

out transverse relaxation. This decrease was calculated²⁰, and the measured values were corrected.

All measurements were performed at a temperature of the sample of 30 °C; the results are given in column 4 of Table 2; the errors are the maximum errors.

Comparing the T_2 values attained by the spin-echo technique of Carr and Purcell with those calculated from the line widths, there is agreement within the limits of error with GeCl_4 , GeBr_4 , and GeMe_4 . The

relaxation time T_2 of $\text{Ge}(\text{OCH}_3)_4$, measured by the Carr-Purcell technique, corresponds to that calculated for a single line by the least square fitting routine. The relaxation times of the other germanium alkyls do not correspond with the widths of the NMR-lines, as these lines consist in an unresolved spectrum of many single NMR-lines.

We like to thank Prof. Dr. H. KRÜGER for his support of this work, Dr. O. LUTZ for many helpful discussions, and the Deutsche Forschungsgemeinschaft for financial support.

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Estimating the Alpha-Particles Transmission through a Barrier

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Among the numerous doubts associated with the estimation of the alpha-decay penetrabilities, two queries have been selected in order to investigate their justification: is the ambiguous determination of α -nucleus potential a real obstacle and is the JWKB an inadequate approximation?

In the study of alpha decay, theoretical successes have been invariably achieved only in reproducing the general features of experimental data, i. e. in explaining behaviours but not absolute values. Thus the first great accomplishment was the explanation of the marked dependence of the halflife upon the energy of the emitted α -particle as due to the energy dependence of the penetrability factor^{1, 2} and the second was the explanation of the reduced widths varying with the mass number as due to the variation of the α -particle formation probability with the level assignments of the most loosely bound four nucleons³.

As for absolute values, no approach has given a satisfactory explanation, and every time the authors, in their conclusions, nurtured the hope that the discrepancy recorded was largely due to some insufficiencies in the determination of the penetrabilities. The impossibility of unequivocal determination of the α -nucleus potential, the inaccuracy of the first-

order JWKB approximation, the nonlocality of the potential barrier, the uncertainties in assessing the decay energies, the neglect or approximate consideration of the coupling between different possible channels, are only some of the numerous insufficiencies invoked⁴⁻⁸.

The first two have been taken up in this letter in order to establish if these can really be held responsible for the said discrepancy, of some orders of magnitude, existing between the theoretical and the experimental absolute values of the decay constant. For this purpose we have applied the theoretical considerations briefly reviewed below to the ground-ground state transitions in even-even polonium isotopes.

Alpha-decay constant has long been considered⁹ to be a product of the probability of α -particle formation inside the nucleus and the probability of where R_{in} and R_{out} are the internal and outer turning points given by $Q(r) = 0$.

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this particle penetrating the nuclear and coulombic barrier, expressed in the form

$$\lambda = \frac{1}{\hbar} \delta^2(r_c) P(r_c) \quad (1)$$

where r_c is the channel radius.

In agreement with most previous works we will use the following definition for the penetrability factor $P(r_c)$

$$P(r_c) = 2 \pi r_c \cdot |\psi(\infty)|^2 / |\psi(r_c)|^2 \quad (2)$$

where $\psi(r)$ is the radial outgoing wave of the Schrödinger equation

$$\frac{d^2\psi}{dr^2} + Q^2(r) \psi = 0,$$

$$Q^2(r) = \frac{2m}{\hbar^2} \left[E - \frac{2(z-2)e^2}{r} - U(r) \right]. \quad (3)$$

Here E is the alpha decay energy, i. e. the experimental α -particle energy corrected by recoil and electron screening¹⁰, z the charge of the initial nucleus and $U(r)$ the alpha-nucleus potential assumed to be of Woods-Saxon form

$$U(r) = -V_0 \left[1 + \exp \left(\frac{r-R_0}{a} \right) \right]^{-1}; \quad (4)$$

V_0 being the depth, $R_0 = r_0 A^{1/3}$ the radius and a the diffusivity of the potential.

If the first order JWKB approximation is used the penetrability factor (2) becomes

$$P(r_c) \cong 2 |Q(r_c)| r_c \cdot \exp \left[-2 \int_{r_c}^{R_{out}} Q(\xi) d\xi \right] \quad \text{for } R_{in} < r_c < R_{out},$$

$$P(r_c) \cong \frac{r_c Q(r_c) \exp \left[-2 \int_{R_{in}}^{R_{out}} Q(\xi) d\xi \right]}{2 \cos^2 \left[\int_{r_c}^{R_{in}} Q(\xi) d\xi - \frac{1}{4} \pi \right]} \quad \text{for } r_c < R_{in}. \quad (5)$$

In order to visualize the effects of the well known ambiguities of the optical model analysis of α -particle elastic scattering on alpha penetrabilities we have plotted in Fig. 1 the reduced widths $\delta^2(8.6 \text{ fm})$ derived from Eq. (1) as function of mass number. We have used the existing experimental data (see Table 1) and the three sets of Woods-Saxon parameters, which yield minimum χ^2 -values for the angular distribution of α elastic scattering on Bi target, obtained in Ref. ¹¹.

From this figure we see that only the shallow potential (curve a) can be distinguished from the other two deep potentials (curves b and c). This characteristic remains the same even if we compute the penetrabilities for every isotope in its turning point.

Based on the coupled channels analysis combined with cluster information about the bound states¹² or on the calculation of composite-particle potentials from the known nucleon potentials^{5,13} we can exclude the shallow potential (curve a).

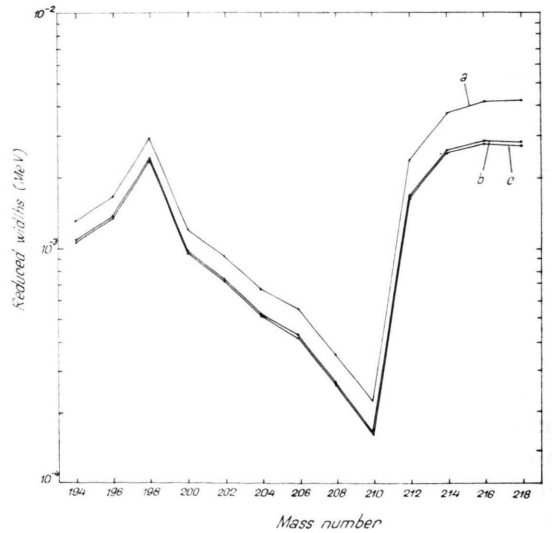


Fig. 1. The experimental reduced widths $\delta^2(r_c=8.6 \text{ fm})$ for Polonium isotopes for the following three sets of Woods-Saxon parameters¹¹:

- Set a: $V_0 = 58.8 \text{ MeV}$, $r_0 = 1.454 \text{ fm}$, $a = 0.560 \text{ fm}$.
 Set b: $V_0 = 124.7 \text{ MeV}$, $r_0 = 1.380 \text{ fm}$, $a = 0.566 \text{ fm}$.
 Set c: $V_0 = 177.3 \text{ MeV}$, $r_0 = 1.342 \text{ fm}$, $a = 0.569 \text{ fm}$.

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Table 1. Experimental data for alpha-decay ground state transition of even-even polonium isotopes.

Mass number	Experimental energies [MeV]	Corrected energies [MeV]	Branching ratios [%]	Total half-life [second]
194	6.850	7.026	100 ^a	0.5
196	6.530	6.698	100 ^a	5.9
198	6.160	6.319	100 ^a	1.02×10^2
200	5.850	6.001	12.2	6.84×10^2
202	5.581	5.726	2	2.7×10^3
204	5.376	5.515	0.645	1.296×10^4
206	5.224	5.359	5	7.6×10^1
208	5.114	5.246	100	9.24×10^7
210	4.305	5.440	100	1.196×10^7
212	8.785	8.986	100	3.05×10^{-7}
214	7.687	7.865	100	1.643×10^{-4}
216	6.777	6.937	100	1.45×10^{-4}
218	6.002	6.146	99	1.83×10^2

^a Assumed value in the absence of experimental data.

As the two remaining possibilities (curves b and c) are superposed we conclude that the determination of Woods-Saxon parameters from the fit of alpha decay data is not possible, since such a procedure leads to the same ambiguities as the optical model analysis of elastic scattering data.

As regarding the exact and JWKB values of the penetrability factor, rather different conclusions have been already reported^{5, 14, 15}.

The validity of the approximate formulas (5) have been tested by comparing their r_c dependence with that of the exact formula (2). The results for three Polonium isotopes are represented in Figure 2. Despite the similitude between JWKB and exact curves we consider the JWKB approximation as a somewhat inadequate method owing to its inapplicability round the internal turning point R_{in} . This area of 0.3 fm to the left and 0.4 f to the right is the only physical region where the origin of the α -particle may be located¹⁶. Even without taking into account physical reasons the phase-integral method can not be applied far inside the barrier where

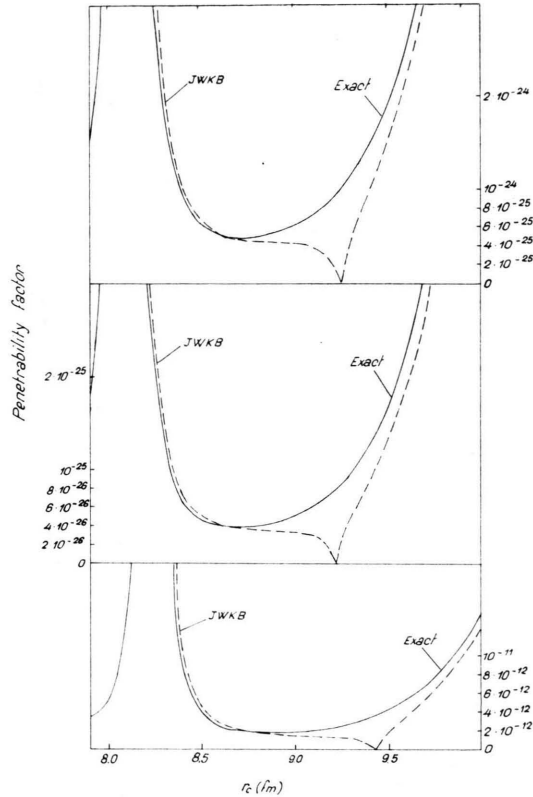


Fig. 2. Comparison of exact and JWKB penetrabilities for 212, 208 and 210 polonium isotopes (from down upward). $V_0=198$ MeV, $r_0=1.35$ fm, $a=0.59$ fm stand for the used set of parameters¹⁸.

a restriction of its valability occurs and where higher approximation must be used¹⁷. On the other hand the region inside the nucleus can be employed only up to the proximity of the first zero of $\psi(r)$, i. e. at most one fermi from the internal turning point.

Finally, we can conclude that neither the JWKB method nor the ambiguous shape of alpha-nucleus potential can explain the discrepancy in the absolute values of alpha decay constant.

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