AQA

A Level

A Level Physics

Particle physics (Answers)

Name:

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Total Marks: /30

1. Rutherford's experiment challenged the paradigm of Thomson's 'plum pudding' model - that the atom comprised a collection of negative plums in a positive pudding.

Total for Question 1: 15

(a) Describe Rutherford's experiment and explain why it demonstrates 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. [4]

Solution:
A narrow beam of alpha particles are fired at a sheet of very thin 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).

(b) Why must the sheet of metal used be extremely thin (10^{-7} m)? [1]

Solution: So that each alpha particle can be assumed to have only endured one collision with a gold nucleus.

(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) By first determining the magnitude of the electrostatic repulsion, calculate the maximum acceleration of the alpha particle. [3]

Solution: 1.8×10^{47} ms^{-2}

The radius of a metal nucleus can also be determined by considering the number of incident alpha particles that are deflected through large angles. Joe attempts this by firing alpha particles at a sheet of aluminium which is 3000 atoms thick. 1 in 10,000 are direct hits (i.e. they scatter at angles close to 180°).

(e) Calculate the radius of the aluminium nucleus. You may assume the following: that the aluminium is layered such that there is no overlap between nuclei; that there is no 'empty space' in the foil; that the radius of an aluminium atom is 118 pm. [4]

Solution: 2.15×10^{-14} m

2. Using observations from experiments like that of Rutherford, experimental values of nuclear radii can be obtained.

Total for Question 2: 15

(a) Estimate 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) 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

(c) 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.

Nuclear radii can be determined accurately using electron diffraction patterns. The first order minimum will occur at an angle governed by $\sin\theta = 1.22\frac{\lambda}{d}$, where λ is the wavelength of the electron and d is the diameter of the particle.

(d) A beam of electrons with energy 560 MeV is fired at a particle. The resulting diffraction pattern indicates that the particle has a radius of 4.6×10^{-15} m. At what angle was the first order minimum measured? [4]

> **Solution:** 17°