THE UNIVERSITY OF NEW SOUTH WALES

SCHOOL OF PHYSICS

PHYS3050 NUCLEAR PHYSICS

EXAMINATION – SEPTEMBER, 2006

PAPER 1 – MID-SESSION

Time allowed = 50 minutes

Total number of questions = 4

Total number of marks = 40

Answer ALL questions

The questions are of equal value

Portable battery powered electronic calculators (without alphabetic keyboards) may be used.

The paper may be retained by the candidate

General Data:

1 unified mass unit (u) = 931.5 MeV/c^2

Planck's constant h = 6.63×10^{-34} Js

Boltzmann's constant k = 1.38×10^{-23} JK^{-1}

Avogadro's number = 6.022×10^{23} $(g\text{-mole})^{-1}$

Permittivity constant $\varepsilon_o = 8.85 \times 10^{-12}$ Fm^{-1}

Fundamental charge unit e = 1.60×10^{-19} C

speed of light (vacuum) c = 3.0×10^8 m/s

electron mass = 9.11×10^{-31} kg = 5.4858×10^{-4} u = 0.511 MeV/c^2

neutron mass = 1.6749×10^{-27} kg = 1.008665 u = 939.573 MeV/c^2

proton mass = 1.6726×10^{-27} kg = 1.0072765 u = 938.280 MeV/c^2

1 year = 3.156×10^7 s

Question 1 [10 marks]

Radionuclides are useful sources of small amounts of energy in space vehicles, remote communication stations, heart pacemakers etc. Calculate the power available in Watts from a gram of ^{210}Po, an α-emitter with an energy of 5.30 MeV and a half-life of 138 days. [Atomic mass of $^{210}_{84}Po$ = 209.982848 u].

Question 2 [10 marks]

The lowest energy levels in the Shell Model, in order of increasing energy, are

$$1s_{1/2}, 1p_{3/2}, 1p_{1/2}\ 1d_{5/2}\ 2s_{1/2}\ 1d_{3/2}\ 1f_{j} \cdots .$$

(i) What are the possible values of j for the 1f levels.

(ii) What is the value of j for the lowest 1f level ? Justify your answer !

(iii) Determine the spin and parity of the ground states of both the $^{40}_{20}Ca$ and $^{41}_{20}Ca$ nuclides.

(iv) In the Shell model, a 'spin-orbit' interaction splits all energy levels except the 's-type' levels. Why do the s-type levels remain unsplit ?

Question 3 [10 marks]

In stars slightly more massive than the Sun, hydrogen burning is carried out mainly by the CNO cycle, whose first step is $p+^{12}_{6}C \rightarrow ^{13}_{7}N + \gamma$. Estimate the energy of the gamma (in MeV), assuming the two initial nuclei are essentially at rest. Justify any simplifying assumptions you make. [Atomic masses: $^{1}_{1}H$ = 1.007825, $^{12}_{6}C$ = 12.000000, $^{13}_{7}N$ = 13.005739 u].

Question 4 [10 marks]

(a) Describe **briefly** the 'origin' of the various terms in the Semi-Empirical Mass Formula. [NB: detailed mathematical expressions and values of constants are not required].

(b) Suggest a simple reason why the $^{12}_{6}C$ nuclide has a higher binding energy (i.e. more stable) than $^{12}_{7}N$, even though they are isobars (i.e. same number of nucleons, A) ?

Mid-Session 06

1/ 1g ^{210}Po $t_{1/2} = 138d$

$E_\alpha = 5.3$ MeV

no' nuclei $= \frac{\text{Avogadro}}{210}$

$= 2.87 \times 10^{21}$

$\lambda = \frac{\ln 2}{t_{1/2}} = \frac{0.693}{138 \times 24 \times 3600} = 5.81 \times 10^{-8}\ s^{-1}$

Activity $= \lambda N = 1.67 \times 10^{14}$ Bq

Power $= \frac{\text{Energy}}{\text{second}} = 1.67 \times 10^{14} \times 5.3 \times 10^{6} \times 1.6 \times 10^{-19}$

$= 141$ W

2/ $1f_j$ a) $l = 3$ (it's an 'f')

$\therefore j = l \pm \frac{1}{2} = 5/2$ or $7/2$

b/ $1f_{5/2}$ and $1f_{7/2}$ have different energies due to spin-orbit effect

$$\propto \underline{l} \cdot \underline{s}$$

You don't know the sign of the constant of proportionality, a priori, but you can get it from the given level scheme

$1p_{3/2}$ is lower energy than $1p_{1/2}$

$1d_{5/2}$ " " " $1d_{3/2}$

$\therefore$ $1f_{7/2}$ is lower than $1f_{5/2}$

c/ $^{40}_{20}Ca$ - even Z, even N

∴ all nucleons are paired

$\therefore \underline{I}^{\pi} = 0^{+}$

2c/ $^{41}_{20}Ca$, I^{π} determined by the unpaired n (#21)

Fill the levels (n) $\quad$ 2j+1 - degenerate

$1s_{1/2} = 2$

$1p_{3/2} = 4$

$1p_{1/2} = 2$

$1d_{5/2} = 6$

$2s_{1/2} = 2$

$1d_{3/2} = 4$

$\overline{20}$ $\therefore$ 21st n is in $1f_{7/2}$

$\therefore$ spin $I = 7/2$

parity $= (-1)^{\ell} = (-1)^{3} = -$

$\therefore$ $^{41}_{20}Ca$ is $\frac{7}{2}^{-}$

d/ 's' levels have $l=0$ i.e. no orbital a.m. $\therefore$ no spin-orbit effect.

(4)

3/ $p + {}^{12}_{6}C \rightarrow {}^{13}_{7}N + \gamma$

can use atomic masses since no 'e⁻' cancels

$$Q = (M_i - M_f)c^2$$

$$= (1.007825 + 12.000000 - 13.005739)u . c^2$$

$$= 0.002086 \ u \ . c^2$$

$$= 0.002086 \times 931.5 = 1.943 \ MeV$$

4/ a. SEMF terms.

Volume $\propto A$
Surface $\propto -A^{2/3}$
Coulomb $\propto -Z^2/A^{1/3}$
Symmetry
Pairing

b. ${}^{12}_{7}N$ has 7p cf ${}^{12}_{6}C$ which has 6. ∴ greater Coulomb repulsion in ${}^{12}_{7}N$.