The Handbook of Mathematics, Physics and Astronomy Data is provided

KEELE UNIVERSITY

EXAMINATIONS, 2010/11

Level II

Wednesday 25th May 2011, 16.00-18.00

PHYSICS

PHY-20009

NUCLEAR AND PARTICLE PHYSICS

Candidates should attempt to answer FOUR questions.

NOT TO BE REMOVED FROM THE EXAMINATION HALL

1. (a) Determine the charge numbers Q, strangeness S, charm C and baryon number B of particles having quark structures;

   i. dds [5]

   ii. dus [5]

   iii. $c\bar{s}$ [5]

   iv. $b\bar{c}$ [5]

   v. $\bar{c}s$ [5]

   (b) Discuss how the masses of the *baryons* of part (a) compare with each other and with the mass of a proton. [20]

   (c) Explain, with reference to the particles of part (a)iii and (a)v, how the intrinsic properties of a particle and its antiparticle compare. [10]

   (d) The Σ^- (dds) decays to the Λ^o (dus) as follows:

$$\Sigma^- \rightarrow \Lambda^o + e^- + ?$$

   i. Identify the particle indicated by the "?" in this decay. [5]

   ii. Draw a Feynman diagram for the decay and show how charge number, baryon number, lepton number and strangeness are conserved at each vertex. [40]

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2. (a) State what the semi-empirical mass formula (SEMF) is used [illegible] describe the *pairing term* in this formula, and explain how this term varies with nuclear composition. [25]

(b) Describe how a plot of the difference between the two-neutron separation energy and the SEMF prediction versus neutron number provides evidence for a shell model of nuclei. [20]

(c) State what is meant by a *magic number* in the shell model. [5]

(d) Explain why the plot of part (b) is more useful than an equivalent plot using one-neutron separation energy. [5]

(e) The lowest shell model states are, in order of increasing energy: $1s_{1/2}$, $1p_{3/2}$, $1p_{1/2}$, $1d_{5/2}$, $2s_{1/2}$, $1d_{3/2}$, $1f_{7/2}$.

i. With the aid of a simple shell model diagram, predict with explanation the ground state spin and parity of ^{41}Sc. [30]

ii. Predict with explanation the spin and parity of the first excited state of ^{41}Sc. [15]

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3. The ^{142}Sm nucleus exhibits vibrational energy states.

   (a) Explain why the ^{142}Sm nucleus has a 0^+ ground state and state the shape of the nucleus in its ground state. [15]

   (b) Describe the vibration including

   - a sketch of nuclear shape during vibration
   - an explanation of the spin and parity of the state
   - a calculation of the vibrational frequency

   for

   i. the 2^+ first excited state at 0.768 MeV and [30]

   ii. the lowest 3^- state (4^{th} excited state) at 1.784 MeV. [30]

   (c) State and explain the energies observed in the γ ray spectrum for the decay of the 0^+ 2^{nd} excited state at 1.450 MeV and state the multipolarity of the γ rays and whether they are electric or magnetic. [25]

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4. (a) Consider an α particle as part of a larger nucleus. Sketch the potential energy, E and the wavefunction, ψ, of the α particle as a function of distance, r, from the centre of the nucleus. [10]

(b) With reference to the sketch of part (a) explain the process of α decay. [20]

(c) A radioactive source contains 2.3 μg of ^{226}Ra which decays to the daughter nucleus ^{222}Rn with a half life of 1600 years. Calculate:

i. The number of ^{226}Ra nuclei in the source. [10]

ii. The decay constant. [10]

iii. The activity of the source. [5]

iv. The number of ^{226}Ra nuclei remaining in the source after 3750 years. [15]

v. The time taken in years for the initial activity to reduce by a factor of 6. [15]

vi. The Q value for the α decay to the ground state of the daughter, in MeV. [15]

[Atomic masses in u (1u=931.5 MeV/c^2):
^{4}He 4.002603 ^{222}Rn 222.017571 ^{226}Ra 226.025403]

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5. (a) With reference to fundamental forces in nuclei, explain for a fission reaction, why some lone neutrons are emitted and why some of the fission fragments are β^- radioactive. [25]

(b) A particular neutron-induced fission reaction on a $^{235}_{92}U$ target nucleus results in the emission of two fission fragments and two neutrons. One of the fission fragments decays by a chain of four β^- decays to the stable $^{93}_{41}Nb$ nucleus.

i. Determine the atomic number of the fission fragment which decays by the four β^- decays to ^{93}Nb. [5]

ii. Determine the atomic number of the other fission fragment. [5]

iii. Determine the atomic number of the stable nucleus produced by a decay chain of four β^- decays from the fission fragment of part ii. [5]

(c) In a particular neutron-induced fission reaction, the compound nucleus $^{234}_{92}U$ is formed.

i. Identify the target nucleus used as the fuel in this reaction. [5]

ii. Two fission fragments and four neutrons are emitted from the compound nucleus. The atomic number and mass number of one fragment are both 30% larger than those of the other fragment. Determine the atomic and mass numbers of both fragments. [55]

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6. (a) The fusion reactions which occur in the hydrogen burning ph
of a first generation star are:

$$
\begin{aligned}
{}^{1}\mathrm{H} + {}^{1}\mathrm{H} &\rightarrow {}^{2}\mathrm{H} + e^{+} + \nu \\
{}^{2}\mathrm{H} + {}^{1}\mathrm{H} &\rightarrow {}^{3}\mathrm{He} + \gamma \\
{}^{3}\mathrm{He} + {}^{3}\mathrm{He} &\rightarrow {}^{4}\mathrm{He} + 2{}^{1}\mathrm{H}
\end{aligned}
$$

Give a detailed explanation of these reactions, including in your answer a description of why it is these particular reactions that occur and how rapid the reactions are. [50]

(b) The neutrino flux from the Sun, at the Earth a distance 1.5×10^{11} m away, is $6.6\times10^{14}\ \mathrm{m^{-2}s^{-1}}$. Calculate the power generated by the sun. [35]

[Atomic masses in u:
^{1}H 1.007825 ^{4}He 4.002603]

(c) State how a second generation star differs from the first generation star of part (a) and name the series of reactions this allows (it is not necessary to list these reactions). [15]