UNIVERSITY OF BIRMINGHAM

School of Physics and Astronomy

DEGREE OF BSc & MSci WITH HONOURS

SECOND YEAR EXAMINATION

03 26017

LI PARTICLES AND NUCLEI

AFFILIATE EXAMINATIONS 2013

Total Time Allowed: 45 minutes

Answer Section 1 and one question from Section 2

Section 1 counts for 40% of the marks for the examination.
Full marks for this Section may be obtained by correctly answering **two** questions.
You may attempt more questions, but any marks in excess of 40% will be disregarded.

Section 2 consists of two questions and carries 60% of the marks for the examination.
You should answer **one** question from this section. If you answer more than one question from this section only the best mark will be counted.

The approximate allocation of marks to each part of a question is shown in [ ].

All symbols have their usual meaning.

Calculators may be used in this examination but must not be used to store text.
Calculators with the ability to store text should have their memories deleted prior to the start of the examination.

Tables of physical constants and units that may be required will be found at the end of this question paper.

SECTION 1

Full marks may be obtained by correctly answering two questions.
You may attempt as many questions as you wish, but any marks in excess of 20 will be disregarded.

1. Which of the following reactions are allowed by conservation laws (all are allowed by energy conservation)?

   For each reaction explain which force is primarily responsible.

   Explain your answers for each reaction.

   (a) $W^+ \rightarrow \mu^+ \nu_\mu$

   (b) $p\bar{p} \rightarrow \bar{p}\pi^+\pi^0$

   (c) $B^{*-} \rightarrow B^-\gamma$ (quark content of B^{*-} is $b\bar{u}$, B^- is $b\bar{u}$)

   (d) $p \rightarrow n\ e^-\bar{\nu}_e$ **[10]**

2. Explain the meanings of the terms *lepton*, *quark*, *baryon* and *meson*, giving an example of each. **[10]**

3. An $\Upsilon(5S)$ particle at rest decays to two charged *B* mesons, B^+B^-. Calculate the momentum of the B^+ meson and hence its mean decay length in the rest frame of the Υ.

   (The $\Upsilon(5S)$ has a mass of 10.865 GeV/c^2, the $B^\pm$ mass is 5.279 GeV/c^2, and the mean lifetime of the $B^\pm$ in its own rest frame is 1.64ps). **[10]**

SECTION 2

You should attempt one question from this Section. If you answer more than one question, only the best mark will be counted.

4. (a) Explain why the neutron to proton ratio increases with mass for naturally occurring isotopes. **[5]**

(b) Calculate the density of nuclear matter in kgm^{-3} given that the nuclear radius, r, is given by $r = 1.41\, A^{1/3}$ fm. **[4]**

The ground state of ${}^{24}_{14}\mathrm{Si}$ undergoes radioactive decay to ${}^{24}_{13}\mathrm{Al}$ via two processes.

(a) One of the decay processes is electron capture. State what the other process is, and for each process write down the decay particles emitted. Draw Feynman diagrams for the two decays. **[6]**

(b) The atomic mass of ${}^{24}_{14}\mathrm{Si}$ is 24.0115 atomic mass units (amu) and that of ${}^{24}_{13}\mathrm{Al}$ is 23.99994 amu. Calculate the Q-values of the two decay modes. **[6]**

(c) The universal decay law can be written as

$$N(t) = N_0 e^{-t/\tau}.$$

Derive an expression for the half-life in terms of τ. State whether the half-life will be longer or shorter than the mean life and justify your answer. **[6]**

(d) Calculate the percentage of ${}^{24}_{14}\mathrm{Si}$ which will have decayed after 6.4 half-lives. **[3]**

5. The Ω^- baryon has a mass of 1672 MeV/c^2, a strangeness of -3, a spin J = 3/2, and the quarks that compose it are in states of zero relative orbital angular momentum (L = 0).

(a) Explain why the existence of this particle requires the introduction of a new quark property in addition to the flavour. **[7]**

(b) Briefly describe and explain an independent piece of experimental evidence which supports the introduction of this property. **[6]**

Ω^- baryons are produced via the interaction

$$K^- p \rightarrow \Omega^- K^0 K^+ ,$$

where a K^- collides with a stationary proton.

(c) Calculate the threshold K^- energy for which the Ω^- can be produced. **[12]**

(d) Which force is responsible for this reaction? Justify your answer. **[5]**

Physical Constants and Units

Acceleration due to gravity	g	9.81 m s^{-2}
Gravitational constant	G	6.673×10^{-11} N m^{2} kg^{-2}
Avogadro constant	N_A	6.022×10^{23} mol^{-1}
		Note: 1 mole = 1 *gram* molecular-weight
Ice point	T_{ice}	273.15 K
Gas constant	R	8.314 J K^{-1} mol^{-1}
Boltzmann constant	k, k_B	1.381×10^{-23} J K^{-1} = 0.862×10^{-4} eV K^{-1}
Stefan constant	σ	5.670×10^{-8} W m^{-2} K^{-4}
Rydberg constant	R_∞	1.097×10^{7} m^{-1}
	$R_\infty hc$	13.606 eV
Planck constant	h	6.626×10^{-34} J s = 4.136×10^{-15} eV s
$h/2\pi$	$\hbar$	1.055×10^{-34} J s = 6.582×10^{-16} eV s
Speed of light *in vacuo*	c	2.998×10^{8} m s^{-1}
	$\hbar c$	197.3 MeV fm
Charge of proton	e	1.602×10^{-19} C
Mass of electron	m_e	9.109×10^{-31} kg
Rest energy of electron		0.511 MeV
Mass of proton	m_p	1.673×10^{-27} kg
Rest energy of proton		938.3 MeV
One atomic mass unit	u	1.66×10^{-27} kg
Atomic mass unit energy equivalent		931.5 MeV
Electric constant	ε_0	8.854×10^{-12} F m^{-1}
Magnetic constant	μ_0	$4\pi \times 10^{-7}$ H m^{-1}
Bohr magneton	μ_B	9.274×10^{-24} A m^{2} (J T^{-1})
Nuclear magneton	μ_N	5.051×10^{-27} A m^{2} (J T^{-1})
Fine-structure constant	$\alpha = e^2/4\pi\varepsilon_0\hbar c$	7.297×10^{-3} = 1/137.0
Compton wavelength of electron	$\lambda_c = h/mc$	2.426×10^{-12} m
Bohr radius	a_o	5.2918×10^{-11} m
angstrom	Å	10^{-10} m
torr (mm Hg, 0°C)	torr	133.32 Pa (N m^{-2})
barn	b	10^{-28} m^{2}