barrier are roughly equal, and calculated the neutron widths from

$$\Gamma_n/E^{\frac{1}{2}} \sim 4\times 10^{-4}(\text{ev})^{\frac{1}{2}}. \tag{5}$$

Which was empirically determined from the available data on neutron capture cross sections. Relation (5) is furthermore in agreement with the expected relation that, all other things being equal,

$$\Gamma \propto E^{\frac{1}{2}} \tag{6}$$

which can be derived from considerations of the momentum space degeneracy of the outgoing particles.

In line with the suggestions of Weisskopf, Feshbach, and Peaslee,[7] Wigner[8] has shown that widths are also proportional to level spacing, D, whence (6) becomes

$$\Gamma \propto E^{\frac{1}{2}}D. \tag{7}$$

Relation (5) must then be considered valid only in cases of neutron capture. Since level spacings in neutron capture are about 10 ev, in general, (5) must be replaced by

$$\Gamma/E^{\frac{1}{2}}D \sim 4\times 10^{-5}(\text{ev})^{-\frac{1}{2}}. \tag{8}$$

Applying (8) to the case of alpha-decay,

$$E^{\frac{1}{2}} \sim 2.5\times 10^{3}(\text{ev})^{\frac{1}{2}}, \quad D\sim 10^{5}\text{ ev}$$

whence

$$\Gamma \sim 10^{4}\text{ ev}. \tag{9}$$

The value of D was obtained from the measured energy differences between various energy groups in natural alpha-decay.[9] Comparison of (9) with (3) indicates that the ratio of neutron width to alpha-width without barrier is about 0.1; and comparison of (3) with the width from the one-body theory (0.8 Mev) indicates that the "probability of formation of an alpha-particle" in a nucleus (i.e., the correction for the many-body theory over the one-body theory) is about one-eighth. Either of these last two values may be in error by a factor of 10 or more.

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Ionization by Recoil Particles from Alpha-Decay

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SINCE the energy loss of a slow heavy particle is predominantly to recoiling gas atoms, ionization by secondary heavy particles contributes a large fraction of the total ionization resulting from a slow heavy particle that is stopped in a gas.

Let η be the ionization efficiency $\omega^e I/E$ of a primary particle of energy E which gives rise to the number of ion pairs I, where ω^e is the energy loss per ion pair of a particle the energy of which is very high. The ionization efficiency satisfies an equation of the form

$$\frac{d}{dE}(E\eta)=\mu+\lambda\int_0^{E_m'} dE'k(E,E')\eta'(E'), \quad \eta(0)=0, \tag{1}$$

in which $\eta'=\omega^e I'/E'$ is the ionization efficiency of a gas atom of energy E' in its own gas. The functions μ and λ are given by

$$\mu=\omega^e\sigma^e/(b^e+b^\nu), \quad \lambda=b^\nu/(b^e+b^\nu),$$

where σ^e is the cross section for the production of an ion pair in a collision between the primary particle and an atom of the gas including ionization by ejected electrons, and b^e and b^ν are the stopping cross sections per atom for the loss of energy by the primary particle to excitation and ionization and to atomic recoil, respectively. The kernel $k(E, E')$ is

$$\sigma(E,E')E'\Big/\int_0^{E_m'} dE'\sigma(E,E')E',$$

where $\sigma(E, E')$ is the cross section per unit energy range for the production of a recoil atom of energy E'; the maximum energy transferred to an atom is $E_m'=4MM'E/(M+M')^2$. The ionization efficiency η' of a gas atom satisfies the differential-integral equation obtained from (1) by regarding the initial particle as identical in nature with the recoil atom; the corresponding functions are designated μ', λ', etc.

We consider a heavy particle ($Z=82$, $M=208$ proton masses) in argon. For velocities less than about $0.4v_0$, where $v_0=e^2/\hbar$, the primary scattering is very nearly spherically symmetrical in the center of gravity system and therefore $k(E,E')\approx 2E'/E_m'^2$. Deviations from spherically symmetrical secondary scattering are unimportant until velocities of the primary particle considerably greater than $0.12v_0$ are attained ($E\gg 78$ kev). Up to these velocities b^ν and $b^{\nu\prime}$ are practically constant,[1] except for negligible linear decrease at very small velocities.

There is evidence[2] to indicate that $\sigma^{e\prime}$ increases very roughly as the square root of the energy in the kev range. Assuming $\mu'\approx a'v'$ and $\lambda'\approx 1$, we obtain $\eta'\approx 10a'v'/7$. Since primary ionization alone gives $(2/3)a'v'$, it is seen that on this basis 53 percent of the ionization due to a gas atom in its own gas is secondary heavy particle ionization.

Assuming, likewise, $\mu\approx av$ and $\lambda\approx 1$, (1) gives

$$\eta\approx[\tfrac{2}{3}a+(16a'\gamma/21)]v, \quad v/v_0\ll 1, \tag{2}$$

where $\gamma=2M/(M+M')=1.68$.

The ionization in argon by single recoil particles from Po, ThC, and ThC′ has been measured by Madsen.[3] His data are well represented by (2) with the proportionality factor

$$\tfrac{2}{3}a+16a'\gamma/21=\omega^e/(15.4\text{ ev})v_0.$$

In order to estimate $\sigma^{e\prime}$, we put a equal to a' and obtain $a'\approx\omega^e/(30\text{ev})v_0$. With[1] $b^{\nu\prime}\approx 30\pi a_0^2\epsilon_0$, this gives $\sigma^{e\prime}\approx 30\pi a_0^2(v/v_0)$ which at 1 kev is about 10^{-16} cm^2, in satisfactory agreement with the measurements of Berry,[2] who found $0.7\cdot 10^{-16}$ cm^2 at 1 kev, and of Rostagni,[4] who found $0.8\cdot 10^{-16}$ cm^2 at 600 ev. It is found from (2) that about 66 percent of the ionization by a recoil particle from natural alpha-decay is heavy-particle secondary ionization.

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The Meson Spectrum and Meteorological Variations in Cosmic-Ray Intensity

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THE production spectrum of mesons has been derived by Sands[1] from calculations based on the sea-level spectrum and the known behavior of mesons produced in the atmosphere. His results indicate approximately an inverse power law spectrum of the form $dE/E^{2.5}$ over a wide range of energies. Calculations of a similar nature have been made in Ottawa in an attempt to present a physical picture of the meteorological variations in cosmic-ray intensity at sea level. These calculations when compared with measured values of the "barometer effect" give a surprising amount of information about the meson spectrum in the higher momentum range (above about 1.8 Bev/c).