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Department of Physics

Examination paper for TFY4225 Nuclear and Radiation Physics

Examination date: 15.12.2020

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

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

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OTHER INFORMATION

Make your own assumptions: If a question is unclear/vague, make your own assumptions and specify them in your answer. Only contact academic contact in case of errors or insufficiencies in the question set.

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Weighting: The number of points is shown for each question in the exam. The maximum possible points in this exam are 60. These points will be added together with the points from the midterm (max 20) and the lab report (max 20) to a maximum of 100 points achievable. The grade is based on these points.

ABOUT SUBMISSION

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.

How to digitize your sketches/calculations
How to create PDF documents
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NB! You are responsible to ensure that you upload the correct file(s) for all questions. 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.

The additional 30 minutes are reserved for submission. If you experience technical problems during upload/submission, you must contact technical support before the examination time expires. If you can’t get through immediately, hold the line until you get an answer.

Your answer will be submitted automatically when the examination time expires and the test closes, if 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.

Withdrawing from the exam: If you become ill or wish to submit a blank test/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.

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1

Detectors and PET

a) List three different types of detectors for different types of ionization radiations. Describe what kind(s) of radiation each detector is suitable to detect and explain the principles behind the detection mechanism(s).

b) Time-of-flight (TOF) is a technique to measure the distance between a point of interest and a detector. In positron emission tomography (PET), TOF can be used to improve accuracy and image quality by measuring the time difference it takes for coincident photons to reach the detectors along the line-of-response (LOR). Assume the diameter of a PET scanner ring is 0.5 meter. Calculate the time it takes for a photon to travel from the center of the scanner to the detector ring.

c) Draw a simple sketch of the detector ring setup in a PET scanner. Assume a point of interest 15 cm from the center of the ring. Calculate the maximum time difference between two photons from an annihilation event to reach the detector ring.

d) Possible scintillator crystal materials for PET and their characteristics are listed in the table below. Which of the scintillator crystal materials listed in the table is suitable to build a TOF-PET detector ring (based on the primary decay constant)? Justify your answer.

Scintillation and Optical Properties of Some Common Scintillator Crystals

Crystal	Primary decay constant (ns)	Secondary decay constant (ns)	Relative emission intensity	Emission wavelength (nm)	Index of refraction
BaF_2	0.8	600	12	220 and 310	1.49
CsF	4		5	390	1.48
Lu_2SiO_5(Ce) (LSO)	40		75	420	1.82
Gd_2SiO_5(Ce) (GSO)	60	600	30	430	1.85
NaI(Tl)	230	~10,000	100	410	1.85
$Bi_4Ge_3O_{12}$ (BGO)	300		15	480	2.15
CsI(Na)	630		75	420	1.84
CaF_2(Eu)	900		40	435	1.44
CsI(Tl)	1000		45	565	1.80
$CdWO_4$	5000	~20,000	20	480	2.20

e) 50 MBq of a positron-emitting radiotracer is accumulated in this point of interest, and your detector ring consists of 1024 crystals made of the material of your choice. Calculate how many counts per second each crystal receive based on its emission intensity relative to NaI(Tl). The light yield of NaI is 38 photons/keV, 20% of the ultraviolet/visible photons will hit the photocathode, and the PMT efficiency is ~20%.

f) Based on your knowledge about PET, list one advantage of PET over SPECT, and one main challenge in PET in terms of image resolution.

(18 points)

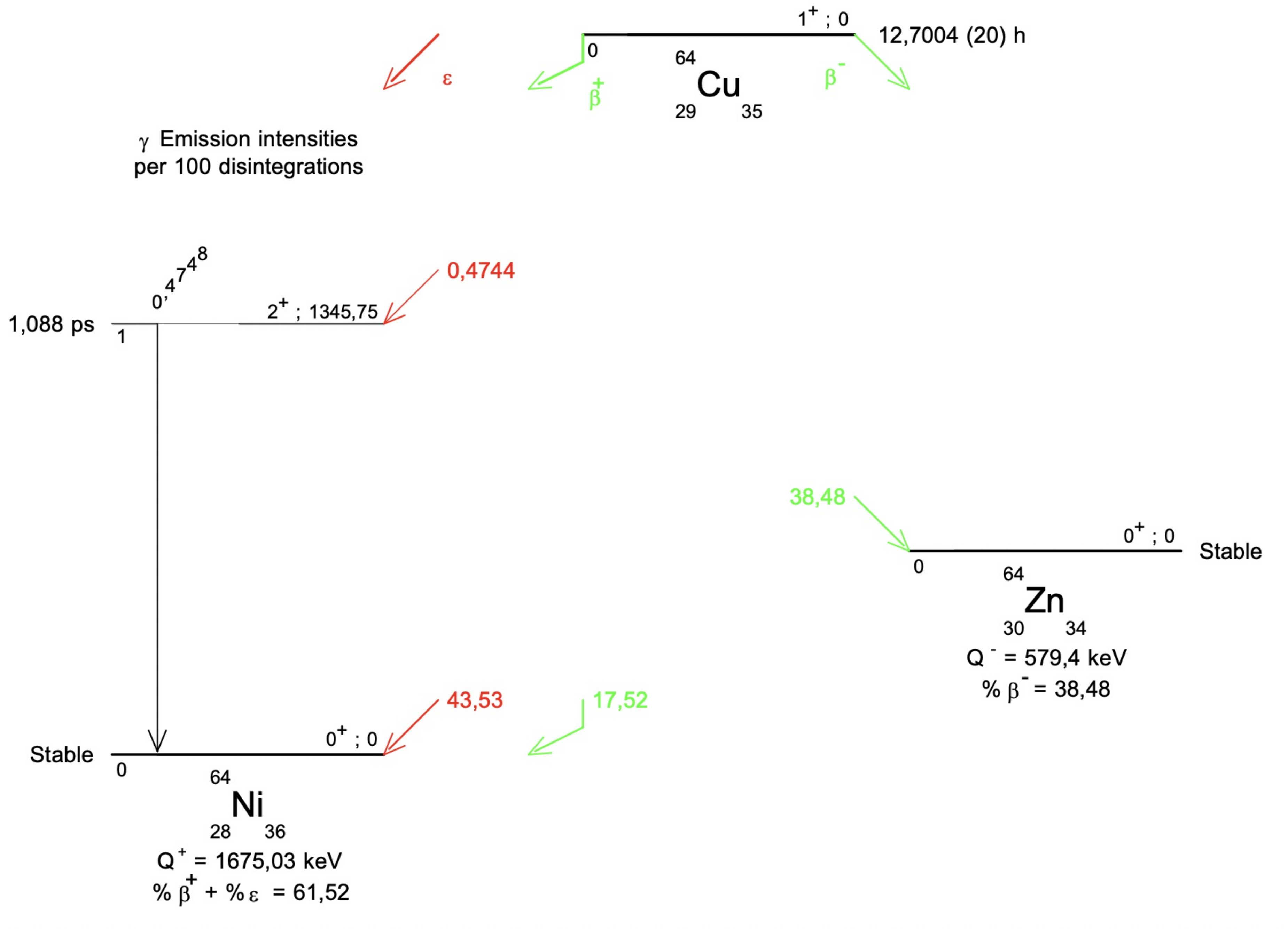
Fill in your answer here

Words: 0

Maximum marks: 18

2 Dosimetry

Copper-64 (Cu-64) is a synthetic radioactive isotope of copper with half-life of 12.7 hours. The decay scheme of Cu-64 is shown in the figure below.



a) Write down the definition of Q-value in a nuclear transition.
Explain the physical meaning of the Q-value and its relation with excess mass.
Explain why Cu-64 can undergo β-, β+, and EC decays.

b) Calculate the Q-values for the disintegration of Cu-64 by β-, β+, and EC, respectively.

In the decay to Ni-64, why is EC more favorable than β+?

c) Cu-64 radiopharmaceuticals have been used to develop PET tracers that specifically accumulate in regions with low tissue oxygenation (hypoxia).

A patient is injected with 370 MBq of a Cu-64 radiotracer.

Use the MIRD formalism for internal dosimetry and estimate the total absorbed dose.

Assume no biological clearance and uniform distribution.

(12 points)

Fill in your answer here

Format B I U x_2 x^2 I_x Ω Σ

Words: 0

Maximum marks: 12

3 Alpha decay

You are given the task to analyse the following α decay and estimate the half-life of $^{238}_{92}U$.
$^{238}_{92}U \rightarrow^{234}_{90} Th + \alpha$

The reaction energy is 4.268 MeV and the Coulomb potential is 120 MeV.
The following questions will guide you through the estimation.

a) Find the radius to where the Coulomb potential is equal to the Q-value.

b) The Gamow factor is 44.4, what is the tunnelling probability?

c) Besides the tunnelling probability, to calculate the decay rate we need to calculate the frequency for the reduced effective particle to be at the edge of the Coulomb potential. Here, v is the reduced particle velocity inside the nuclear well when taking Q as the (classical) energy.

d) Finally, give the decay rate λ and the half-life $t_{1/2}$ for the α decay of $^{238}_{92}U$. Is the half-life for this α decay fast or slow?

(10 points)

Fill in your answer here

Format B I U x₂ x² Tx Ω Σ

Words: 0

Maximum marks: 10

4 Potential well

a) Consider an infinitely deep 1-dimensional potential well where an electron is trapped inside. The width of the well is 10^{-9} m.

What is the the Schrödinger equation for this potential?

The equations does not need to be normalised but should comply with the boundary conditions.

b) Consider the state n = 5. Can you draw the wave function for this state?

c) What is the difference in energy between the n = 4 and n = 5 stage?

(10 points)

Fill in your answer here

Format B I U x_2 x^2 I_x Ω Σ

Words: 0

Maximum marks: 10

5 Multiple choice questions

(1 point per correct answer, 0 point for wrong answer)

a) Two electrons, each with 100 keV of kinetic energy, pass close to a tungsten nucleus and produce x-ray photons via bremsstrahlung. The first electron passes close to the nucleus and emits a photon of energy E1, whereas the second electron passes by at a greater distance from the nucleus and produces a photon of energy E2. The photon energies satisfy:

Select one alternative:

- 100 keV < E1 < E2
- 100 keV< E2 < E1
- E2 < E1 < 100 keV
- E1 = E2 < 100 keV
- E1 < E2 < 100 keV

b) Of the following radiations, which would be the most desirable for radionuclide imaging?

Select one alternative

- 150 keV beta
- 1500 keV gamma
- 15 keV gamma
- 5 MeV alpha
- 150 keV gamma

c) In SPECT, one way to improve the image resolution is to use a high-resolution collimator (such as pinholes). Which of the following represents a principle limitation (trade-off) when using this collimator?

Select one alternative

- Reduced sensitivity
- Limited field of view
- There is no trade-offs
- More distortion
- Decreased scattering rejection

d) m_H is the atomic mass of hydrogen, m_n is the mass of a neutron, and M is the atomic mass of the atom. Which of the following is the mass defect formula?

Select one alternative

- $\Delta m = Z \cdot m_H - N \cdot m_n - M$
- $\Delta m = Z \cdot m_H + N \cdot m_n + M$
- $\Delta m = Z \cdot m_H - N \cdot m_n + M$
- $\Delta m = M - Z \cdot m_H - N \cdot m_n$
- $\Delta m = Z \cdot m_H + N \cdot m_n - M$

e) The reaction $^{1}n + ^{235}U \rightarrow ^{141}Ba + ^{92}Kr + 3^{1}n$ is called:

Select one alternative

- Gamma decay
- Beta decay
- Fusion
- Alpha decay
- Fission

f) Which of the following statements is correct?

Select one alternative

- Compton scattering between a gamma photon and an atom is between the photon and inner shell electrons of the atom
- The kinetic energy of an electron knocked out from the atom by a gamma photon via photoelectric interaction is equal to the energy of the gamma photon
- Photoelectric effect is dominant for low energy gamma photons and is independent of Z
- The interaction cross section of a gamma photon absorbed by an atom via photoelectric effect is dependent of Z but independent of which isotope of the same element
- Absorption cross section of a neutron with a certain energy by an atom is dependent of the atomic number Z; different isotopes of the same element will have the same absorption cross section

g) Which of the following statement is incorrect?

Select one alternative

- The linear energy transfer (LET) of low kinetic energy alpha particles is much higher than high energy electrons
- Auger electrons are typically considered high energy electrons and therefore they have high linear energy transfer (LET)
- Linear energy transfer (LET) increases with the speed of a charged particle decreases
- Linear energy transfer (LET) increases with increasing charge
- Linear energy transfer (LET) is an average quantity and can be calculated in different ways

h) A nucleus with A = 235 splits into two nuclei of mass numbers in the ratio 1 : 2. The ratio of the radii of the new nuclei are:

Select one alternative

- 1:1.41
- 8:1
- 1:2
- 1:2.82
- 1:1.26

i) The Surface-energy term appears in semi-empirical mass formula as a result of

Select one alternative

- Intrinsic nucleonic spin
- Reduction of total binding energy due to nucleons not on the surface of the nucleus
- Repulsion between the protons
- Reduction of total binding energy due to nucleons on the surface of the nucleus
- Excess number of neutrons in the nucleus

j) It is Friday afternoon and you are still working on your project in the lab alone, which involves making a new PET tracer using F-18 ($t_{1/2}$ = 110 minutes). Accidentally, a vial of 100 GBq of F-18 solution is dropped at the floor and is broken (luckily you are not contaminated with any radioactive materials). What is the best way to handle this situation?

Select one alternative

- Leave the lab and put a warning sign on the door. Come back to clean up on Monday.
- Use a pipet to collect the spilled F-18 solution on the floor and transfer into a new vial in a lead shield container.
- Cover the part of the floor with the spilled F-18 solution with ~1 cm of sand, then continue the experiment.
- Immediately use clean paper towels to absorb the spilled F-18 solution, then clean the floor with soap and water.
- Ignore and continue the experiment with a new vial of F-18 solution.

Maximum marks: 10

6 Upload of files

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