HW: Compute the half-life of:

- $^{141}$Ho proton emitter ($\Gamma = 2 \cdot 10^{-20}$ MeV)
- 3$^-$ state in $^{10}$Be at $E = 10.16$ MeV ($\Gamma = 296$ keV)
- First 2$^+$ state in $^6$He at $E = 1.797$ MeV ($\Gamma = 113$ keV)
- Hoyle state in $^{12}$C at $E = 7.654$ MeV ($\Gamma = 8.5$ eV)
- $^8$Be ground state ($\Gamma = 5.57$ eV)
- Baryon N(1440)1/2$^+$ ($\Gamma = 350$ MeV)

Discuss the result.

$$T_{1/2} = \ln 2 \frac{\hbar}{\Gamma}, \quad \hbar = 6.58 \cdot 10^{-22} \text{ MeV} \cdot \text{sec}$$
Alpha decay
Alpha Decay

Chart of Nuclides

Click on a nucleus for information

| Color code | Half-life | Decay Mode | Q_{\beta}^- | Q_{EC} | Q_{\beta}^+ | S_n | S_p | Q_{\alpha} | S_{2n} | S_{2p} | Q_{2\beta}^- | Q_{2EC} | Q_{ECP} |
|------------|----------|-------------|-------------|--------|-------------|-----|-----|------------|--------|--------|-------------|--------|--------|
| Q_{\beta^-} | BE/A     | (BE-LDM Fit)/A | E_{1st \ ex. \ st.} | E_{2+} | E_{3-} | E_{4+} | E_{4+}/E_{2+} | \beta_2 | B(E2)_{42}/B(E2)_{20} | \sigma(n,\gamma) | \sigma(n,F) | 235U FY | 239Pu FY |

Z, number of protons

N, number of neutrons

Search options:
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2
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Uncertainty:
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Screen Size:
Narrow
Wide

Evidence:
Stable
EC+\beta+
\beta^{-}
\alpha
P
N
SF
Unknown

Tooltips:
On
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Alpha Decay

Energy relations

\[ S_\alpha(A,Z) = -Q_\alpha(A,Z) = B(A,Z) - B(A-4,Z-2) - 28.3 \text{MeV} \]

\[ Q_\alpha = T_\alpha + T_d = T_\alpha \left( \frac{M_D + M_\alpha}{M_D} \right) \approx T_\alpha \left( \frac{A}{A-4} \right) \]

recoil term effect

experimental binding energy of $^4\text{He}$

+electron screening
+bremsstrahlung

http://www.nndc.bnl.gov/chart/reColor.jsp?newColor=qa
At $t=0$, alpha particle is localized inside the nucleus. It can be represented by a wave packet. At large times, the wave function is an outgoing wave.
Two potential approach to tunneling
(decay width and shift of an isolated quasistationary state)
Phys. Rev. A 38, 1747 (1988); Phys. Rev. A69, 042705 (2004)

Fermi’s golden rule!

\[ V(r) = U(r) + W(r) \]

open \ closed \ scattering

\[ \tilde{W} = W + V_0 \]
Alpha particle cannot escape (classically)

Potential energy of alpha particle

Alpha particle cannot enter (classically)

Kinetic energy of alpha particle

Wave function of alpha particle
\[ P = \frac{\left| \chi_{III} \right|^2}{\left| \chi_I \right|^2} \propto \exp \left[ -2 \int_{r_1}^{r_2} k(r) \, dr \right] \quad T \propto \frac{1}{P} \]

In the case of the Coulomb barrier, the above integral can be evaluated exactly.

\[ \log T = a + \frac{b}{\sqrt{Q_\alpha}} \]

Geiger-Nuttall law of alpha decay 1911

XC: For the Coulomb barrier above, derive the Geiger-Nuttall law. Assume that the energy of an alpha particle is \( E = Q_\alpha \), and that the outer turning point is much greater than the potential radius.
The greatest challenge was thus to understand how the particle could leave the mother nucleus without any external agent disturbing it. The first successful theoretical explanation was given by Gamow [9] and independently by Condon and Gurney [10], who explained the penetration (tunneling) through the Coulomb barrier by a process that depends on the magnitude of the electric charge of the alpha particle. The cross-section for the barrier penetration increases with the charge of the alpha particle, so the probability of alpha decay increases with the charge of the incident alpha particle. This means that the alpha particles of a given nucleus with a small charge have to overcome a smaller energy barrier, and thus have a smaller probability to decay than the alpha particles of a nucleus with a larger charge.

The Geiger-Nuttall (GN) law relates the partial decay partial half-life $T_{1/2}^{\text{GN}}$ to the total energy of the decay $Q$ and the charge of the alpha particle $Z$ as given by,

$$T_{1/2}^{\text{GN}} = \frac{A}{B} \frac{Z^2}{Q} \alpha_1$$

This expression is supported by several phenomenological approaches, in which the GN law have a deep physical meaning and is generally valid. Recently the amount of experimental data within a factor 2 of the GN law has a deep physical meaning and is considered to be generally valid. The GN law is still fulfilled, reproducing most experimental data within a factor 2.

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Fine structure in alpha decay

$^{238}\text{Pu}$

One still has to consider:
- alpha-particle formation
- angular momentum of alpha particle (centrifugal barrier effect)
FIG. 1. (Color online) Decay properties of $^{294}_{117}$ (a) and $^{293}_{117}$ [(b) and (c)] and their decay products observed at 48 Ca energies of 244, 256, and 260 MeV, respectively. The upper rows for each chain show strip number (str) and time and date of registration (on the left side) as well as ER (in red) energies and positions from the top (t) and bottom (b) of the strip (on the right side). Subsequent rows provide $\alpha$-particle (in yellow) and SF fragment (in green) energies, time intervals between events and their positions. Energies of summed signals are given in parentheses. Events marked with a shadow were registered during the beam-off periods. The $\alpha$-particle energy errors are shown by smaller italic numbers. Time intervals for events following a “missing $\alpha$” were measured from previous registered events and shown in italic. The calculated number of random sequences is given at the bottom of each chain [9].

Fig. 1(a)). The summary $\alpha$-particle energy spectra of the isotopes observed in the decay chains originating from $^{294}_{117}$ and decay-time distributions on a logarithmic scale for the same isotopes are given in Fig 3. As noted in [1, 3], in the three new decay chains we observed longer lifetimes for $^{290}_{115}$ and $^{282}_{Rg}$ compared with the values detected in the first experiment [2, 3]. All other decay properties of all nuclei in the new decay chains are in good agreement with data measured in the first experiment [2, 3] and point to the same activities arising from $^{294}_{117}$ detected in the two experiments using the $^{249}_{Bk}$ target.

Experimental values of the cross section for the production of the isotopes of element 117 measured in the $^{249}_{Bk} + ^{48}_{Ca}$ reaction at five excitation energies of the compound nucleus, $^{297}_{117}$, are given in Fig. 4. As mentioned in [1], the cross sections for the $3n$ and $4n$ evaporation channels at $0^{+}$ are given in Fig. 4.
close half-lives that were observed for even-even neighboring isotopes by about 1–3 orders of magnitude. The SF half-lives for even-even stabilization effect and, therefore, a decrease of half-lives of odd-even isotopes. The SF half-life which similar value for these odd-even and even-odd isotopes. The SF half-life of Hs is even lower than those for the neighboring isotopes, similarly to Ca reactions, which allows one to assume lower SF half-lives for nuclei with Z = 111, 113, etc. But the Q values for Db isotopes are larger than those for the neighboring Rg, 21, 23, etc. However, in this approach, which similar results in overestimated values for Mt was not included in this figure because the energy measured by the focal-plane detector is far from 274, 277, 278, respectively. Bearing in mind that SF decays cannot be excluded.

The SF half-life of Hs [9.7 ± 0.3 MeV, respectively] is evidently larger than that for Rg, 9.28 MeV, while EC/α decays cannot be excluded.

Thus, occurrence of SF in Hs together with partial or presumable assignments remains at a=+ and ¬,

FIG. 7. (Color online) Half-lives vs neutron number for the even-even Rf and Hs isotopes by 3–4 orders of magnitude for even-even nuclei shown in

T values for Db isotopes are larger than values for the known SF decaying even-even Rf and Hs isotopes by about 10–100. Such an additional hindrance factor

With a half-life of about 1 ms (compare with 293, 296, and 299 Hs (8.73 MeV) and SF) or its precursors, electron capture/EC decays cannot be excluded.

The SF half-life of Mt is rather close to that for 243 Am, 87 Bi, and

All the nuclides isotopes of elements 109, 111, and 113. The value

281, 284 Hs observed in [1547, 1548, 1549, 1550] a n d p r e s u m a b l y a s s i g n e d α-particles detected by the focal-plane or both

Branching ratio is not shown if only one decay mode was observed.
The inversion of the ground-state spins between $^{103}\text{Sn}$ and $^{101}\text{Sn}$ is due to the strong pairing interaction between $g_{7/2}$ valence neutrons.

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