**Mid session test, 2002**
**Nuclear physics**

**Monday, September 23, 9 - 10 am.**
**All questions are of equal value**

Question 1

**(i)** Estimate the depth of the proton-neutron potential approximated by the spherical square well. It is known from experiment that the binding energy is close to zero (deuteron), nucleon mass $m \approx 940MeV$, and radius of the potential $R \approx 2fm$. ($fm \approx 1/197MeV$ in units $\hbar = c = 1$).

**(ii)** Compare your answer for (i) with the Coulomb interaction of two protons at the distance $2fm$ ($e^2 \approx 1/137$ in units $\hbar = c = 1$).

Question 2

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

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

where $\mathbf{j} = \mathbf{l} + \mathbf{s}$ is angular momentum of the external nucleon which coincides with the nuclear spin $I$. $g_l = 1$, $g_s \approx 5.6 \times 0.6$ for proton and $g_l = 0$, $g_s \approx -3.8 \times 0.6$ for neutron.

**(b).** **(i)** Using shell model energy levels presented in the picture, and results of part **(a)**, calculate the ground state spin $I$, parity and magnetic moment for ${}^{11}_{6}\mathrm{C}$, ${}^{12}_{6}\mathrm{C}$, and ${}^{13}_{6}\mathrm{C}$ nuclei.
**(ii)** Answer the same question but for the first excited state of ${}^{11}_{6}\mathrm{C}$.

$1d_{3/2}$ ——————————
$2s_{1/2}$ ——————————
$1d_{5/2}$ ——————————

$1p_{1/2}$ ——————————
$1p_{3/2}$ ——————————

$1s_{1/2}$ ——————————