PHYSICS 722/822 - Fall Semester 2018 - ODU

Nuclear Physics - FINAL

This is a take-home Final - your solution is due back to me by 3:30 on Thursday, December 13 (either as hardcopy delivered to my office or as email with attachments). You may use any sources you can find (including our text books) but you must cite any sources used.

Problem 1)

Both the lambda baryon (Λ^{o}) and the neutral delta (Δ^{o}) decay into a nucleon and a pion. However, the lambda has a life time of about 0.26 ns, while the delta lives for less than 10^{-23} s. Can you explain this difference? (2-3 sentences)

Problem 2

Consider semi-exclusive electron scattering on a nucleus, A(e,e'p). If the residual nucleus (A-1) is left in its ground state, the energy transfer ν from the electron is uniquely determined by the momentum transfer **q** from the scattered electron and the momentum **p'** of the observed final state proton. Derive the corresponding equations, using relativistic kinematics for the proton throughout. What is the interpretation of p' in a Fermi-gas or shell model picture of the reaction (in the Impulse Approximation)?

SOLVE (ONLY!) ONE OF THE TWO FOLLOWING PROBLEMS:

Problem 3a)

In a certain experiment, a 1 mm thick target of Carbon-13 (density: 2 g/cm^3) is irradiated with a proton beam of 100 nA. Among other reactions, Nitrogen-13 is produced in the reaction ^{13}C(p,n)^{13}N. Assume the reaction cross section for this is 1 mb. ^{13}N decays via electron capture with a half life of 9.97 minutes.
a) Classify this transition (degree of allowed-ness, Gamov-Teller vs. Fermi).
b) After a long time (many hours) of continuous irradiation, an equilibrium is reached, where as many new ^{13}N nuclei are produced per unit time as decay in the same time interval. How many ^{13}N nuclei will be present in the target in this equilibrium state?

Problem 3b)

Consider the stripping reaction ${}^{12}_{6}C(d,p){}^{13}_{6}C$ with incident deuterons of 19.4 MeV kinetic energy. The stripped-off neutron gets put in the lowest possible shell model state (the ground state of ^{13}C); what would be its quantum numbers? How much energy (and momentum) would the proton (have to) carry away? (Assume it continues in the same direction as the deuteron was travelling). How much momentum would get transferred to the residual nucleus? Does this momentum transfer make sense, given the angular momentum that also must be transferred? You may use the fact that the radius of the ^{12}C nucleus is about 2.75 fm.

FOR THE FOLLOWING 2 PROBLEMS, READ THE ARTICLE BY HANS BETHE (posted on our web page).

Problem 4)

In Bethe's article, Eq. (1) shows the well-known relationship between nuclear radius R and baryon number A. Describe a typical electron scattering experiment and what information one extracts from it to arrive at the size of a given nucleus. As an example, what is the expected magnitude of the derivative $dF(Q^2)/dQ^2$ of the charge form factor of an ^{208}Pb nucleus according to this equation? To measure this, what kind of incoming electron energy and electron scattering angle would you choose?

Problem 5)

Referring to Part III of Bethe's article, explain in your own words why the isotopes ^{235}U and ^{239}Pu can be fissioned using slow (eV) neutrons, while one needs fast (MeV) neutrons to fission ^{238}U. Note that the explanation given in the article (at the end of section D) is a bit misleading: Since fission usually ends up liberating several neutrons and huge amounts of energy in the final state, the number of neutrons in the final fission products does **not** play an important role. Instead the excitation energy of the compound nucleus after the neutron has been captured is important. From the mass formula (in the article or our books), explain why this excitation energy is needed for fission to occur, and where it comes from in the case of ^{235}U and ^{239}Pu (which term in the mass formula is responsible for that extra "oomph"?).