THE UNIVERSITY OF NEW SOUTH WALES
SCHOOL OF PHYSICS

PHYS3050/PHYS3031 – Nuclear Physics
Session 2, 2013

Midsession test

Duration: 50 minutes
University-approved calculators may be used.

Question 1 (15 marks)

(a) Using whatever units you like, find the approximate density of nuclear matter. Hence approximate the radius of a neutron star with mass $2M_\odot$ ($M_\odot \approx 2 \times 10^{30}$ kg). Express your answer in humanish units.

(b) Calculate the Coulomb energy density of a uniformly charged sphere with charge Q and radius R (Hint: in Gaussian units, the energy between two point charges is $E = q_1 q_2/r$). Hence estimate the electrostatic contribution to the proton mass (in MeV).

(c) The nuclear magneton is

$$\mu_N = \frac{e\hbar}{2m_N c} \qquad \text{(Gaussian units)}$$
$$= \frac{e\hbar}{2m_N} \qquad \text{(SI units)} \ .$$

Estimate the "Zeeman splitting" of the nuclear spectrum in a 5 Tesla field. What is the order of magnitude of the required frequency resolution, $\Delta\omega/\omega$, needed to observe this splitting in a spectral line with frequency $\hbar\omega = 1$ MeV? How does this compare to usual atomic Zeeman splitting, $\Delta\omega/\omega$, in the same field?

Question 2 (15 marks)

(a) Using the attached picture of single particle energy levels, find the shell model configuration for the ground state of $^{41}_{21}$Sc and $^{41}_{20}$Ca. What are the parities and spins of these nuclei?

(b) Calculate the magnetic moment of these nuclei using the formula

$$\mu = \begin{cases} \mu_N \left[g_l(j-1/2) + \frac{1}{2}g_s\right], & j = l + \frac{1}{2} \\ \mu_N \left[g_l \frac{j(j+3/2)}{j+1} - \frac{1}{2}\frac{j}{j+1}g_s\right], & j = l - \frac{1}{2} \end{cases}$$

where $g_l = 1$, $g_s = 5.6$ for a proton and $g_l = 0$, $g_s = -3.8$ for a neutron.

(c) The first two excited states of $^{41}_{20}$Ca have quantum numbers $J^P = 3/2^-$ and $3/2^+$. Find the shell model configurations for these states (they have energies of 1.943 MeV and 2.010 MeV, respectively).

(d) The spin-orbit partner of the $^{41}_{20}$Ca ground state has energy 2.577 MeV. By calculating the expectation value of the spin-orbit contribution to the Hamiltonian $H_{ls} = a\,(\boldsymbol{l} \cdot \boldsymbol{s})$ in the ground state and this excited state, find the value of the spin-orbit constant a for this spin-orbit pair.