M2 NPAC — From Nuclei to Stars

Phenomenological aspects : mid-term exam

November 15th 2019

1 Course-related questions

Question 1

(a) Explain what is a collapsed nuclear state.

(b) This state, for a given mass number A, has larger or smaller mass than the actual (real) A nucleus? Why?

(c) Give the major experimental pieces of evidence against the existence of the collapsed nuclear state.

Question 2

Consider a central two-body potential in which both Wigner and Majorana forces are present but no Heisenberg nor Bartlett forces, such as :

$$V_{ij} = V_W + V_M P^M_{i,j} \qquad (\text{for } r_{i,j} \leq b) \tag{1}$$

$$= 0 \qquad (\text{for } r_{i,j} > b) \tag{2}$$

(a) What is b in this definition?

(b) Is V_W a positive or a negative quantity? Same question for V_M.

(c) $P^M_{i,j}$ is an operator, what is its definition?

(d) Give an expression for the average potential energy of a nucleus of mass number A in a collapsed state as a function of A, V_W, V_M and the quantities n_+ and n_- introduced during the lectures. Explain your expression.

Question 3

Explain how we obtained the A dependence of the surface term of the Weiszaecker mass formula.

Question 4

We have seen in class that certain saturation properties have led physicists to imagine the notion of infinite nuclear matter. What would be the isospin of infinite nuclear matter? (explain)

Turn the page.

2 Nano problem

Question 5

(a) What is the Wigner super-multiplet?

(b) What terms in the central nucleon-nucleon potential lift the Wigner super-multiplet degeneracy?

(c) The experimental mass excess values for the $A = 14$ isobaric chain are:

Nucleus:	${}^{14}_{9}\mathrm{F}_5$	${}^{14}_{8}\mathrm{O}_6$	${}^{14}_{7}\mathrm{N}_7$	${}^{14}_{6}\mathrm{C}_8$	${}^{14}_{5}\mathrm{B}_9$	${}^{14}_{4}\mathrm{Be}_{10}$
$\Delta({}^{14}X)c^2$ [MeV]=	+31.960	+8.007	+2.863	+3.020	+23.664	+39.950

Calculate the charge energy difference between all isobars and ^{14}N (i. e. use ^{14}N as a reference point) using $M_n c^2 - M_p c^2 = 1.29$ MeV, the value of the fine structure constant $e^2/\hbar c = 1/137$ and $\hbar c = 197$ MeV$\cdot$fm and assuming that the charge of the nucleus (Ze) is homogeneously distributed in a sphere of radius $R = d \cdot A^{1/3}$ with $d = 1.23$ fm. Correct the experimental mass excess for charge effect for all isobars.

(d) Using some results you obtained in (c) previously propose an interpretation for the excited state of ^{14}N with $T = 1$ discovered experimentally at 2313 keV excitation energy.

(e) At what energy should the first excited state of ^{14}N with $T = 2$ be looked for? Would this state be bound (against proton or neutron emission)? (justify)

Question 6

Give the partition numbers for the six $A = 14$ isobars above (explain how you obtain them).