PC1144

NATIONAL UNIVERSITY OF SINGAPORE

PC1144 PHYSICS IV

(Semester 2: April 2007)

Time Allowed: 2 Hours

INSTRUCTIONS TO CANDIDATES

1. This examination paper contains **8 questions** and comprises 7 printed pages.
2. Answer **all five** questions in Part I and any **two out of three** questions in Part II.
3. This is a CLOSED BOOK examination.
4. The total mark for Part I is 40 and that for Part II is 60.

PC1144 — PHYSICS 4
PART I

This part of the examination paper contains **five** (5) short-answer questions (page 2 – page 3). **Answer ALL questions.**

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1) A muon formed high up in the Earth's atmosphere is observed by a scientist to travel at a speed v = 0.9990 c for a distance of 4.60 km before it decays into an electron, a neutrino and an anti-neutrino.

   (a) How long does the muon live, as measured in the muon's reference frame?

   (b) How far does the muon travel as measured in its own frame?

2) Cosmic ray protons can have energies of 10^{13} MeV.

   (a) How long would it take a proton of this energy to cross the Milky Way galaxy if the galaxy is 10^6 light years across? [1 light year is the distance traveled by light in one year]. Express your answer in the frame of the proton.

   (b) From the point of view of the proton, what is the size of the Milky Way?

3) Find the probability that a particle trapped in a box of infinite sides and width L will be found between 0.45L and 0.55L. Assume the particle is in its ground state. Is this greater or less than the classical value? Explain your answer.

   Hints:

   (i) The allowed wavefunctions of a particle in a box are given by:

   $\psi(x) = \sqrt{(2/L)}\ \sin(n\pi x/L)$

   (ii) $\sin^2(x) = ½\,[1-\cos(2x)]$

4) (a) A particle with kinetic energy E travelling from left to right impinges on a rectangular potential barrier U where $E < U$. Sketch the wavefunctions before, inside, and after the barrier, and state the boundary conditions required for a full solution.

(b) Sketch the wavefunctions for the case where $E > U$. Explain your reasoning.

5) Use the table on page 4 together with relevant conservation laws to determine the missing particles: Assume that the Ω^- and K^+ decay using the weak interaction. Explain your reasoning.

(a) $\Omega^- \rightarrow ?? + \pi^-$

(b) $K^+ \rightarrow ?? + \mu^+ + \upsilon_\mu$

Table of Particle properties:

Category	Particle Name	Symbol	Anti-particle	Rest Mass (MeV/c^2)	B	L_e	L_μ	L_τ	S	Lifetime (s)
Photon	Photon	γ	Self	0	0	0	0	0	0	Stable
Leptons	Electron	e^-	e^+	0.511	0	+1	0	0	0	Stable
	Neutrino (e)	ν_e	$\bar{\nu}_e$	0(?)	0	+1	0	0	0	Stable
	Muon	μ^-	μ^+	105.7	0	0	+1	0	0	2.20×10^{-6}
	Neutrino (μ)	ν_μ	$\bar{\nu}_\mu$	0(?)	0	0	+1	0	0	Stable
	Tau	τ^-	τ^+	1784	0	0	0	−1	0	$<4 \times 10^{-13}$
	Neutrino (τ)	ν_τ	$\bar{\nu}_\tau$	0(?)	0	0	0	−1	0	Stable
Hadrons Mesons	Pion	π^+	π^-	139.6	0	0	0	0	0	2.60×10^{-8}
		π^0	Self	135.0	0	0	0	0	0	0.83×10^{-16}
	Kaon	K^+	K^-	493.7	0	0	0	0	+1	1.24×10^{-8}
		K^0_S	$\overline{K^0_S}$	497.7	0	0	0	0	+1	0.89×10^{-10}
		K^0_L	$\overline{K^0_L}$	497.7	0	0	0	0	+1	5.2×10^{-8}
	Eta	η^0	Self	548.8	0	0	0	0	0	$<10^{-18}$
Baryons	Proton	p	$\bar{p}$	938.3	+1	0	0	0	0	Stable
	Neutron	n	$\bar{n}$	939.6	+1	0	0	0	0	920
	Lambda	Λ^0	$\overline{\Lambda^0}$	1115.6	+1	0	0	0	−1	2.6×10^{-10}
	Sigma	Σ^+	$\overline{\Sigma}^-$	1189.4	+1	0	0	0	−1	0.80×10^{-10}
		Σ^0	$\overline{\Sigma}^0$	1192.5	+1	0	0	0	−1	6×10^{-20}
		Σ^-	$\overline{\Sigma}^+$	1197.3	+1	0	0	0	−1	1.5×10^{-10}
	Xi	Ξ^0	$\overline{\Xi^0}$	1315	+1	0	0	0	−2	2.9×10^{-10}
		Ξ^-	Ξ^+	1321	+1	0	0	0	−2	1.64×10^{-10}
	Omega	Ω^-	Ω^+	1672	+1	0	0	0	−3	0.82×10^{-10}

PART II

This part of the examination paper contains THREE (3) long-answer questions from page 5 to 7. **Answer any <u>TWO</u> questions.**

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6 a) Consider an experiment where light of wavelength λ is shone on to a metal surface in a vacuum chamber and photoelectrons with a maximum energy E are emitted. Explain the following using the photon theory of light, and describe briefly why classical arguments do not work:

(i) No electrons are emitted if the wavelength of the incident light is increased above some cut-off wavelength λ_c .

(ii) If the light intensity is increased, the maximum kinetic energy of the photoelectrons remains the same.

(iii) The maximum kinetic energy E of the photoelectrons decreases with increasing wavelength of the incident light.

(iv) Electrons are emitted from the surface almost instantaneously ($< 10^{-9}$ secs) independent of the light intensity.

b) The longest wavelength of light that will cause the emission of electrons from caesium is 653nm.

(i) What is the work function for caesium in eV ?

(ii) If ultraviolet light of wavelength 200nm were to shine on caesium, what would be the energy of the ejected electrons in eV ?

c) X-ray radiation of wavelength 0.200 nm is shone onto a thin flat caesium surface. Detectors are placed at a backward angle of 45^{0} to the incoming radiation. These detectors not only detect energetic photoelectrons, but also detect X-rays which appear to have 2 different energies. What are the wavelengths of these X-rays? Explain your results.

7) a) In the Bohr model of the hydrogen atom, an electron is orbiting around a proton such that its angular momentum $mvr = nh/2\pi$ (where n is an integer 1,2,3.....) and its kinetic energy $KE = k_e e^2/2r$.

(i) Show that the radius of a Bohr orbit is given as $r_n = n^2h^2 / [(2\pi)^2 m k_e e^2]$

(ii) If E (the total energy of the atom = kinetic energy + potential energy) is given by $E = - k_e e^2/2r$, and the Bohr radius $a_0 = h^2 / [(2\pi)^2 m k_e e^2]$, then show that the energy of the electron in the hydrogen atom is given by $E_n = -[1/n^2] k_e e^2/2a_0$

(iii) Calculate the ionisation energy for the hydrogen atom in eV.

[k_e is the Coulomb constant = $8.988 \times 10^9 Nm^2/C^2$]

b) Hydrogen gas is put in a glass tube at low pressure, a potential difference is applied between the ends, and an electric current is passed through the gas. The radiation emitted is analysed by a diffraction grating spectrometer and the wavelengths of the emitted spectral lines are 656.3 nm (red), 486.1 nm (green), 434.1 nm (blue), and 410.2 nm (violet).

(i) Using an energy level diagram, show the origins of these spectral lines.

(ii) A further line is discovered at 122 nm. Calculate the energy of this line, and determine its origin.

(iii) The potential difference across the glass tube is gradually reduced. Although the 122 nm line remains, the red, green, blue and violet lines begin to disappear. Why?

8) a) The ***fission*** process is utilized in a nuclear reactor: Describe ***briefly*** the role of the following in the process:

(i) Binding energy.

(ii) Chain reaction.

(iii) The reproduction constant.

(iv) Moderator.

(v) Control rods.

continued....

b) A ^{235}U nucleus at rest absorbs a low energy neutron. (i) What is the internal excitation energy of the $^{236}U^*$ nucleus that is produced? Give your answer in MeV. (ii) State briefly why your answer is relevant to the fission process.

[The atomic masses of the neutral atoms in their ground states are 235.043923u for ^{235}U, 236.045562u for ^{236}U, and 1.008665u for the neutron].

c) The basic energy producing process in the sun is a multi-step process involving the fusion of hydrogen nuclei into helium nuclei, as follows:

$$^{1}H + {}^{1}H \rightarrow {}^{2}H + e^{+} + \upsilon$$
$$^{1}H + {}^{2}H \rightarrow {}^{3}He + \gamma$$
$$^{3}He + {}^{3}He \rightarrow {}^{4}He + {}^{1}H + {}^{1}H$$

(i) What is the ***total*** energy released in these combined processes? Express your answer in MeV. (ii) How does this compare to the energy released in the fission process? Explain your result.

Hints:

(a) There is no need to calculate each process step individually.

(b) The mass of the proton is 938.3 MeV, the mass of the alpha particle is 3727.4 MeV, and the mass of the electron is 0.511 MeV.

END OF PAPER: FW