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Department of Physics

Examination paper for TFY4225 and FY6023 Nuclear and Radiation Physics

Examination date: 01.12.2021

Examination time (from-to): 9:00-13:00

Permitted examination support material: A / All support material is allowed

Academic contact during examination: Johanna Vannesjö
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Technical support during examination: Orakel support services
Phone: 73 59 16 00

If you experience technical problems during the exam, contact Orakel support services as soon as possible before the examination time expires/the test closes. If you don't get through immediately, hold the line until your call is answered.

OTHER INFORMATION

If a question is unclear/vague – make your own assumptions and specify in your answer the premises you have made.

Language: All questions are given in English, but you may answer in either English or Norwegian.

Physical constants/nuclide information: If you need physical constants or information about specific nuclides to answer a question, please use either information from the course books or from reliable online sources (e.g. https://www.nndc.bnl.gov/nudat2/). Please cite the source of information in your answer if you use sources outside of the course syllabus.

Do not open Inspera in multiple tabs, or log in on multiple devices, simultaneously. This may lead to errors in saving/submitting your answer.

Get an overview of the question set before you start answering the questions.

Read the questions carefully, make your own assumptions and specify them in your answer. Only contact academic contact if you think there are errors or insufficiencies in the question set.

Cheating/Plagiarism: The exam is an individual, independent work. Examination aids are permitted, but make sure you follow any instructions regarding citations. During the exam it is not permitted to communicate with others about the exam questions or distribute drafts for solutions. Such communication is regarded as cheating. All submitted answers will be subject to plagiarism control. *Read more about cheating and plagiarism here.*

Notifications: If there is a need to send a message to the candidates during the exam (e.g. if there is an error in the question set), this will be done by sending a notification in Inspera. A dialogue box

will appear. You can re-read the notification by clicking the bell icon in the top right-hand corner of the screen. All candidates will also receive an SMS to ensure that nobody misses out on important information. Please keep your phone available during the exam.

ABOUT SUBMISSION

Answering in Inspera: You may answer all questions directly in Inspera in the given fields. In Inspera, your answers are saved automatically every 15 seconds. NB! We advise against pasting content from other programs, as this may cause loss of formatting and/or entire elements (e.g. images, tables).

If you prefer to use handwriting (e.g. for equations) you may also scan documents with your answers, and upload them in the final question. Note that the final question is just a placeholder to allow for the upload of scanned files. See information below about uploading files.

File upload:
All files must be uploaded before the examination time expires.
30 minutes are added to the examination time to manage the sketches/calculations/files. The additional time is included in the remaining examination time shown in the top left-hand corner.

The file types allowed are specified in the upload assignment(s). Note that it is only possible to upload one file per upload assignment.

NB! You are responsible to ensure that the file(s) are correct and not corrupt/damaged. Check the file(s) you have uploaded by clicking “Download” when viewing the question. All files can be removed or replaced as long as the test is open.

How to digitize your sketches/calculations
How to create PDF documents
Remove personal information from the file(s) you want to upload

Automatic submission: Your answer will be submitted automatically when the examination time expires and the test closes, as long as you have answered at least one question. This will happen even if you do not click “Submit and return to dashboard” on the last page of the question set. You can reopen and edit your answer as long as the test is open. If no questions are answered by the time the examination time expires, your answer will not be submitted. This is considered as “did not attend the exam”.

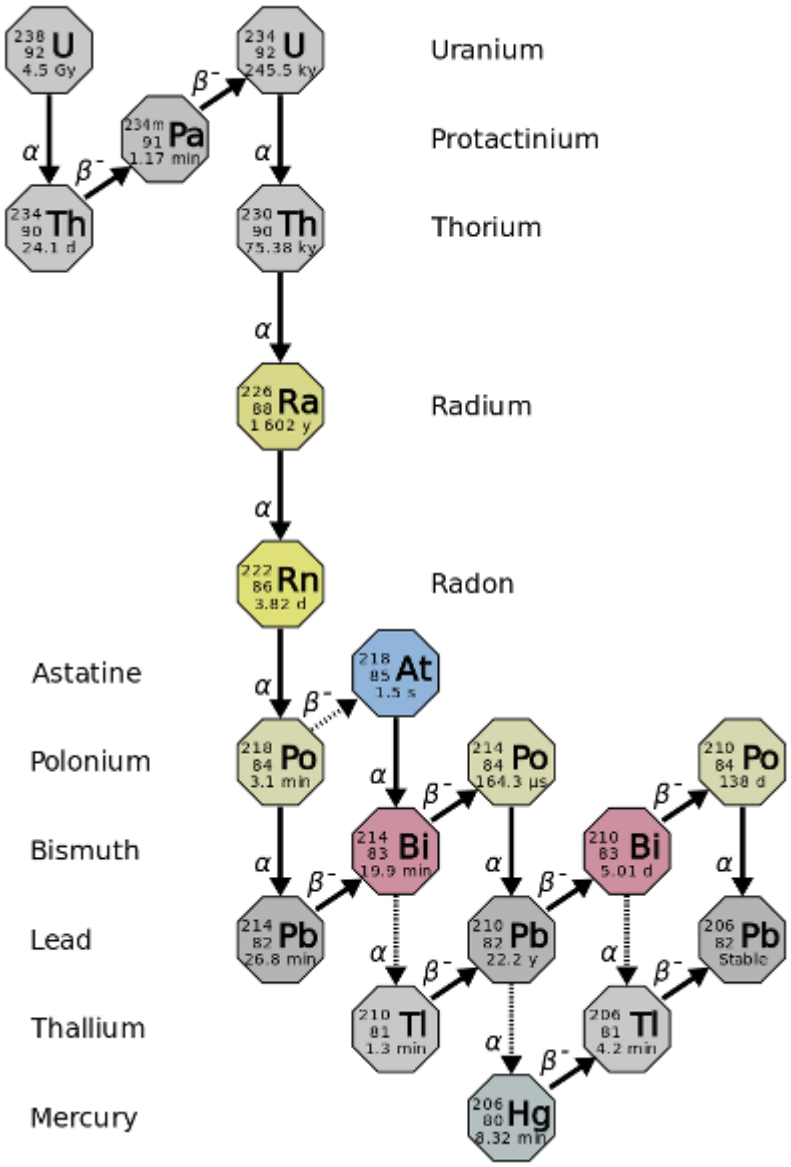
Withdrawing from the exam: If you become ill during the exam or wish to submit a blank answer/withdraw from the exam for another reason, go to the menu in the top right-hand corner and click “Submit blank”. This cannot be undone, even if the test is still open.

Accessing your answer post-submission: You will find your answer in Archive when the examination time has expired.

Essay questions - pdf

1 Question 1

1. Radon gas in buildings is a public health hazard, which contributes to the development of lung cancer. The maximum threshold value for Radon in air is set at 200 Bq/m^3, and action (e.g. improved ventilation) to reduce the Radon content is recommended above 100 Bq/m^3. (14p)
    a. Most of the Radon present naturally in the environment is Rn-222, which is part of the decay chain pictured below. Assuming an activity of 200Bq/m3 of Rn-222 in the air, how many atoms of Rn-222 are present per cubic meter of air? (1)
    b. Assume that you have a poorly ventilated space, such that all radioactive decay products of Rn-222 are in equilibrium, and that the activity of Rn-222 stays constant as in a). How many atoms are there of the first daughter nuclide, Po-218, per cubic meter of air? (1)
    c. The main dose from the radioactive decay chain of Rn-222 stems from the short-lived alpha-emitters Po-218 and Po-214, as they attach to dust particles in the air, which stick to the airways when inhaled. Assume a breathing volume of 6 l/minute. Assume that 10% of the Polonium daughters (Po-218 and Po-214) in the air that you inhale will stick in the airways and decay there. Assume a weight of the airways of 0.8kg. Calculate the yearly total dose to the airways (in Gy) and the effective dose (in Sv), assuming you spend 60% of your time in that environment. (6)
    d. Explain how ionizing radiation can increase the risk of cancer (2)
    e. In c) we assumed that the total dose was due only to the short-lived alpha-emitting decay products of Rn-222. Radon as an inert gas will not stick to the surface of the airways, and most of the decay will therefore happen outside the body. Explain the significance of this in terms of biological effect (i.e. why can we ignore Rn-222 contribution to the dose?). (2)
    f. Why is alpha radiation inside the body more dangerous than beta or gamma radiation? (2)


238 92 U 4.5 Gy
234 92 U 245.5 ky
234m 91 Pa 1.17 min
234 90 Th 24.1 d
230 90 Th 75.38 ky
226 88 Ra 1 602 y
222 86 Rn 3.82 d
218 85 At 1.5 s
218 84 Po 3.1 min
214 84 Po 164.3 µs
210 84 Po 138 d
214 83 Bi 19.9 min
210 83 Bi 5.01 d
214 82 Pb 26.8 min
210 82 Pb 22.2 y
206 82 Pb Stable
210 81 Tl 1.3 min
206 81 Tl 4.2 min
206 80 Hg 8.32 min
α
β-
Uranium
Protactinium
Thorium
Radium
Radon
Astatine
Polonium
Bismuth
Lead
Thallium
Mercury

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2 Question 2

^{222}Ra is created by alpha-decay from ^{226}Ra. Looking at the possible decay routes listed on the NNDC nuclide database, a second decay possibility with very low probability is mentioned as being 14-C decay. Estimate the expected branching ratio between 14-C and alpha decay, based on the semiclassical model of alpha decay. How does that compare to the measured branching ratios? Assume a well depth (V_0) of 35 MeV in both cases. (8p)

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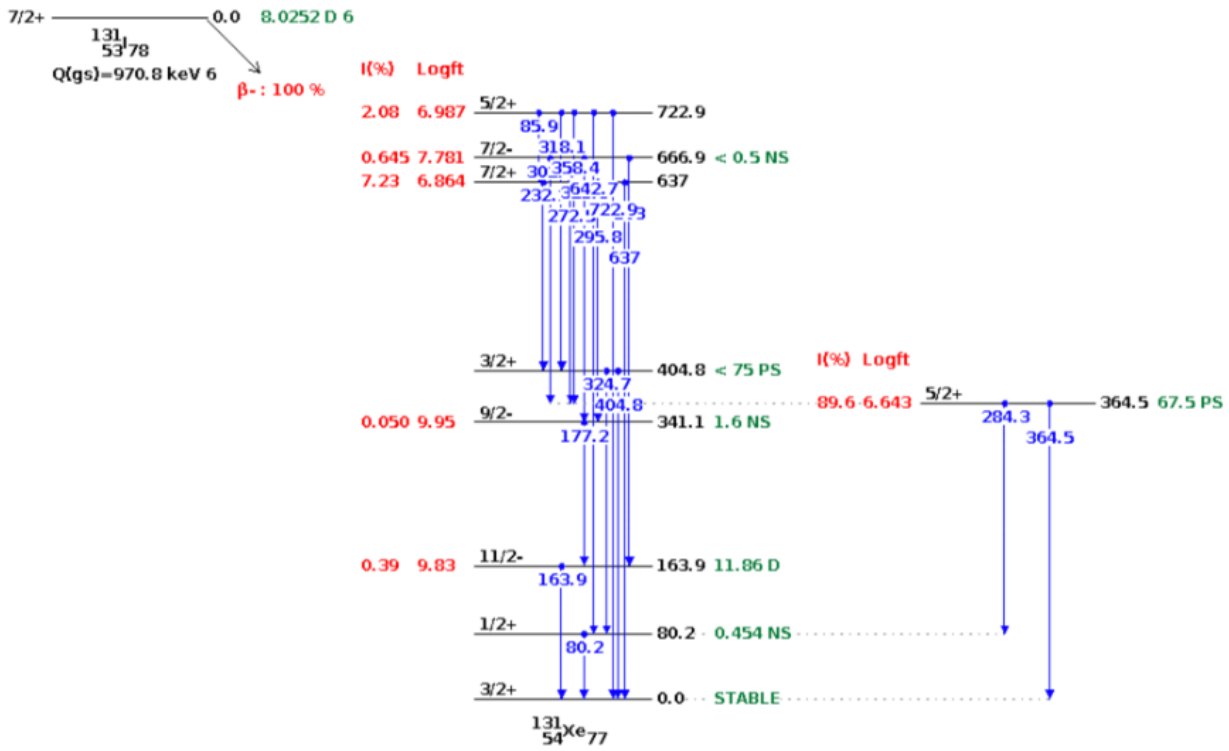
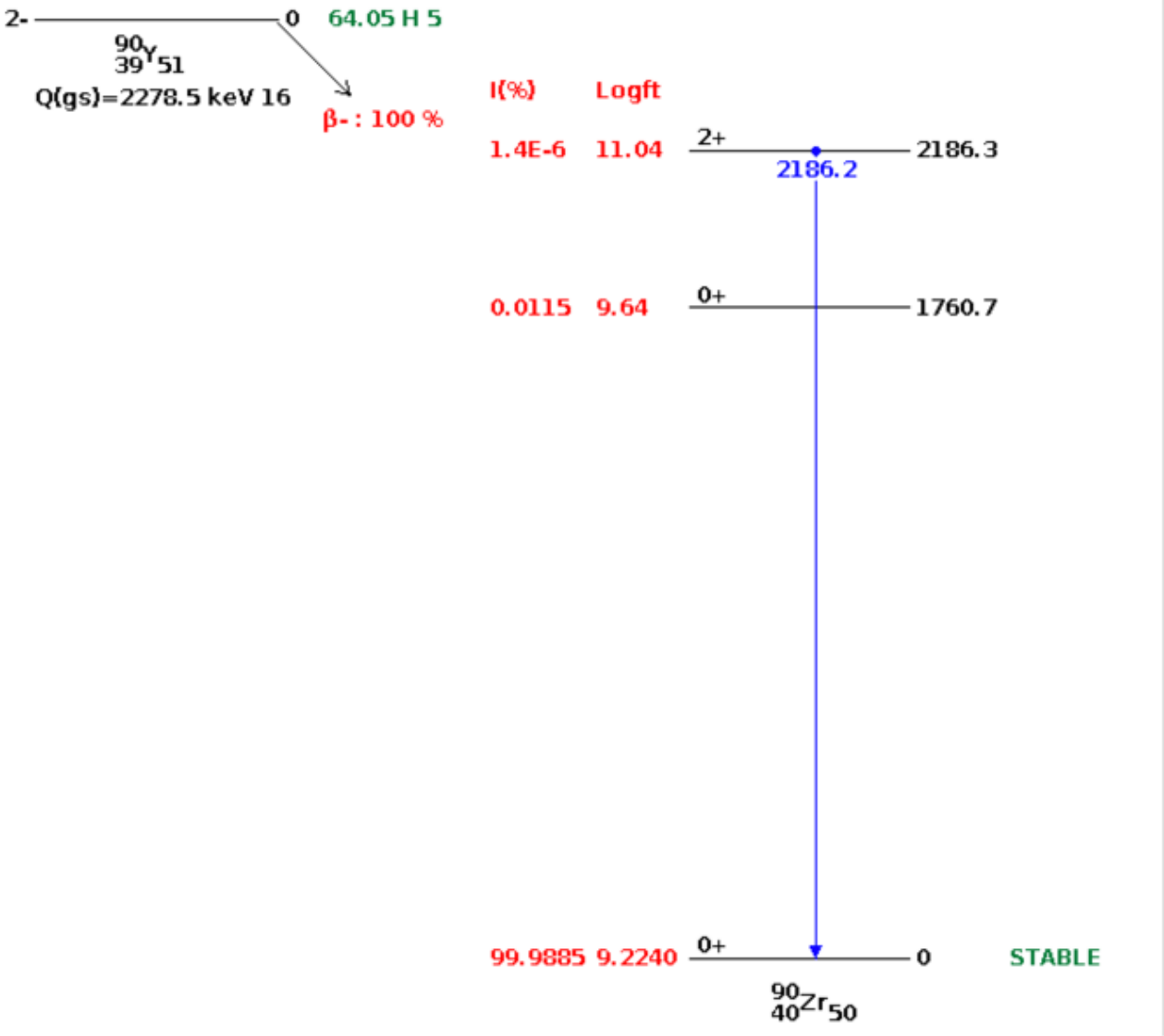
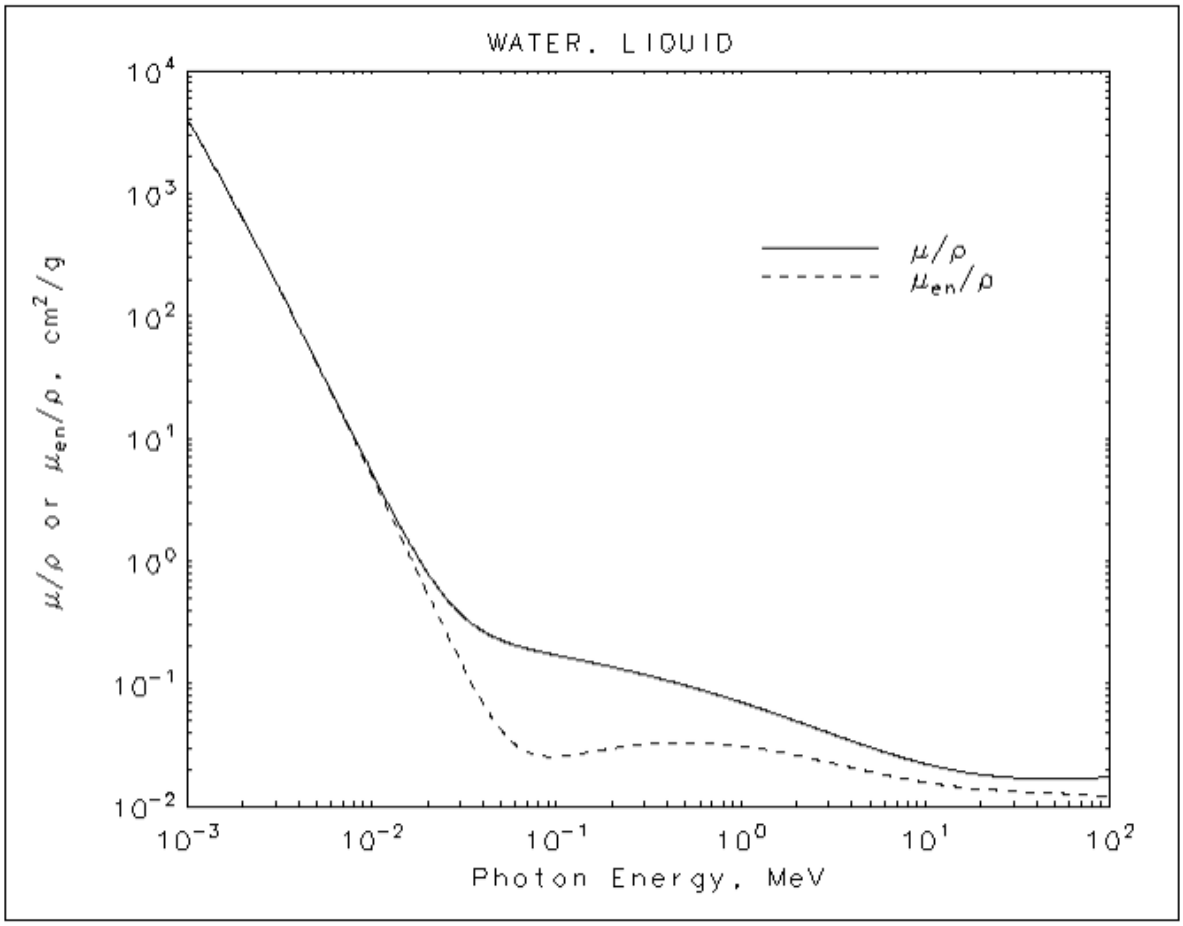
3 Question 3

^{131}I has been used for treating tumours with radionuclides (antibodies labelled with a radionuclide are injected and bind to the tumour, so as to deposit the dose locally in the tumour). However, for tumours other than thyroid cancer, ^{131}I has been replaced by other radionuclides, for example ^{90}Y. Below is a plot of the decay schemes of ^{131}I and ^{90}Y. (16p)

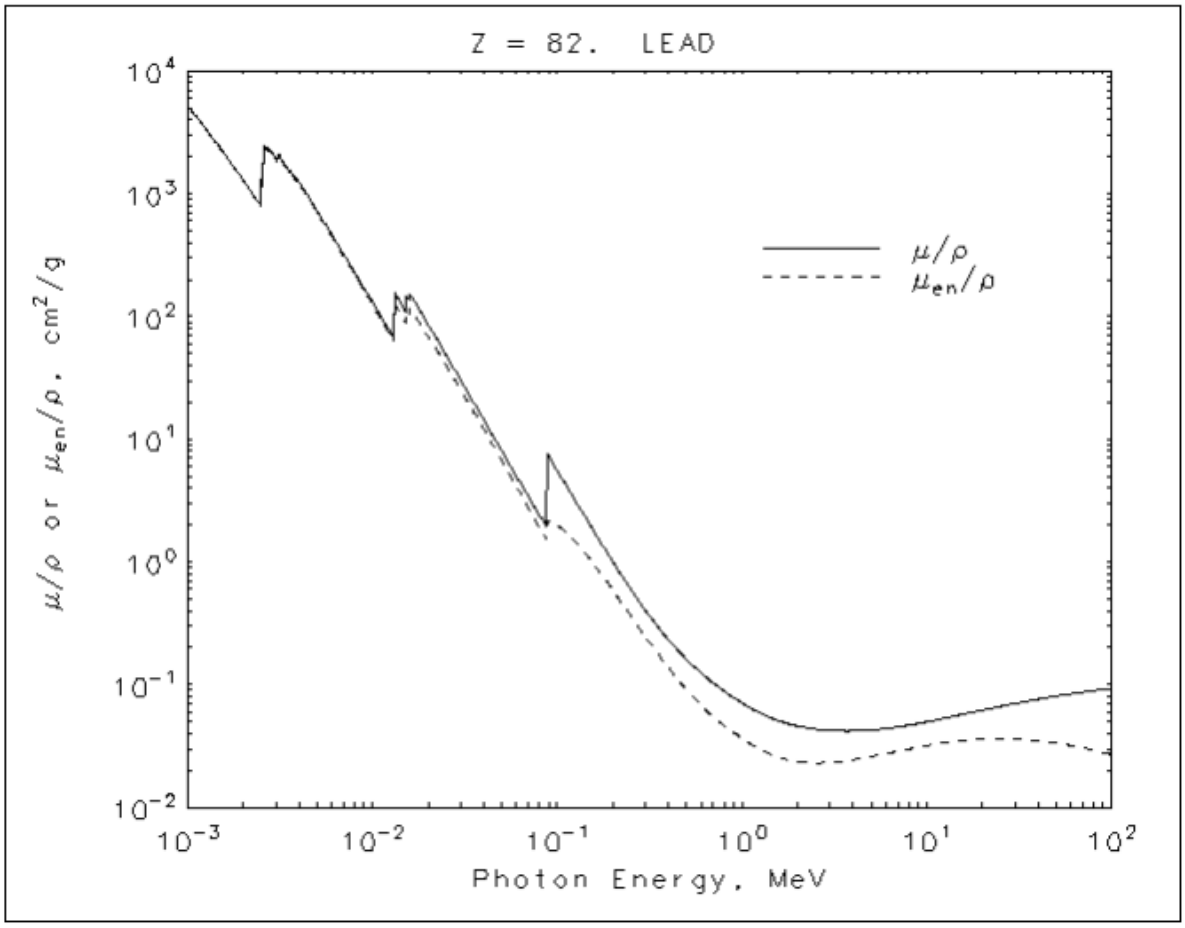




a. Based on these decay schemes, explain why ^{90}Y may be preferable to ^{131}I for radiotherapy. (2)
b. Analyse the beta-decays of ^{90}Y and ^{131}I (only the most probable decay for each) in terms of allowed/forbidden & Fermi vs Gamow-Teller decay (2)
c. ^{131}I decays via negative beta decay only, whereas other isotopes of Iodine (^{126}I and ^{128}I) can decay via either negative beta decay or electron capture. Describe why this is possible (please use a sketch). How can you know that the same would not be possible for ^{127}I, without looking up decay information for that specific isotope? (2)
d. Below is a plot of the mass attenuation coefficient (μ/ρ) and mass energy absorption coefficient (μ_{en}/ρ) of photons in water. Explain why the two are almost identical at low photon energies, and why $\mu_{en}/\rho < \mu/\rho$ at higher photon energies. (2)



e. Below is the corresponding plot for lead (https://physics.nist.gov/PhysRefData/XrayMassCoef/ElemTab/z82.html). Explain the sharp peaks in the mass attenuation coefficient. (2)



f. Assume you have a well-collimated beam of monoenergetic photons of 300 keV, with a fluence of $8*10^{10}$ cm^{-2}. Estimate the dose delivered inside soft tissue, at a depth where the charged particle equilibrium holds. (3)

g. To protect yourself while working with the photon beam, you use a lead shield which can attenuate the beam to 1% of its initial value. How thick does the lead shield need to be? (3)

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4 Question 4

Nuclear reactions (6p)

a. Fission reactors rely on materials used for neutron moderation (e.g. water, heavy water or graphite). Explain what neutron moderation is. Generally speaking, what types of materials are suitable for neutron moderation, and why? (2)
b. Calculate the Q-value for the nuclear reactions below. What is the minimum kinetic energy of the projectile needed to induce a reaction (assuming a stationary target). (4)
    i. $^{3}H(p,n)^{3}He$
    ii. $^{14}N(n,p)^{14}C$

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5 Question 5

Radioactivity can be utilised for various purposes in society. (10p)

a. One well-known use of radiation physics is for dating old fossils and rocks. K-Ar radioactive dating can be used to estimate the age of rocks. Radioactive ^{40}K is present in many rocks, and decays via electron capture to ^{40}Ar with a branching ratio of 10.7% and a half-life of $1.248*10^{9}$ years. Its stable daughter nuclide, ^{40}Ar, can escape molten magma, but is trapped after the rock solidifies. Thus the age since the formation of the rock can be estimated. (3)
    i. Derive an expression for the age of the rock given measured amounts of ^{40}K and ^{40}Ar (assuming no ^{40}Ar present at the time of formation).
    ii. Estimate the age of the rock if you have measured 2% of ^{40}Ar relative to ^{40}K.
b. Choose one of the following material analysis techniques and describe the principles behind: (3)
    i. Accelerated mass spectrometry
    ii. Rutherford backscattering
    iii. Particle-induced X-ray emission
    iv. Neutron activation analysis
c. You want to analyse the amount of C-14 in a fossil, to determine its age. Which one of the techniques in b) would you prefer for the analysis, and why? (2)
d. Now instead you want to analyse the composition of the paint used in an old and extremely valuable painting. Which technique would you choose, and why? (2)

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6 MC 1

Which of the following statements is true

Velg ett alternativ

- Nuclear scattering cross-sections are always smaller than nuclear reaction cross-sections
- Nuclear scattering cross-sections are equal to nuclear reaction cross-sections
- If there is some probability of a nuclear reaction to occur, then there is also a probability of scattering
- If there is some probability of nuclear scattering to occur, then there is also a probability of a nuclear reaction
- Nuclear reactions and nuclear scattering cannot happen with the same types of nuclei

Maks poeng: 1

7 MC 2

Bremsstrahlung refers to:
Velg ett alternativ:

- Electrons emitted when photons interact with matter in the photoelectric effect
- Recoil protons from elastic scattering of neutrons
- Lower-energetic photons after Compton scattering
- Photons emitted through acceleration of electrons
- Neutrons being slowed down through scattering

Maks poeng: 1

8 MC 3

Which of the following statements is true.
Velg ett alternativ:

- A Geiger-Mueller counter has a higher voltage between electrodes than a proportional counter
- Semiconductor detectors are ideal to detect neutrons
- Geiger-Mueller counters are ideal for fast applications
- A proportional counter has no energy resolution
- Scintillator materials are often gases

Maks poeng: 1

9 MC 4

Which statements about cyclotrons are true. Note that more than one is possible.
Velg ett eller flere alternativer

- [ ] Cyclotrons use an oscillating voltage between electrodes and a fixed magnetic field to accelerate charged particles
- [ ] Cyclotrons use oscillating magnetic fields and a fixed voltage difference between electrodes to accelerate charged particles
- [ ] The maximum energy of a charged particle accelerated in a cyclotron is independent of the radius of the cyclotron
- [ ] The maximum energy of a charged particle accelerated in a cyclotron depends on the strength of the magnetic field
- [ ] Cyclotrons accelerate charged particles at a fixed radius

Maks poeng: 1

10 MC 5

Which of the following statements is **false** concerning the shell model:
Velg ett alternativ:

- Ground state spin and parity can be predicted for many elements based on the shell model
- The shell model is based on solving the Schrödinger equation for a 3D harmonic oscillator
- The shell model is a quantum mechanical model of the nucleus
- Spin-orbit coupling is accounted for in the shell model
- The shell model helped explain the magic numbers

Maks poeng: 1

11 MC 6

Which of the following statements is true:
Velg ett alternativ:

- The nuclear radius is approximately proportional to the atomic mass number
- Nuclear density is highly dependent on the isotope of an element
- Charge and mass are very differently distributed inside the nucleus
- The nuclear radius is independent of the atomic mass number
- Nuclear density is approximately constant between elements

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