DEPENDENCE OF THE YIELD OF THE (α ,n) REACTION
ON ALPHA PARTICLE ENERGY

E. M. Tsenter and A. B. Silin

Translated by K. W. Foster

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Neutron yields resulting from (α ,n) reactions have a practical interest, particularly for many radiation monitoring problems.¹⁻⁴ Data for yields for the (α ,n) reaction of different elements are necessary for solution of some problems in geochemistry and geophysics.⁶⁻¹⁰

Reference 11 contains the empirical formula

$$n = 0.152 E^{3.56} \quad (1)$$

for the dependence of the neutron yield from beryllium on alpha particle energy. Formula (1) was developed from three values of alpha particle energy:

$$E_{\alpha} = 5.14 \text{ MeV (Pu}^{239}\text{)},$$

$$E_{\alpha} = 5.48 \text{ MeV (Am}^{241}\text{)}, \text{ and}$$

$$E_{\alpha} = 6.11 \text{ MeV (Cm}^{242}\text{)}.$$

Analogous empirical formulas of the type

$$Q = k E^n \quad (2)$$

are given for a number of substances in references 12 and 13. For determination of k and n, authors of these works utilized values of Q that they measured with sources of polonium-210 ($E_{\alpha} = 5.3 \text{ MeV}$), radium C' ($E_{\alpha} = 7.68 \text{ MeV}$), and radon + radium A + radium C' ($E_{\alpha} = 5.5, 6.0, \text{ and } 7.68 \text{ MeV}$, respectively).

It is not possible to utilize these formulas with energies above the cited limits without special verification. Verification is also necessary to confirm that the indicated formulas correspond to curves with monotonically increasing first derivatives of energy. In general, such monotonicities are not necessary in the

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case of resonance peaks in the curve of neutron dependence of reaction cross section on the alpha particle energy.

For beryllium, boron, carbon, magnesium and oxygen there exist in the literature curves for the cross section of the reaction (α, n) for energies up to 5.3 MeV.^{14, 15} With these cross sections it is possible to calculate the dependence of the neutron yield on the alpha particle energy. Data necessary for calculation of loss of alpha particle energy per unit track length were the result of the conversion of energy loss in air¹⁶ according to well-known values of relative stopping power, and which we considered to be constant in the energy intervals under consideration.

For oxygen-18 the dependence $\sigma(E)$ is presented in references 14 and 15. Taking into account (α, n) reactions on oxygen composed principally of oxygen-18, it is possible to compare the results of such calculation (See Figure 1a, Curve 1) with experimental data produced by a natural mixture of oxygen isotopes.¹⁷⁻¹⁹ Calculation of the value 4.5 neutrons per 10^8 alpha particles, with an energy of 5.3 MeV (converted to a natural mixture of oxygen isotopes) disagrees with the experimental value for this point, i.e., 7 neutrons per 10^8 alpha particles,^{18, 19} by $\approx 35\%$. The latest value derived by the other authors as a result of direct experiments appears to be more reliable than what was calculated by us with cross sections from reference 15, the precision of which is no better than 25%. Obviously Curve 1 (Figure 1a) accurately reflects the character of the dependence of neutron yield on the alpha-particle energy, so we derived the curve more closely to the true curve by normalizing Curve 1 to experimental values at 5.3 MeV (see Curve 3, Figure 1a). Also presented in Figure 1a is Curve 2, derived from formula (2).

Calculations were likewise performed for beryllium, boron, carbon, and magnesium, using cross sections given in references 14 and 15; analogous graphs were plotted (see Figures 1b, 1c, 1d, and 1e). The numbers 1, 2 and 3, respectively, are designated as in Figure 1a. Moreover, in Figure 1b is presented Curve 4, which corresponds to formula (1).

It should be possible to compare formula (2) for oxygen with data given in reference 20. The author reports two new neutron sources developed by S. Amiel and A. Nier. One of these sources is polonium-210/oxygen-18 (The neutron yield is 30 neutrons per 10^6 alpha particles, and the average neutron energy is approximately 2.4 MeV).

Figure 1

In reference 17 the neutron yield for the polonium-210/oxygen-18 source is given as 31 neutrons per 10^6 alpha particles. In 1959 data were published on the gamma radiation²¹ and neutron spectrum²² of the neutron source polonium-210/oxygen-18. The maximum of the energy curve was at 2.4 MeV. In reference 20 the data of the neutron yield from the source thorium-228/oxygen-18 are questionable (1500 neutrons per 10^6 alpha particles). Energies of alpha particles from thorium-228 and its decay products are equal to 5.4, 5.7, 6.3, 6.8, 6.08, and 8.8 MeV;²³ the last group occurs in a portion of approximately 13%. For alpha particles of radium C ($E_\alpha = 7.68$ MeV) the yield from (α, n) conversion on oxygen-18 is 280 neutrons per 10^6 alpha particles.¹² Judging from the spectrum of alpha particles, the neutron yield from the source thorium-228/oxygen-18 must be smaller than the neutron yield from the source radium C'/oxygen-18. Thus, the value of 1500 neutrons per 10^6 alpha particles reported in reference 20 is overestimated by approximately one order of magnitude.

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