Nuclear-practice-1-Extended

[104 marks]

1a. State the quark structures of a meson and a baryon. *[2 marks]*

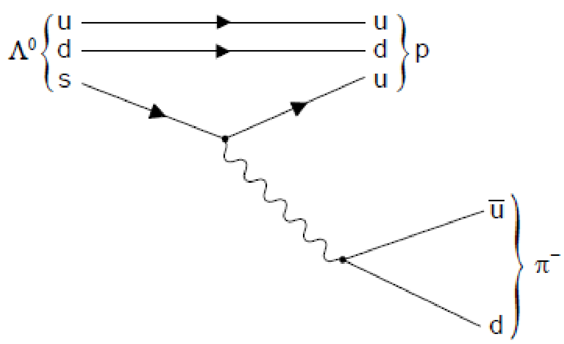
Meson: . . . .

. . . .

Baryon: . . . .

. . . .

A possible decay of a lambda particle (Λ^0) is shown by the Feynman diagram.



1b. Explain which interaction is responsible for this decay. *[2 marks]*

1c. Draw arrow heads on the lines representing $\bar{u}$ and d in the π^-. *[1 mark]*

1d. Identify the exchange particle in this decay. *[1 mark]*

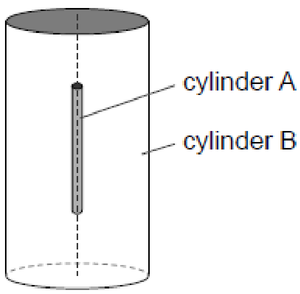
1e. Outline **one** benefit of international cooperation in the construction or use of high-energy particle accelerators. *[1 mark]*

The first scientists to identify alpha particles by a direct method were Rutherford and Royds. They knew that radium-226 ($^{226}_{86}\mathrm{Ra}$) decays by alpha emission to form a nuclide known as radon (Rn).

2a. Write down the missing values in the nuclear equation for this decay. *[1 mark]*

$$^{226}_{88}\mathrm{Ra} \rightarrow {}^{\cdots\cdots}_{86}\mathrm{Rn} + {}^{\cdots\cdots}_{2}\alpha$$

2b. Rutherford and Royds put some pure radium-226 in a small closed cylinder A. Cylinder A is fixed in the centre of a larger closed cylinder B. *[1 mark]*



At the start of the experiment all the air was removed from cylinder B. The alpha particles combined with electrons as they moved through the wall of cylinder A to form helium gas in cylinder B.

The wall of cylinder A is made from glass. Outline why this glass wall had to be very thin.

2c. Rutherford and Royds expected 2.7×10^{15} alpha particles to be emitted during the experiment. The experiment was carried out at a temperature of 18 °C. The volume of cylinder B was 1.3×10^{-5} m^3 and the volume of cylinder A was negligible. Calculate the pressure of the helium gas that was collected in cylinder B. *[3 marks]*

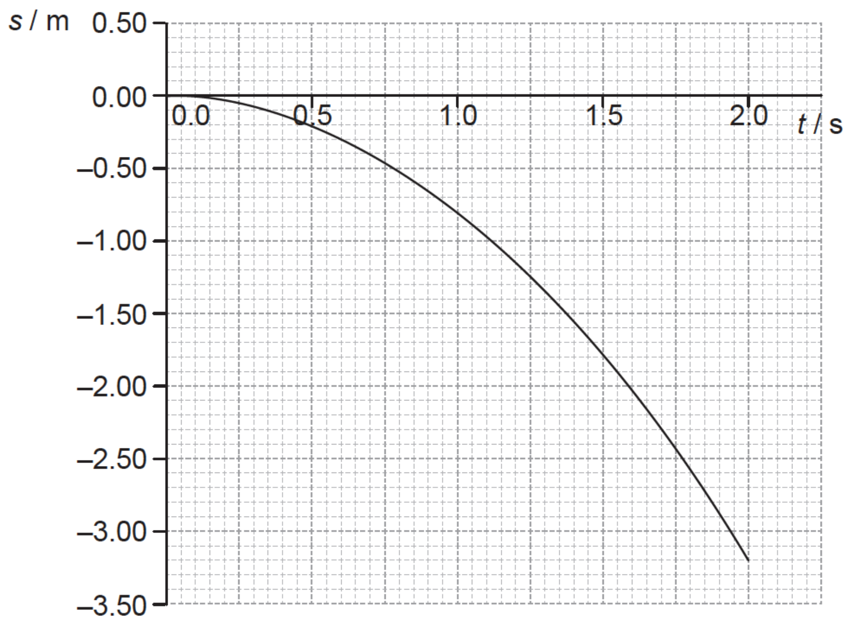
2d. Rutherford and Royds identified the helium gas in cylinder B by observing its emission spectrum. Outline, with reference to atomic energy levels, how an emission spectrum is formed. *[3 marks]*

2e. The work was first reported in a peer-reviewed scientific journal. Outline why Rutherford and Royds chose to publish their work in this way. *[1 mark]*

This question is in **two** parts. **Part 1** is about kinematics and gravitation. **Part 2** is about radioactivity.

Part 1 Kinematics and gravitation

A ball is released near the surface of the Moon at time $t=0$. The point of release is on a straight line between the centre of Earth and the centre of the Moon. The graph below shows the variation with time t of the displacement s of the ball from the point of release.



3a. State the significance of the negative values of s. *[1 mark]*

3b. Use the graph to *[6 marks]*

(i) estimate the velocity of the ball at $t = 0.80$ s.

(ii) calculate a value for the acceleration of free fall close to the surface of the Moon.

3c. The following data are available. *[4 marks]*

Mass of the ball = 0.20 kg

Mean radius of the Moon = 1.74×10^6 m

Mean orbital radius of the Moon about the centre of Earth = 3.84×10^8 m

Mass of Earth = 5.97×10^{24} kg

Show that Earth has no significant effect on the acceleration of the ball.

3d. Calculate the speed of an identical ball when it falls 3.0 m from rest close to the surface of Earth. Ignore air resistance. *[1 mark]*

3e. Sketch, on the graph, the variation with time *t* of the displacement *s* from the point of release of the ball when the ball is dropped close to the surface of Earth. (For this sketch take the direction towards the Earth as being negative.) *[3 marks]*

Part 2 Radioactivity

Two isotopes of calcium are calcium-40 $\left(\frac{40}{20}\mathrm{Ca}\right)$ and calcium-47 $\left(\frac{47}{20}\mathrm{Ca}\right)$. Calcium-40 is stable and calcium-47 is radioactive with a half-life of 4.5 days.

3f. Calculate the percentage of a sample of calcium-47 that decays in 27 days. *[3 marks]*

3g. The nuclear equation for the decay of calcium-47 into scandium-47 $\left({}^{47}_{21}\mathrm{Sc}\right)$ is given by *[4 marks]*

$${}^{47}_{20}\mathrm{Ca} \rightarrow {}^{47}_{21}\mathrm{Sc} + {}^{0}_{-1}\mathrm{e} + \mathrm{X}$$

(i) Identify X.

(ii) The following data are available.

Mass of calcium-47 nucleus = 46.95455 u
Mass of scandium-47 nucleus = 46.95241 u

Using the data, determine the maximum kinetic energy, in MeV, of the products in the decay of calcium-47.

(iii) State why the kinetic energy will be less than your value in (h)(ii).

This question is in **two** parts. **Part 1** is about nuclear reactions. **Part 2** is about thermal energy transfer.

Part 1 Nuclear reactions

4a. (i) Define the term *unified atomic mass unit.* *[2 marks]*

(ii) The mass of a nucleus of einsteinium-255 is 255.09 u. Calculate the mass in $\mathrm{MeV}c^{-2}$.

4b. When particle X collides with a stationary nucleus of calcium-40 (Ca-40), *[6 marks]* a nucleus of potassium (K-40) and a proton are produced.

$$^{40}_{20}\mathrm{Ca} + \mathrm{X} \rightarrow {}^{40}_{19}\mathrm{K} + {}^{1}_{1}\mathrm{p}$$

The following data are available for the reaction.

Particle	**Rest mass / MeV c^{-2}**
calcium-40	37214.694
X	939.565
potassium-40	37216.560
proton	938.272

(i) Identify particle X.

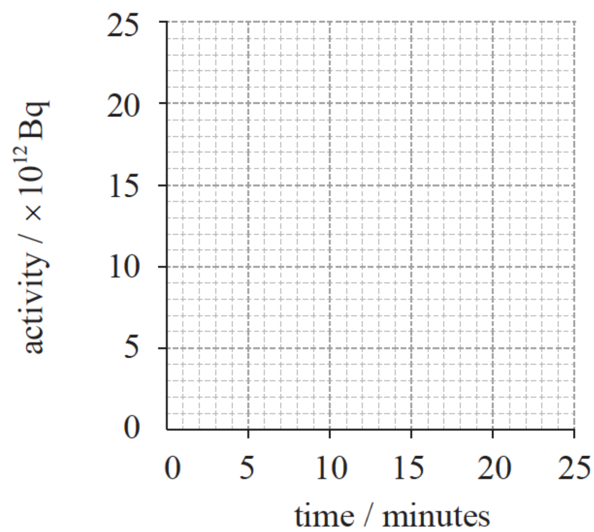
(ii) Suggest why this reaction can only occur if the initial kinetic energy of particle X is greater than a minimum value.

(iii) Before the reaction occurs, particle X has kinetic energy 8.326 MeV. Determine the total combined kinetic energy of the potassium nucleus and the proton.

4c. Potassium-38 decays with a half-life of eight minutes. *[5 marks]*

(i) Define the term *radioactive half-life*.

(ii) A sample of potassium-38 has an initial activity of 24×10^{12} Bq. On the axes below, draw a graph to show the variation with time of the activity of the sample.



(iii) Determine the activity of the sample after 2 hours.

Part 2 Thermal energy transfer

4d. (i) Define the *specific latent heat* of fusion of a substance. *[5 marks]*

(ii) Explain, in terms of the molecular model of matter, the relative magnitudes of the specific latent heat of vaporization of water and the specific latent heat of fusion of water.

4e. A piece of ice is placed into a beaker of water and melts completely. *[5 marks]*

The following data are available.

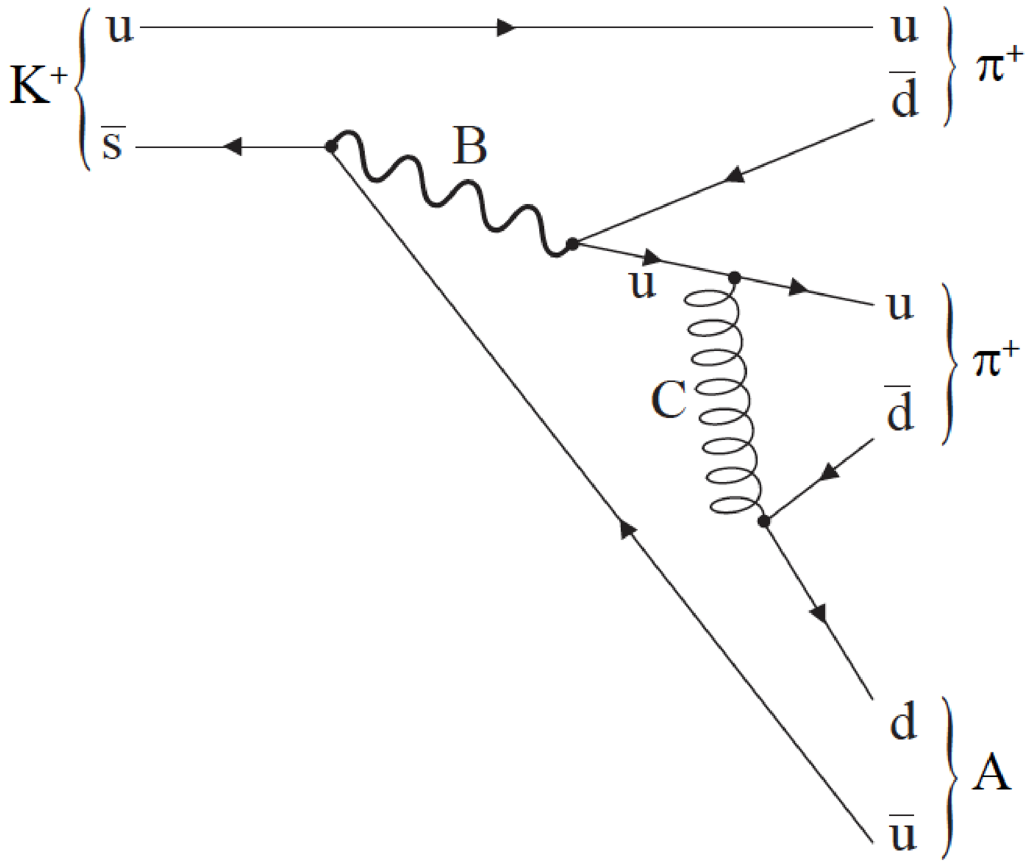
Initial mass of ice = 0.020 kg
Initial mass of water = 0.25 kg
Initial temperature of ice = 0°C
Initial temperature of water = 80°C
Specific latent heat of fusion of ice = 3.3×10^5 J kg^{-1}
Specific heat capacity of water = 4200 J kg^{-1}K^{-1}

(i) Determine the final temperature of the water.

(ii) State **two** assumptions that you made in your answer to part (f)(i).

This question is about fundamental interactions.

The Feynman diagram shows the decay of a K^+ meson into three other particles.



5a. Identify particle A. *[1 mark]*

5b. (i) Identify the interaction whose exchange particle is represented by B. *[2 marks]*

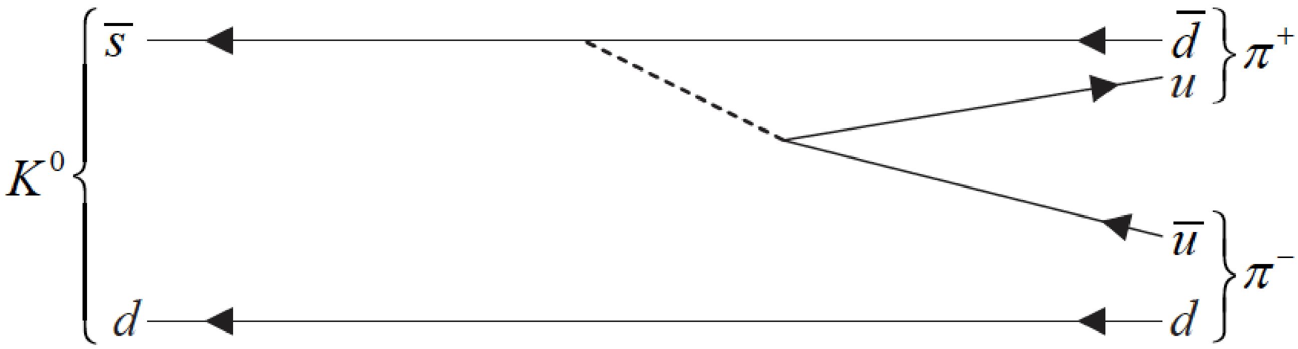
(ii) Identify the exchange particle labelled C.

5c. Outline how the concept of strangeness applies to the decay of a K^+ meson shown in this Feynman diagram. *[2 marks]*

This question is about quarks.

6a. State the name of a particle that is its own antiparticle. *[1 mark]*

6b. The meson K^0 consists of a d quark and an anti s quark. The K^0 decays into two pions as shown in the Feynman diagram. *[3 marks]*



(i) State a reason why the kaon K^0 cannot be its own antiparticle.

(ii) Explain how it may be deduced that this decay is a weak interaction process.

This question is about atomic energy levels.

7a. Outline a laboratory procedure for producing and observing the atomic absorption spectrum of a gas. *[3 marks]*

7b. (i) Describe the appearance of an atomic absorption spectrum. *[4 marks]*

(ii) Explain why the spectrum in (a) provides evidence for quantization of energy in atoms.

7c. The principal energy levels of the hydrogen atom in electronvolt (eV) are given by *[3 marks]*

$$E_n = \frac{13.6}{n^2}$$

where n is a positive integer.

Determine the wavelength of the absorption line that corresponds to an electron transition from the energy level given by n=1 to the level given by n=3.

Part 2 Radioactive decay

8a. Describe the phenomenon of natural radioactive decay. *[3 marks]*

8b. A nucleus of americium-241 (Am-241) decays into a nucleus of neptunium-237 (Np-237) in the following reaction. *[7 marks]*

$$^{241}_{95}\text{Am} \rightarrow \,^{237}_{X}\text{Np} + \,^{4}_{2}\alpha$$

(i) State the value of *X*.

(ii) Explain in terms of mass why energy is released in the reaction in (b).

(iii) Define *binding energy* of a nucleus.

(iv) The following data are available.

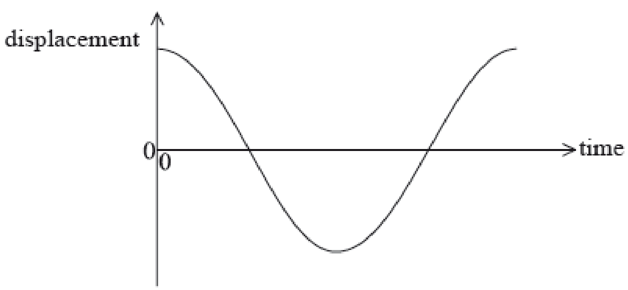
Nuclide	Binding energy per nucleon / MeV
americium-241	7.54
neptunium-237	7.58
helium-4	7.07

Determine the energy released in the reaction in (b).

This question is in **two** parts. **Part 1** is about a simple pendulum. **Part 2** is about the Rutherford model of the atom.

Part 1 Simple pendulum

A pendulum consists of a bob suspended by a light inextensible string from a rigid support. The pendulum bob is moved to one side and then released. The sketch graph shows how the displacement of the pendulum bob undergoing simple harmonic motion varies with time over one time period.



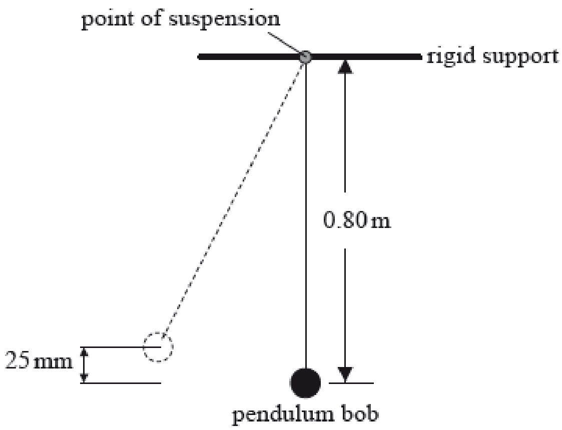
On the sketch graph above,

9a. (i) label with the letter A a point at which the acceleration of the pendulum bob is a maximum. *[2 marks]*

(ii) label with the letter V a point at which the speed of the pendulum bob is a maximum.

9b. Explain why the magnitude of the tension in the string at the midpoint of the oscillation is greater than the weight of the pendulum bob. *[3 marks]*

A pendulum bob is moved to one side until its centre is 25 mm above its rest position and then released.



9c. (i) Show that the speed of the pendulum bob at the midpoint of the oscillation is $0.70\ \mathrm{m\,s^{-1}}$. *[5 marks]*

(ii) The mass of the pendulum bob is 0.057 kg. The centre of the pendulum bob is 0.80 m below the support. Calculate the magnitude of the tension in the string when the pendulum bob is vertically below the point of suspension.

Part 2 Rutherford model of the atom

The isotope gold-197 $\left({}^{197}_{79}Au\right)$ is stable but the isotope gold-199 $\left({}^{199}_{79}Au\right)$ is not.

9d. (i) Outline, in terms of the forces acting between nucleons, why, for large stable nuclei such as gold-197, the number of neutrons exceeds the number of protons. *[4 marks]*

(ii) A nucleus of ${}^{199}_{79}\mathrm{Au}$ decays to a nucleus of ${}^{199}_{80}\mathrm{Hg}$ with the emission of an electron and another particle. State the name of this other particle.