



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

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

$$1 \text{ eV} = 1.602189 \times 10^{-19} \text{ J}$$

$$1 \text{ u} = 931.502 \text{ MeV}/c^2$$

$$= 1.660566 \times 10^{-27} \text{ kg}$$

$$1 \text{ b} = 10^{-28} \text{ m}^2$$

$$1 \text{ Ci} = 3.7 \times 10^{10} \text{ decays/s}$$

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 influence 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 $^{232}_{90}\text{Th}$. Atomic mass excess values are: $^4\text{He} = 2603 \mu\text{u}$, $^{232}_{90}\text{Th} = 38050 \mu\text{u}$ and $^{228}_{88}\text{Ra} = 31064 \mu\text{u}$.

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:

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

where

$$G = \sqrt{\frac{2m}{\hbar^2 Q}} \frac{2Ze^2}{4\pi\epsilon_0} \left[\cos^{-1}(\sqrt{Q/B}) - \sqrt{(Q/B)(1 - Q/B)} \right]$$

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

3 d)

Estimate the half-life of $^{232}_{90}\text{Th}$ using the above expressions. Use $R_0 = 1.2 \text{ fm}$, assume a pre-formation probability of 1 and $U = 120 \text{ MeV}$ for the potential depth inside the heavy nucleus. The Coulomb potential energy between two charges separated by distance R is generally given by $q_1 q_2 / 4\pi\epsilon_0 R$.

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 $^{35}_{17}\text{Cl}$ in its ground state, and suggest possible spin-parity states of excited states. The sequence of the lower states in the shell model is $1s_{1/2}$, $1p_{3/2}$, $1p_{1/2}$, $1d_{5/2}$, $2s_{1/2}$, $1d_{3/2}$.

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?