# Part III Examples Class, Lent 2004
# Nuclear Physics Questions

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1. What properties of the interaction between two nucleons can be deduced from the following facts?

   - The deuteron has a small positive electric quadrupole moment.
   - There is no bound state of two neutrons.
   - Nuclear radii are given roughly by the formula; $R = 1.2A^{1/3}$ fm.

2. The mass of the lightest known strongly interacting meson (the pion) is about 140 MeV/c$^2$. Comment on the possible connection between this and the formula given above for the nuclear radius $R$.

3. Explain the term *pairing energy* and how it is taken into account in the semi-empirical mass formula.

4. The reaction cross-section near an s-wave( $\ell = 0$) nuclear resonance is given by the Breit-Wigner formula:

$$\sigma = g\pi(\lambda/2\pi)^2 \frac{\Gamma_i \Gamma_f}{[(E - E_0)^2 + \Gamma^2/4]}.$$

   Explain what each of the symbols mean and in what circumstances this is an appropriate formula to use. Obtain an expression for the $g$-factor in the case of neutrons incident on nuclei of spin 1. Show that, at a resonance peak and neglecting any background,

$$\pi\sigma^2 = \lambda^2 g \sigma_s$$

   where $\sigma$ and $\sigma_s$ are the total and elastic neutron scattering cross-sections, respectively.

5. What is the *single particle shell model* of the nucleus and how does it explain the observed stability associated with nuclei containing *magic* numbers of neutrons and/or protons ? Give two examples of properties that illustrate this stability.

   How can the single particle shell model be used to predict magnetic moments of nuclei ? Derive an expression for the nuclear $g$-factor.

   Determine the spins, parities and magnetic moments of the following nuclei: $^{41}_{20}$Ca, $^{15}_{7}$N, $^{11}_{5}$B, $^{25}_{12}$Mg, and compare them to the measured values. (Consult data tables for the measured values e.g. in Krane).

6. What occurs when a nucleus decays by beta decay or electron capture ? Why is it possible for $^{40}_{19}$K to exhibit $\beta^-$, $\beta^+$ and electron capture types of decay ?

7. State the selection rules governing the decay of excited nuclei by the emission of gamma rays.

   An experiment is performed in which $^4$He is bombarded with deuterons of various kinetic energies. Pure electric quadrupole gamma rays are detected when the deuterons have kinetic energy 1.08 MeV. When the kinetic energy is increased to 3.12 MeV, pure magnetic dipole radiation is observed. What can one infer about the excitation energies, spins and parities of the energy levels in the compound nucleus ?

| Nuclide | $^2$H | $^4$He | $^6$He | $^6$Li |
|---|---|---|---|---|
| Mass (amu) | 2.014102 | 4.002603 | 6.018893 | 6.015125 |