THE UNIVERSITY OF NEW SOUTH WALES

SCHOOL OF PHYSICS

FINAL EXAMINATION

OCTOBER/NOVEMBER 2009

PHYS3050

Nuclear Physics

Time Allowed – 2 hours

Total number of questions - 4

Answer ALL questions

All questions ARE of equal value

This paper may be retained by the candidate.

Candidates must supply their own, university approved, calculator

Answers must be written in ink. Except where they are expressly required, pencils may only be used for drawing, sketching or graphical work

Periodic Group Numbers

The Periodic Table

1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
1 **H** 1.008																	2 **He** 4.003
3 **Li** 6.941	4 **Be** 9.012											5 **B** 10.81	6 **C** 12.01	7 **N** 14.01	8 **O** 16.00	9 **F** 19.00	10 **Ne** 20.18
11 **Na** 22.99	12 **Mg** 24.31											13 **Al** 26.98	14 **Si** 28.09	15 **P** 30.97	16 **S** 32.07	17 **Cl** 35.45	18 **Ar** 39.95
19 **K** 39.10	20 **Ca** 40.08	21 **Sc** 44.96	22 **Ti** 47.88	23 **V** 50.94	24 **Cr** 52.00	25 **Mn** 54.94	26 **Fe** 55.85	27 **Co** 58.93	28 **Ni** 58.69	29 **Cu** 63.55	30 **Zn** 65.39	31 **Ga** 69.72	32 **Ge** 72.59	33 **As** 74.92	34 **Se** 78.96	35 **Br** 79.90	36 **Kr** 83.80
37 **Rb** 85.47	38 **Sr** 87.62	39 **Y** 88.91	40 **Zr** 91.22	41 **Nb** 92.91	42 **Mo** 95.94	43 ^{99}**Tc** (98.91)	44 **Ru** 101.1	45 **Rh** 102.9	46 **Pd** 106.4	47 **Ag** 107.9	48 **Cd** 112.4	49 **In** 114.8	50 **Sn** 118.7	51 **Sb** 121.8	52 **Te** 127.6	53 **I** 126.9	54 **Xe** 131.3
55 **Cs** 132.9	56 **Ba** 137.3	57 **La** 138.9	72 **Hf** 178.5	73 **Ta** 180.9	74 **W** 183.9	75 **Re** 186.2	76 **Os** 190.2	77 **Ir** 192.2	78 **Pt** 195.1	79 **Au** 197.0	80 **Hg** 200.6	81 **Tl** 204.4	82 **Pb** 207.2	83 **Bi** 209.0	84 ^{210}**Po** (210.0)	85 ^{210}**At** (210.0)	86 ^{222}**Rn** (222.0)
87 ^{223}**Fr** (223.0)	88 ^{226}**Ra** (226.0)	89 ^{227}**Ac** (227.0)															

58 **Ce** 140.1	59 **Pr** 140.9	60 **Nd** 144.2	61 ^{145}**Pm** (144.9)	62 **Sm** 150.4	63 **Eu** 152.0	64 **Gd** 157.3	65 **Tb** 158.9	66 **Dy** 162.5	67 **Ho** 164.9	68 **Er** 167.3	69 **Tm** 168.9	70 **Yb** 173.0	71 **Lu** 175.0
90 **Th** 232.0	91 ^{231}**Pa** (231.0)	92 **U** 238.0	93 ^{237}**Np** (237.0)	94 ^{239}**Pu** (239.1)	95 ^{243}**Am** (243.1)	96 ^{247}**Cm** (247.1)	97 ^{247}**Bk** (247.1)	98 ^{252}**Cf** (252.1)	99 ^{252}**Es** (252.1)	100 ^{257}**Fm** (257.1)	101 ^{256}**Md** (256.1)	102 ^{259}**No** (259.1)	103 ^{260}**Lr** (260.1)

KEY

Atomic N° →	6
Symbol →	**C**
Atomic Weight →	12.01

( ) is the relative atomic mass of the most common radioactive isotope, the mass number of which is given as a superscript.

Final exam, 2009
Nuclear physics 3050

All questions are of equal value

Question 1

In heavy nuclei the number of neutrons is $N \approx 0.6A$ and the number of protons is $Z \approx 0.4A$. The nuclear radius is $R = r_0 A^{1/3}$, where $r_0 \approx 1.1 fm = 1.1\ 10^{-13} cm$. Consider protons and neutrons in the ideal Fermi gas approximation.

a. (5 marks) Calculate values of the Fermi momentum p_F for protons and for neutrons. Use natural units ($\hbar = c = 1$) and present your answers in MeV. Remember that in these units $1fm \approx 1/197MeV$. The rest energy of nucleon is $m_p \approx m_n \approx 940$MeV.

b. (5 marks) Calculate values of the Fermi energy ϵ_F and of the average kinetic energy E_{kin} for protons and for neutrons. Present your results in MeV.

Compare the values of the Fermi energies with typical depth of the nuclear selfconsistent potential.

Question 2

Five lowest energy levels of ${}^{18}_{9}$F are shown below. The quantum numbers J^P are indicated in the left hand side and values of the energies in MeV with respect to the ground state are shown in the right hand side.

5^+	1.121
0^-	1.080
0^+	1.042
3^+	0.937
1^+	0.

a. (5 marks) Using selection rules for electromagnetic transitions show all the decay channels which go via (i) E1-transition, (ii) M1-transition, (iii) E2-transition.

In natural units ($\hbar = c = 1$) the decay probabilities for E1 and M1 transitions are given by

$$W_{E1} = \frac{4}{3}\omega^3 |d_{fi}|^2 \, , \qquad W_{M1} = \frac{4}{3}\omega^3 |\mu_{fi}|^2 \, .$$

b. (5 marks) Using these Eqs. estimate lifetimes of 0^- and 0^+ states. For the estimate you can use the following typical values of the transition amplitudes: $d_{fi} \sim 0.1e \times fm$, $\mu_{fi} \sim \mu_N = \frac{e}{2m_p}$. Remember that in natural units $e^2 \approx \frac{1}{137}$. Convert the lifetimes into seconds using $\hbar = 6.582 \times 10^{-22} MeV \cdot sec$.

Question 3

a. (4 marks) For the following β-decays state whether the decay is of the Fermi type, Gamow-Teller type, both mechanisms contribute, or the decay is forbidden. Give the reasons.

$$\mathrm{n} \rightarrow \mathrm{p}$$

$$^{111}_{51}\mathrm{Sb}(5/2^+) \rightarrow ^{111}_{50}\mathrm{Sn}(7/2^+)$$

$$^{3}_{1}\mathrm{H}(1/2^+) \rightarrow ^{3}_{2}\mathrm{He}(1/2^+)$$

$$^{171}_{68}\mathrm{Er}(5/2^-) \rightarrow ^{171}_{69}\mathrm{Tm}(1/2^+)$$

$$^{235}_{94}\mathrm{Pu}(5/2^+) \rightarrow ^{235}_{93}\mathrm{Np}(5/2^+)$$

b. (3 marks) Supply the missing component(s) in the following processes

$$\bar{\nu} +^3 He \rightarrow$$
$$e^- +^8 B \rightarrow$$
$$^{40}K + e^- \rightarrow$$
$$^{40}K \rightarrow \bar{\nu} +$$
$$^6He \rightarrow^6 Li + e^- +$$
$$\nu +^{12} C \rightarrow$$

c. (3 marks) Calculate the minimum photon energy necessary to dissociate the deuteron, i.e. $\gamma + d \rightarrow p + n$. The deuteron is in rest and you must account for the recoil effect. The deuteron binding energy is 2.2246MeV, the proton rest energy is 938.2720MeV, the neutron rest energy is 939.5654MeV.

Question 4

a. (4 marks) Give the quark content of the following particles: p, Δ^{++}, Δ^-, π^0, Λ, Ω^-, D^+, D_s^-.

Quantum numbers of these particles are presented in the table. (Q is electric charge, B is barion number, T is isospin, S is strangeness, and C is charm)

particle	Q	B	T	S	C
p	1	1	1/2	0	0
Δ^{++}	2	1	3/2	0	0
Δ^-	−1	1	3/2	0	0
π^0	0	0	1	0	0
Λ	0	1	0	−1	0
Ω^-	−1	1	0	−3	0
D^+	1	0	1/2	0	1
D_s^-	−1	0	1/2	−1	−1

b. (3 marks) Using Δ^{++} and Δ^- as examples, explain why an extra quantum number, colour, is necessary.

c. (3 marks) State whether the following reactions proceed via strong, electromagnetic, or weak interactions, or are forbidden. Present corresponding Feynman diagrams for these reactions at the quark-lepton level (with intermediate particles g, γ, W, Z)

$$e^+ + e^- \to J/\psi \to \pi^+ + \pi^-$$
$$e^+ + e^- \to Y \to \tau^+ + \tau^-$$
$$\mathrm{n} + \nu_e \to \mathrm{p} + \mathrm{e}^-$$
$$\tau^- \to e^- + \gamma$$
$$\mu^- \to e^- + \bar{\nu}_e + \nu_\mu$$
$$K^+ \to \pi^+ + \pi^0$$
$$\eta \to \gamma + \gamma$$
$$\eta \to \nu_e + \gamma$$
$$\rho^0 \to \pi^+ + \pi^-$$
$$\pi^- \to e^- + \gamma$$
$$\pi^- \to \mu^- + \bar{\nu}_\mu$$
$$\pi^0 \to 2\gamma$$
$$\Lambda \to \mathrm{p} + \pi^-$$
$$\Sigma^+ \to p + \pi^0$$
$$Z \to e^+ + e^-$$
$$Z \to \nu_\mu + \bar{\nu}_\mu$$
$$J/\psi \to \mu^+ + \mu^-$$
$$W^+ \to e^+ + \nu_e$$