NTNU – Trondheim
Norwegian University of
Science and Technology

Department of Physics

Examination paper for TFY4225 Nuclear and Radiation Physics

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Examination date: 01.12.2015

Examination time (from-to): 9.00-13.00

Permitted examination support material (code C):

- **Simple specified calculator**
- **Barnett & Cronin: Mathematical Formulae**
- **Rottmann: Matematische Formelsammlung**

Other information: Each sub-question (1, 3a, 3b etc) carries equal weight in the evaluation. Exam might be answered in English or Norwegian.

Language: English

Number of pages (front page excluded): 3

Checked by:

Date Signature

CONSTANTS

Speed of light	c	2.99792458×10^{8} m/s
Charge of electron	e	1.602189×10^{-19} C
Boltzmann constant	k	1.38066×10^{-23} J/K
		8.6174×10^{-5} eV/K
Planck's constant	h	6.62618×10^{-34} J · s
		4.13570×10^{-15} eV · s
	$\hbar = h/2\pi$	1.054589×10^{-34} J · s
		6.58217×10^{-16} eV · s
Gravitational constant	G	6.6726×10^{-11} N · m^2/kg^2
Avogadro's number	N_A	6.022045×10^{23} mole^{-1}
Universal gas constant	R	8.3144 J/mole · K
Stefan-Boltzmann constant	σ	5.6703×10^{-8} W/m^2 · K^4
Rydberg constant	R_∞	1.0973732×10^{7} m^{-1}
Hydrogen ionization energy		13.60580 eV
Bohr radius	a_0	5.291771×10^{-11} m
Bohr magneton	μ_B	9.27408×10^{-24} J/T
		5.78838×10^{-5} eV/T
Nuclear magneton	μ_N	5.05084×10^{-27} J/T
		3.15245×10^{-8} eV/T
Fine structure constant	α	1/137.0360
	hc	1239.853 MeV · fm
	$\hbar c$	197.329 MeV · fm
	$e^2/4\pi\epsilon_0$	1.439976 MeV · fm

PARTICLE REST MASSES

	u	MeV/c^2
Electron	5.485803×10^{-4}	0.511003
Proton	1.00727647	938.280
Neutron	1.00866501	939.573
Deuteron	2.01355321	1875.628
Alpha	4.00150618	3727.409
$\pi^\pm$	0.1498300	139.5669
π^0	0.1448999	134.9745
μ	0.1134292	105.6595

CONVERSION FACTORS

1 eV = 1.602189×10^{-19} J

1 u = 931.502 MeV/c^2
= 1.660566×10^{-27} kg

1 b = 10^{-28} m^2

1 Ci = 3.7×10^{10} decays/s

Problem 1

Choose an analytical or industrial application of radiation discussed in this course.

- Explain the main physical principles of the method.
- Describe typical applications.

Problem 2

Describe the experimental setup you would use to measure the linear attenuation coefficient of a material:

- Draw a sketch of the setup and the different components involved, and name all the parts.
- Describe the measurement procedure and the data analysis.
- Explain what is meant by "buildup", and describe how your setup is designed to avoid influcence from this effect.

Problem 3

3a)

Write down the expression for the reaction energy Q in an alpha-decay process and explain the terms. Use energy and momentum conservation to derive an expression for the kinetic energy of the alpha-particle expressed as a function of Q and particle masses of the decay products. Assume the parent nucleus is at rest.

3b)

Rewrite the expression of Q in terms of atomic mass excess values and calculate the value of Q for the alpha-decay of ${}^{232}_{90}Th$. Atomic mass excess values are: ${}^{4}He$ = 2603 μu, ${}^{232}_{90}Th$ = 38050 μu and ${}^{228}_{88}Ra$ = 31064 μu.

3c)

The semi-classical theory of alpha decay allows us to estimate the half-life of an alpha-decaying nuclide based on the following expression:

$$\lambda = P f \exp(-2G) \qquad (1)$$

where

$$G = \sqrt{\frac{2m}{\hbar^2 Q}} \frac{2Ze^2}{4\pi\varepsilon_0}\left[\cos^{-1}\left(\sqrt{Q/B}\right) - \sqrt{(Q/B)(1 - Q/B)}\right]$$

Explain the physical model which leads to equation 1, and define the terms.

3 d)

Estimate the half-life of ${}^{232}_{90}Th$ using the above expressions. Use R_0=1.2 fm, assume a pre-formation probability of 1 and U = 120 MeV for the potential depth inside the heavy nucleus. The Coulomb potential energy between two charges separated by distance R is generally given by $q_1 q_2/4\pi\varepsilon_0 R$.

Problem 4

Assume a nuclear reaction between a heavy nucleus (A = 113) at rest and a neutron with kinetic energy 0.17 eV. The reaction is a resonance with a total peak width of 0.13 eV. By comparing estimates of the mean lifetime of this resonance and the collision time, determine if the reaction is a compound nucleus reaction or a direct reaction.

Problem 5

An X-ray source is emitting 100 keV photons. How many photons must be emitted from the source in order to give an expected 100 counts from the primary beam in a 2 mm thick CsI-scintillator detector placed behind 15 cm of water. Linear attenuation coefficients of water and CsI @100 keV are 0.227 cm^{-1} and 9.16 cm^{-1} respectively.

Problem 6

Explain the physics behind the term *charged particle equilibrium* (CPE). Plot the local dose D deposition as function of the position across the boundary between two materials where $\left(\frac{\mu_{en}}{\rho}\right)_1 < \left(\frac{\mu_{en}}{\rho}\right)_2$ and $\left(\frac{S_c}{\rho}\right)_1 < \left(\frac{S_c}{\rho}\right)_2$.

Problem 7

Determine spin and parity of ${}^{35}_{17}Cl$ in its ground state, and suggest possible spin-parity states of excited states. The sequence of the lower states in the shell model is 1s1/2, 1p3/2, 1p1/2, 1d5/2, 2s1/2, 1d3/2.

Use angular momentum conservation to determine the multipolarity of the gamma emission from a 1/2+ excited state to the ground state in ^{35}Cl. How will the lifetime of this excited state compare with common lifetimes of excited states in nuclei?