NATIONAL UNIVERSITY OF SINGAPORE

PC3232 Nuclear and Particle Physics

(Semester I: AY 2013-14)

Name of Examiner: Dr. Ng Wei Khim

Time Allowed: 2 Hours

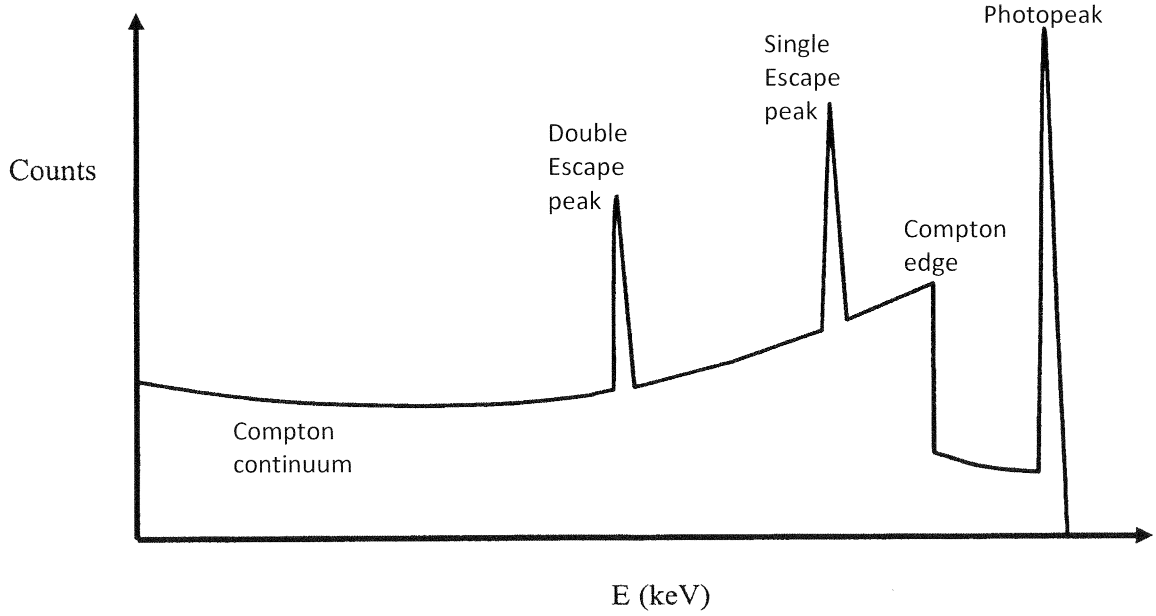
INSTRUCTIONS TO CANDIDATES

1. Please write your matriculation number only. **Do not write your name.**
2. This examination paper contains **5** questions and comprises **12** printed pages.
3. Answer **ALL** questions.
4. Answers to the questions are to be written on this examination booklet.
5. This is a CLOSED BOOK (with authorized materials) examination.
6. A help sheet (A4-size, two-sided, hand-written) is allowed for the examination.
7. Only non-programmable electronic calculator is allowed for the examination.

Matriculation Number: ____________________________

Question	Marks
1	/30
2	/20
3	/20
4	/10
5	/20
Total	/100

1. The diagram below is a typical spectrum of a mono-energetic gamma radiation.



(a) Explain in reasonable detail the origin of the photopeak, double escape peak, single escape peak, Compton continuum and Compton edge. [10 marks]

(b) Describe the origin of the counts between the photopeak and the Compton edge.

[2 marks]

(c) For a mono-energetic gamma ray, the counts between the photopeak and the Compton edge become dominant

i. in thin detectors.

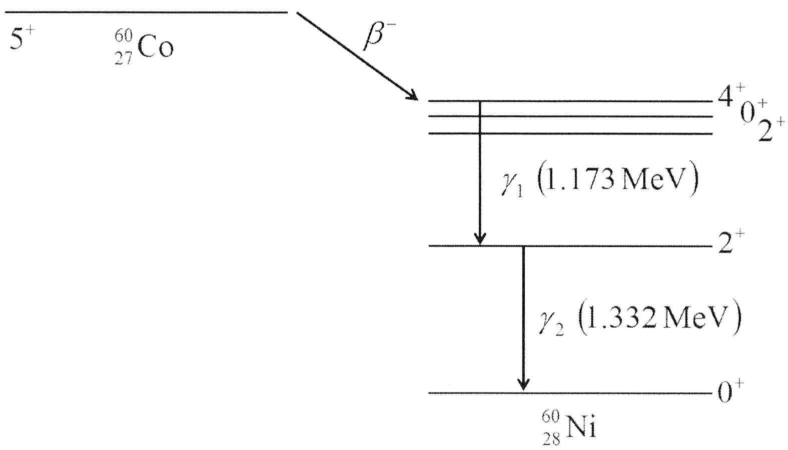
ii. in thick detectors.

iii. Never, this region is always smaller than other parts of the spectrum.

Which of the above statements is true? Discuss. [6 marks]

(d) A radioactive source ^{107}Sn emits two gamma rays of energies 0.679 MeV and 1.129 MeV respectively. Sketch the expected gamma ray spectrum. You are to label the photopeak, Compton edge, single escape peak and double escape peak (if any) by their corresponding energies. You may use the following information: mass of electron = 0.511 MeV and in a Compton scattering event, the energy E_γ' of the scattered photon can be derived to be $E_\gamma' = \dfrac{E_\gamma}{1 + \dfrac{E_\gamma}{mc^2}(1 - \cos\theta)}$ where θ is the scattering angle of the photon. [12 marks]

2. Consider the famous beta decay of ^{60}Co to ^{60}Ni as shown below.



(a) Explain why ^{60}Co decays to the 4^+ state of ^{60}Ni instead of the ground state of ^{60}Ni.

[5 marks]

(b) Explain why ^{60}Ni de-excites via TWO photons (γ_1 and γ_2) rather than one photon (4^+ state to ground state).

[7 marks]

(c) Discuss **briefly** the existence of the singlet 2^+ state and the triplet 4^+, 0^+ and 2^+ states in ^{60}Ni. [8 marks]

3. The semi-empirical mass formula for the binding energy for a spherical nucleus is given by

$$B(A,Z) = a_1 A - a_2 A^{2/3} - a_3 Z^2 A^{-1/3} - a_4 \frac{(A-2Z)^2}{A}$$

where $a_1 = 15.5$ MeV , $a_2 = 16.8$ MeV , $a_3 = 0.72$ MeV and $a_4 = 23$ MeV.

(a) Consider the fusion process ${}^{A}_{Z}X + {}^{A}_{Z}X \rightarrow {}^{2A}_{2Z}Y$. Find the limiting condition (an inequality for Z^2/A) for the fusion to take place. [10 marks]

(b) The Fermi gas model can be used to reproduce the symmetry term in the semi-empirical mass formula. From this model, the total energy for all nucleons is given by $E_{\text{tot}} = \frac{3}{5} 2^{2/3} C \left(\frac{Z^{5/3}}{A^{2/3}} + \frac{N^{5/3}}{A^{2/3}} \right)$, where $C = \frac{\hbar^2}{2mR_0^{\,2}} \left(\frac{9\pi}{4} \right)^{2/3}$. Consider the energy difference $\Delta E = E_{\text{tot}} - E_{\text{min}}$, where $E_{\text{min}} = E_{\text{tot}}(Z = N)$. Using $\delta = N - Z$, this difference is found to be $\Delta E \approx qC \frac{\delta^2}{A} = qC \frac{(A-2Z)^2}{A}$. Find the unknown q. [10 marks]

4. The nucleus charge density is given by $\rho(r) = \dfrac{\rho_0}{1 + e^{\frac{r-R}{a}}}$.

(a) The skin thickness in which the charge density drops from $0.9\rho_0$ to $0.1\rho_0$ is found to be 2.4 fm. Find the unknown a. [8 marks]

(b) What is the significance of the parameter R? [2 marks]

5. (a) The Ω^- baryon is produced when K^- is incident on a stationary proton, $K^- + p \rightarrow \Omega^- + K^+ + K^0$. From first principles, derive an expression for the threshold laboratory kinetic energy of K^- for the Ω^- production. Leave your answers in terms of the various masses. [10 marks]

(b) Explain why the following statements are incorrect.

(i) There exists a meson with charge –1 and strangeness +1. [3 marks]

(ii) The decay $\Xi^0 \rightarrow \Lambda^0 + \overline{K}^0$ can occur. [3 marks]

(c) Draw a possible Feynman diagram at quark level for the decay $K^0 \rightarrow \pi^+ + \pi^-$.

[4 marks]

Quark content and masses (MeV/c^2)
Mesons
$\pi^- = d\bar{u}$ (139.570) ; $\pi^0 = \frac{1}{\sqrt{2}}(u\bar{u} - d\bar{d})$ (134.977) ; $\pi^+ = u\bar{d}$ (139.570)
$K^- = s\bar{u}$ (493.667) ; $\bar{K}^0 = s\bar{d}$ (497.614) ; $K^0 = d\bar{s}$ (497.614) ; $K^+ = u\bar{s}$ (493.667)
Baryons
$n = udd$ (939.565) ; $p = uud$ (938.272) ; $\Delta^- = ddd$; $\Delta^0 = udd$; $\Delta^+ = uud$; $\Delta^{++} = uuu$ (1232 for all Δ)
$\Lambda^0 = uds$ (1115.683) ; $\Sigma^- = dds$ (1197.449) ; $\Sigma^0 = uds$ (1192.642) ; $\Sigma^+ = uus$ (1189.37)
$\Xi^- = dss$ (1321.71) ; $\Xi^0 = uss$ (1314.86)
$\Omega^- = sss$ (1672.45)
Gell-Mann-Nishijima relation $Q = I_3 + \frac{1}{2}(A + S)$ where Q is the charge, I_3 is the 3rd component of isospin, A is the baryon number and S is the strangeness number.

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