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NEUTRON EMISSION BY POLONIUM OXIDE LAYERS

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ABSTRACT

In the following it is calculated how many neutrons are produced by the $O^{16}(\alpha, n)$ reaction in a thin and uniform polonium oxide layer. Factors due to oblique transmission and "effective" α -particle range have been taken into account. Calculations for layer thicknesses between one hundredth curie per square centimeter and one curie per square centimeter indicate the number of neutrons emitted per curie of polonium alpha particles is approximately given by $140 \times C^{0.8}$ where C is the number of curies per square centimeter.

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NEUTRON EMISSION BY POLONIUM OXIDE LAYERS

In the following it is calculated how many neutrons are produced by the $O^{16}(\alpha, n)$ reaction in a thin and uniform polonium oxide layer. We find the result that for layer thicknesses between one-hundredth of a curie and one curie per cm^2 that the number of neutrons emitted per curie of polonium alpha particles is approximately given by $11.9 \times C^{0.8}$ where C is the number of curies per square centimeter.

If there is one curie per cm^2 present the number of polonium atoms present per cm^2 can be found by:

$$\frac{1}{4540} \times \frac{6.02 \times 10^{23}}{226} = 5.86 \times 10^{17}$$

Here the ratio of the half life of radium to the half life of polonium is 4540 and the atomic weight of radium is 226. The number of oxygen atoms present per curie of PoO_2 is therefore $11.72 \times 10^{17}/cm^2$. Because of oblique transmission through the PoO_2 layer the neutron production will be the same as though the layer were crossed perpendicularly by the alphas but as though the O-atoms were more numerous. The factor by which the number of O-atoms must be multiplied is:

$$\int_0^{\pi/2} \frac{\sin \theta d\theta}{\Lambda}$$

where $\Lambda = \cos \theta$ except in the region where the path becomes so oblique that the effective range of the alpha particle is shorter than the line to the surface of the PoO_2 layer. Since the effective range (over which the alpha energy is effectively great enough to cause the reaction) is about 0.23 times the total alpha range, as will be shown later, and since on the average an alpha must cross only half of the PoO_2 layer, the limiting value of θ , where we can still

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put $A = \cos \theta$, is given by:

$$\cos \theta = \frac{\text{average thickness of } \text{FeO}_2}{\text{effective alpha range}} = \frac{(1/2) \times \text{thickness of } \text{FeO}_2}{.23 \times \text{alpha range}}$$

This is an exact value for the alphas starting from the middle layer, and we shall use it as a rough average value for all the alphas.

The stopping power of FeO_2 is arrived at by considering the Fe atom to be 3.62 times more effective in stopping power than an oxygen atom. Therefore the Fe atom may be replaced by 1.81 additional O-atoms per original O-atom in the layer, giving a total stopping power 2.81 times that which is due to the original oxygen atoms present. If $\cos \theta$ is smaller than the limiting value given above, then the full effective alpha range is expended in the FeO_2 layer and A must be set equal to the limiting value, $\cos \theta$.

A sample calculation for a one curie per cm^2 layer:

$$\int_0^{\pi/2} \frac{\sin \theta \, d\theta}{A} \int_0^e \frac{dx}{x} + \int_e^1 \frac{dx}{x} = 1 + \ln (1/e)$$

$$\text{where: } e = \cos \theta \text{ (limiting value)} = \frac{(1/2) \times \text{thickness of } \text{FeO}_2 \text{ (in atoms)}}{.23 \times \text{alpha range (in atoms)}}$$

$$= \frac{(1/2) \times 11.72 \times 10^{17} \times 2.81}{.23 \times 1.93 \times 10^{20}} = 3.709 \times 10^{-2}$$

Therefore the obliquity factor equals $1 + 3.29 = 4.29$. For a one-tenth curie per cm^2 layer the number of FeO_2 atoms is one-tenth the number for one curie per cm^2 and the obliquity factor is 6.60; for a one-hundredth curie per cm^2 layer, 8.90.

Since the alpha particles originate on the average at the middle of the layer they have to cross half the complete layer times the obliquity factor.

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For a one-curie-per-cm² layer the effective number of oxygen atoms in the layer is therefore,

$$11.72 \times 10^{17} \times \frac{4.44}{1} = 52.14 \times 10^{17}$$

To stop the alpha particles of 5.3 Mev requires 3.62 cm of air or 1.93×10^{20} atoms. To allow the alphas to below their effective range requires .25 times as many O-atoms; i.e., 4.84×10^{19} O-atoms. The atoms present in the layer are not sufficient by a factor $\frac{4.44 \times 10^{19}}{52.14 \times 10^{17}} = 17.7$.

The number of neutrons per second and per curie will therefore be (the number of particles per curie) $\times$ (no. of neutrons per 10^6 alphas) $\times 1/17.7 = 5.7 \times 10^{10} \times .075/17.7 = 182.6$. The number of neutrons per 10^6 alphas was taken from report GF-664. Corresponding calculations for a layer of one-tenth curie per cm² of FeO₂ indicate the number of neutrons will be 23.5; for a one-hundredth curie per cm² layer, 3.2 neutrons. Because of the crude way in which obliquity corrections were made these figures may have a maximum error of ± 20 percent. Within this error one may represent the number of neutrons emitted per second and per curie by the approximation formula: $140 \times C^{0.8}$ where C is the number of curies per cm².

In the above calculations the range has been replaced by a shorter effective range because only at the beginning of the range has the alpha particle the energy to be effective in penetrating the oxygen barrier, and hence the probability of neutron production is approximately e^{-Q} , where $Q = (4 e^2 Z^2 / h^2 v) (2u - \sin 2u)$ and u is given by $\cos^2 u = (R/2Ze^2)E$ (R is the sum of the radii of the two colliding particles $\sim 4.1 \times 10^{-13}$ cm²). In the accompanying figure e^{-Q} is plotted as a function of the range (and therefore energy). The

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abscissa value $X(E_0)$ is the range for an alpha particle of E_0 relative energy.

The area under the curve

$$\int_0^{E_0} e^{-E} \frac{dX(E)}{dE} dE,$$

may be considered proportional to the neutron production for the entire range.

The curve is approximated by a rectangle of area $[X(E_0) - X(e)] e^{-E_0}$, where e^{-E_0} is the penetration for the relative energy E_0 . The area of the rectangle is the same as the area under the original curve. The distance on the abscissa axis $X(E_0) - X(e)$ will then represent the effective part of the range. The solution of $X(e) = X(E_0) - \int_0^{E_0} e^{-E} [dX(E)/dE] dE$ yields $X(e) = 2.13$ cm. Since the total range is 2.78 cm, the effective portion is .646 cm or .23 of the total range.

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$x(t)$ in cms.

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