THE UNIVERSITY OF NEW SOUTH WALES

SCHOOL OF PHYSICS

FINAL EXAMINATION

OCTOBER/NOVEMBER 2008

PHYS3050

Nuclear Physics

Time Allowed – 2 hours

Total number of questions - 4

Answer ALL questions

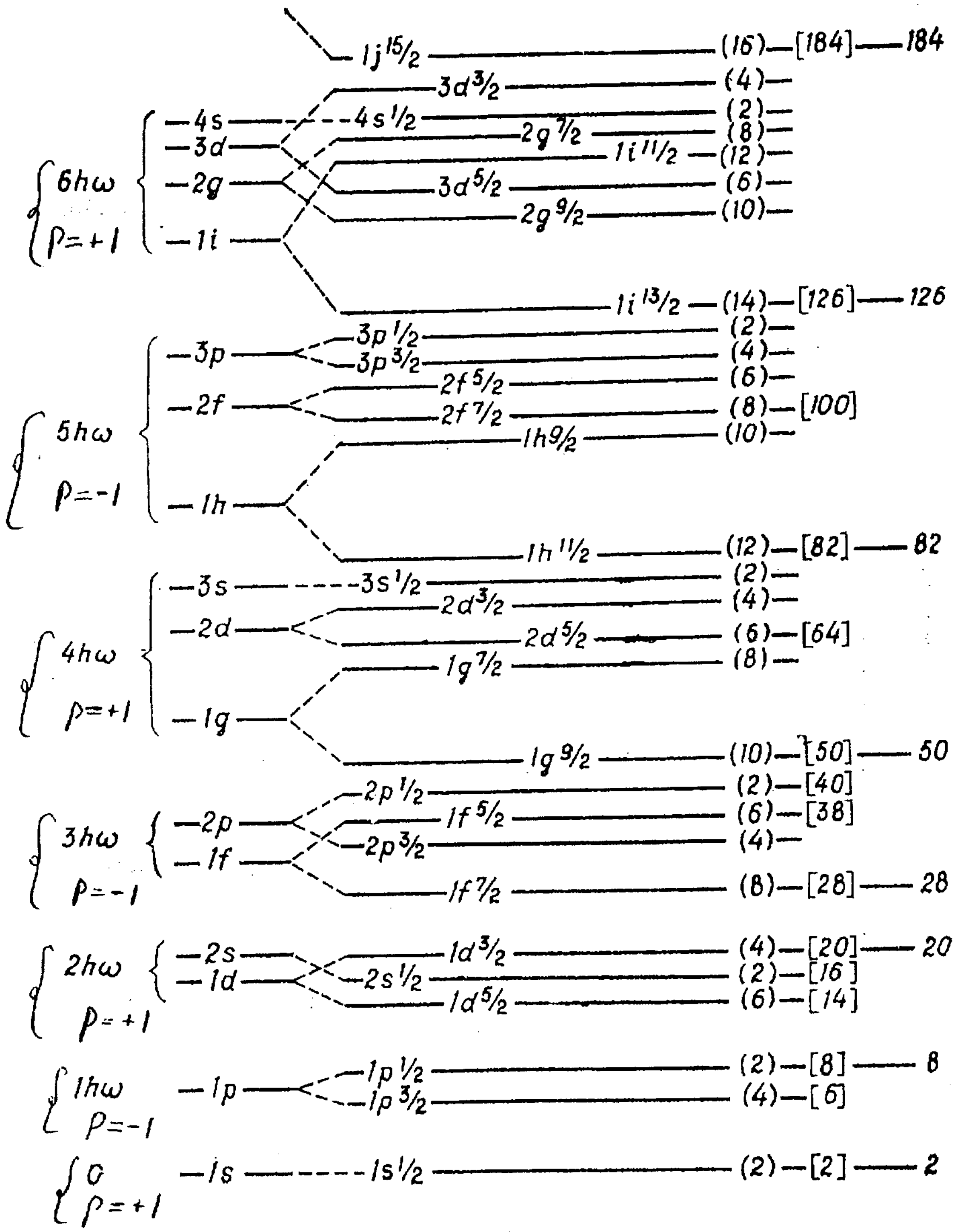
All questions ARE of equal value

Candidates may not bring their own calculators.

The following materials will be provided by the Enrolment and Assesment Section: Calculators.

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

p3



Single particle energy levels in spherical nuclei

Final exam, 2008
Nuclear physics 3050

All questions are of equal value

Question 1

a. (4 marks) Formulate the principle of generalized Fermi statistics for two nucleons. What is the relation which the principle imposes between the total spin S, relative angular momentum l, and total isospin T?

Low energy (s-wave) strong nucleon-nucleon interaction can be approximated by the following formula

$$V(r) = \theta(R-r)\left\{-V_1 + V_t(\mathbf{T_1}\cdot\mathbf{T_2}) + \left[G + G_t(\mathbf{T_1}\cdot\mathbf{T_2})\right](\mathbf{S_1}\cdot\mathbf{S_2})\right\},$$

where r is distance between the nucleons, $\mathbf{S_i}$ and $\mathbf{T_i}$ are spin and isospin operators of the nucleons, V_1, V_t, G, and G_t are the interaction constants, and finally $\theta(x)$ is the step function

$$\theta(x) = \begin{cases} 1, & for\ x > 0 \\ 0, & for\ x < 0 \end{cases}. \tag{1}$$

b. (3 marks) Express nn, and pp interactions in terms of the constants V_1, V_t, G, and G_t.
c. (3 marks) Do the same for the np interaction in the singlet (S=0) and in the triplet (S=1) channels.

Question 2

a. (6 marks) Starting from the operator of the magnetic moment $\mu = \mu_N(g_l\mathbf{l} + g_s\mathbf{s})$, derive the shell model formulas for the magnetic moment of an even-odd nucleus

$$\mu = \mu_N\left[g_l\left(j-\tfrac{1}{2}\right) + \tfrac{1}{2}g_s\right] \quad \text{if } j = l + \tfrac{1}{2}$$
$$\mu = \mu_N\left[g_l\frac{j(j+3/2)}{j+1} - \frac{1}{2}\frac{j}{j+1}g_s\right] \quad \text{if } j = l - \tfrac{1}{2},$$

where $\mathbf{j} = \mathbf{l} + \mathbf{s}$ is the angular momentum of the external nucleon. The parameters are $g_l = 1$, $g_s \approx 5.6 \times 0.6$ for proton and $g_l = 0$, $g_s \approx -3.8 \times 0.6$ for neutron.

b. (3 marks) Ground state of $^{65}_{29}$Cu has the following quantum numbers $J^P = 3/2^-$. Using the enclosed shell model level scheme determine the ground state configuration of the nucleus.

c. (1 mark) Calculate the shell model prediction for the $^{65}_{29}$Cu magnetic moment and compare it with the experimental value $\mu = 2.38167\mu_N$.

Question 3

a. (5 marks) The five lowest energy levels of $^{14}_{7}$N 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.

2^-	5.1059
0^-	4.915
1^+	3.9478
0^+	2.3129
1^+	0.

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

b. (5 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 $^{210}_{84}$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.] Remember that 1 unified mass unit (u) = $1.66\ 10^{-27} kg$, and that 1eV = $1.60\ 10^{-19} J$.

Question 4

a. (4 marks) Give the quark content of the following particles: p, n, π^0, Λ, Ω^-, J/ψ, D^+. 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
n	0	1	1/2	0	0
π^0	0	0	1	0	0
Λ	0	1	0	-1	0
Ω^-	-1	1	0	-3	0
J/ψ	0	0	0	0	0
D^+	1	0	1/2	0	1

b. (3 marks) Using Ω^- as an example, 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)

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