[2] L. V. Spencer and U. Fano, Phys. Rev. **81**, 464 (1951) and J. Research Natl. Bur. Standards **46**, 446 (1951). Also see L. V. Spencer and Fannie Stinson, Phys. Rev. **85**, 662 (1952).
[3] G. R. White, Phys. Rev. **80**, 154 (1950); E. Hayward, Phys. Rev. **86**, 493 (1952); Elliot, Farrar, Myers, and Ravilious, Phys. Rev. **85**, 1048 (1952).
[4] Examples of the results that can be provided by the moments methods will be found in references 2 and 3.
[5] The P_0 case (plane isotropic) can be determined directly from the point isotropic solution.
[6] Semi-asymptotic techniques have been developed which overlap with the moments method and carry the solution out as far as desired. See L. V. Spencer, Phys. Rev. **88**, 793 (1952).
[7] G. R. White, National Bureau of Standards Report No. 1003, 1952 (unpublished).
[8] U. S. Atomic Energy Commission Report, NYO-3075 (to be published).

Heavy Isotopes of Magnesium and Silicon

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IN bombardments of chlorine (as sodium chloride) with 340-Mev protons from the Berkeley 184-inch cyclotron, a magnesium chemical fraction contained a 21-hour activity of high radiochemical purity. The radiations present were beta-particles of about 0.4 Mev and of about 3 Mev, in addition to gamma-rays of less than 100 kev and of about 1.7 Mev. The hard radiations were shown by chemical separation to be due to a 2.3-minute Al^{28} daughter, so that the 21-hour activity must be Mg^{28}.

A silicon fraction was removed from the same target and was found to contain the 160-minute Si^{31} in high abundance. If another activity attributable to the unknown isotope Si^{32} were formed in yield comparable to that of Si^{31}, its half-life would have to be either equal to or less than that of Si^{31}, or greater than several hundred years.

The study of the radiations of Mg^{28} and the search for a silicon isotope attributable to Si^{32} are being continued, and the results will be reported at a later date.