OCR

A Level

A Level Physics

Particle physics (Answers)

Name:

MME
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Total Marks: /30

1. In 1911 the paradigm of Thomson's 'plum pudding' model - that the atom comprised a collection of negative plums in a positive pudding - began to be challenged. Since then, particle physics has progressed significantly. This question explores the fundamental forces that are invoked in the nuclear model.

Total for Question 1: 17

(a) Calculate the density of a $^{7}_{3}Li$ atom (with a radius of 152 pm) and of its nucleus. Explain your results in the context of the nuclear model. Assume that the radius of a proton is 1.2 fm. [4]

> **Solution:** Atom: 790 kgm^{-3}
> Nucleus: 2.3×10^{17} kgm^{-3}
> Most of the atom is empty space and electrons have negligible mass; in calculating the mass of the atom we are essentially averaging the mass of the nucleus over a much greater volume.

(b) Describe an experiment that you could perform to demonstrate the key principles of the nuclear model: that the majority of a nucleus is empty space and that the centre of the atom is positively charged. [3]

> **Solution:**
> A narrow beam of alpha particles are fired at a sheet of gold foil. A fluorescent screen mounted to a rotating microscope detects their impacts.
> Observations: most pass straight through with very little deflection; 1 in 10000 are deflected through angles of more than 90°.
> Measurements: the length L of the wire in the field; the reading on the balance for different currents.
> Inferences: to be turned around, they must have almost collided head on with something positively charged (the nucleus); the fact so few are deflected suggests the relative sizes of the nucleus and atom are very different (the former being much, much smaller).

(c) An ${}^{4}_{2}He^{2+}$ particle is travelling towards the nucleus of an ${}^{108}_{47}Ag$ atom. Its kinetic energy is 1.4×10^{-12} J. Calculate an upper limit for the radius of the Ag nucleus. Why is it an upper bound? [3]

> **Solution:** 1.5×10^{-14} m
> The turning point must be outside the nucleus. But how far outside is not constrained by this calculation.

(d) Calculate the gravitational attraction and the electrostatic repulsion between the two protons in a helium nucleus, which are separated by a distance of approximately 10^{-15} m. [4]

> **Solution:** $F_g = 1.9 \times 10^{-34}$ N
> $F_c = 230$ N

(e) It should be clear that a third force is required to keep the protons together. Describe the nature of this force and illustrate its variation with distance. [3]

Solution: Nuclear strong force. It acts between all nucleons but is effective only at very short range. It is repulsive below 0.5 fm and attractive between about 0.5 and 3 fm.
Sketch of F against r should illustrate the above. Global minimum between 0.5 and 3 fm; tending towards zero with increasing r; tending to infinity at low r.

2. This question will asses your knowledge of the classification of particles and of the transformations that can take place between these classes.

Total for Question 2: 13

(a) Compare and contrast the nature of hadrons and leptons, giving two examples of each type of particle. [4]

> **Solution: Hadrons** Particles and anti particles that experience the strong force. Decay via the weak force. If charged they experience electrostatic forces. Examples: protons, neutrons and mesons.
> **Leptons** Unaffected by the strong force. If charged, they experience electrostatic forces. Examples: electrons, neutrinos, muons.

(b) Express the β^+ decay equation in terms of the transformation of hadrons and leptons. [2]

> **Solution:** ${}^1_1p \rightarrow {}^1_0 n + {}^0_1 e + v_e$

(c) Express the β^- decay equation in terms of the transformation of fundamental particles. [2]

> **Solution:** $d \rightarrow u + {}^0_{-1} e + \bar{v}_e$

(d) State the charges on the following quarks and their antiparticles. [4]

i. Up

Solution: up: 2/3, anti-up: -2/3

ii. Down

Solution: down: -1/3, anti-down: 1/3

iii. Strange

Solution: strange: -1/3, anti-strange: 1/3

(e) By considering the charge of the individual quarks involved, show that the net charges of a proton and an anti-proton are of equal magnitude but opposite polarity. [1]

Solution:
Proton: $uud = 2(2/3) + (-2/3) = 2/3$
Anti-proton: $\bar{u}\bar{u}\bar{d} = 2(-2/3) + (2/3) = -2/3$