THIS IS A LEGACY SPECIFICATION

OCR
RECOGNISING ACHIEVEMENT

ADVANCED GCE

PHYSICS A

Nuclear and Particle Physics

2825/04

Candidates answer on the question paper

OCR Supplied Materials:
None

Other Materials Required:
- Electronic calculator

Tuesday 29 June 2010
Afternoon

Duration: 1 hour 30 minutes

Candidate Forename		Candidate Surname	

Centre Number						Candidate Number				

INSTRUCTIONS TO CANDIDATES

- Write your name clearly in capital letters, your Centre Number and Candidate Number in the boxes above.
- Use black ink. Pencil may be used for graphs and diagrams only.
- Read each question carefully and make sure that you know what you have to do before starting your answer.
- Answer **all** the questions.
- Do **not** write in the bar codes.
- Write your answer to each question in the space provided, however additional paper may be used if necessary.

INFORMATION FOR CANDIDATES

- The number of marks is given in brackets **[ ]** at the end of each question or part question.
- The total number of marks for this paper is **90**.
- You may use an electronic calculator.
- You are advised to show all the steps in any calculations.
- The first six questions concern Nuclear and Particle Physics. The last question concerns general physics.
- This document consists of **24** pages. Any blank pages are indicated.

FOR EXAMINER'S USE		
Qu.	**Max.**	**Mark**
1	**11**	
2	**11**	
3	**12**	
4	**13**	
5	**11**	
6	**12**	
7	**20**	
TOTAL	**90**	

Data

speed of light in free space,	$c = 3.00 \times 10^{8}\ \mathrm{m\,s^{-1}}$
permeability of free space,	$\mu_0 = 4\pi \times 10^{-7}\ \mathrm{H\,m^{-1}}$
permittivity of free space,	$\epsilon_0 = 8.85 \times 10^{-12}\ \mathrm{F\,m^{-1}}$
elementary charge,	$e = 1.60 \times 10^{-19}\ \mathrm{C}$
the Planck constant,	$h = 6.63 \times 10^{-34}\ \mathrm{J\,s}$
unified atomic mass constant,	$u = 1.66 \times 10^{-27}\ \mathrm{kg}$
rest mass of electron,	$m_e = 9.11 \times 10^{-31}\ \mathrm{kg}$
rest mass of proton,	$m_p = 1.67 \times 10^{-27}\ \mathrm{kg}$
molar gas constant,	$R = 8.31\ \mathrm{J\,K^{-1}\,mol^{-1}}$
the Avogadro constant,	$N_A = 6.02 \times 10^{23}\ \mathrm{mol^{-1}}$
gravitational constant,	$G = 6.67 \times 10^{-11}\ \mathrm{N\,m^{2}\,kg^{-2}}$
acceleration of free fall,	$g = 9.81\ \mathrm{m\,s^{-2}}$

Formulae

uniformly accelerated motion,	$s = ut + \frac{1}{2}at^2$
	$v^2 = u^2 + 2as$
refractive index,	$n = \dfrac{1}{\sin C}$
capacitors in series,	$\dfrac{1}{C} = \dfrac{1}{C_1} + \dfrac{1}{C_2} + \ldots$
capacitors in parallel,	$C = C_1 + C_2 + \ldots$
capacitor discharge,	$x = x_0 e^{-t/CR}$
pressure of an ideal gas,	$p = \frac{1}{3}\dfrac{Nm}{V}\langle c^2 \rangle$
radioactive decay,	$x = x_0 e^{-\lambda t}$
	$t_{\frac{1}{2}} = \dfrac{0.693}{\lambda}$
critical density of matter in the Universe,	$\rho_0 = \dfrac{3H_0^2}{8\pi G}$
relativity factor,	$= \sqrt{(1 - \dfrac{v^2}{c^2})}$
current,	$I = nAve$
nuclear radius,	$r = r_0 A^{1/3}$
sound intensity level,	$= 10 \lg \left(\dfrac{I}{I_0}\right)$

Answer **all** the questions.

1 This question is about the strong and electrostatic forces inside a nucleus.

Fig. 1.1 shows how the strong force (strong interaction) and the electrostatic force between two **protons** vary with distance between the centres of the protons.

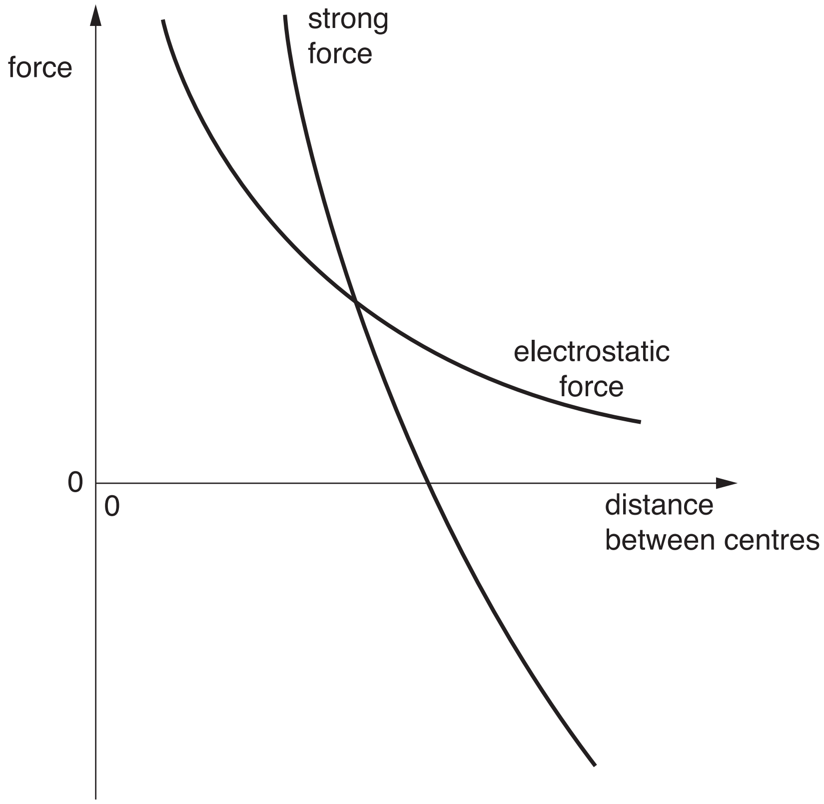

Fig. 1.1

(a) On Fig. 1.1 label the regions of the force axis which represent attraction and repulsion. **[1]**

(b) (i) On Fig. 1.1 mark a point which represents the distance between the centres of two adjacent **neutrons** in a nucleus. Label this point **N**.

Explain why you chose point **N**.

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.... **[2]**

(ii) On Fig.1.1, mark a point **P** which represents the distance between two adjacent **protons** in a nucleus.

Explain why you chose point **P**.

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.... **[2]**

(c) On Fig. 1.1, sketch a line to show how the **resultant force** between two **protons** varies with the distance between their centres. Pay particular attention to the points at which this line crosses any other line. **[3]**

(d) (i) Write an expression for the electrostatic force between two point charges Q which are situated at a distance x apart.

[1]

(ii) The electrostatic force between two protons in contact in a nucleus is 25 N.
Calculate the distance between the centres of the protons.

distance = ...m **[2]**

[Total: 11]

2 This question is about nuclear fission of uranium-235.

(a) (i) State what is meant by a *thermal neutron*.

....

.... **[1]**

(ii) State the importance of thermal neutrons in relation to the fission of uranium-235.

....

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.... **[1]**

(b) A uranium-235 nucleus $\left({}^{235}_{92}\text{U}\right)$ undergoes fission, producing nuclei of barium-145 $\left({}^{145}_{56}\text{Ba}\right)$ and krypton-88 $\left({}^{88}_{36}\text{Kr}\right)$. The binding energies per nucleon of these nuclides are shown in the table.

nuclide	binding energy per nucleon / MeV
${}^{235}_{92}\text{U}$	7.6
${}^{145}_{56}\text{Ba}$	8.0
${}^{88}_{36}\text{Kr}$	8.4

(i) Plot these values on the grid of Fig. 2.1. **[1]**

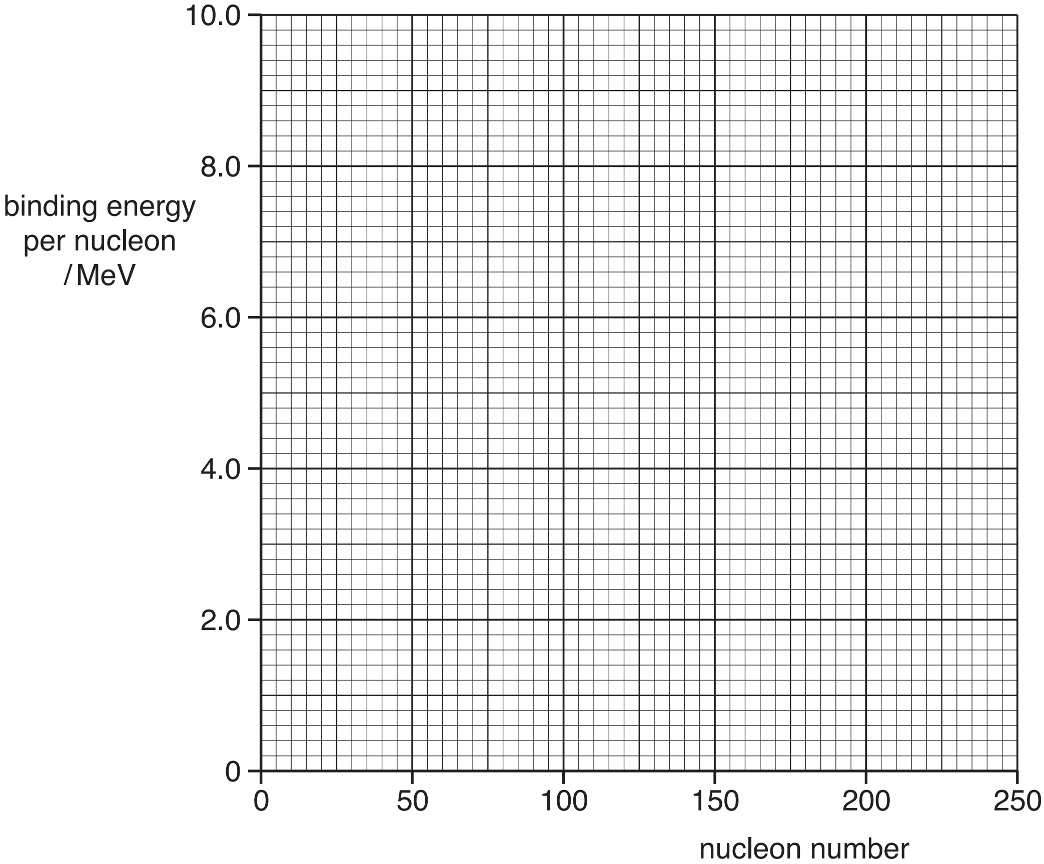

Fig. 2.1

(ii) Sketch a graph on Fig. 2.1, to show how the binding energy per nucleon varies with nucleon number for **all** nuclei. **[2]**

(iii) Use information from the table to calculate how much energy in MeV is released when a $^{235}_{92}U$ nucleus undergoes fission.

energy = ... MeV **[3]**

(c) **(i)** Neutrons emitted from a fission reaction may be slowed down by colliding with carbon-12 nuclei $\left({}^{12}_{6}\mathrm{C}\right)$. The initial speed of the neutrons is $1.5 \times 10^{7}\,\mathrm{m\,s^{-1}}$. On average the neutron loses 7.0% of its speed during each collision. Calculate the speed of the neutron after 120 collisions.

speed = ... $\mathrm{m\,s^{-1}}$ **[2]**

(ii) When a neutron collides head-on with a ${}^{12}_{6}\mathrm{C}$ nucleus, as shown in Fig. 2.2, its speed is reduced by about 15%.

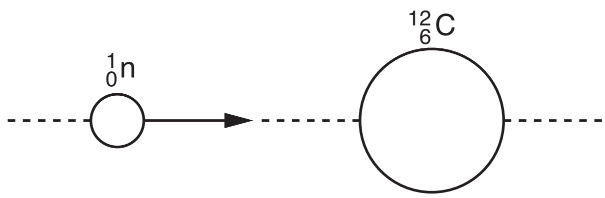

Fig. 2.2

Suggest why this speed reduction is different from the reduction stated in **(i)**.

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.... **[1]**

[Total: 11]

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3 **(a)** Give a brief account of the principles of operation of the JET fusion experiment.
Your account should refer to

- the energy-generating nuclear reaction
- confinement of the reacting materials
- **two** methods of supplying energy to the reactants
- the reason why high temperatures are important.

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.... [8]

(b) State and explain **two** possible **advantages** of using nuclear fusion rather than nuclear fission for generating useful energy on a large scale.

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.... [4]

[Total: 12]

4 The linear accelerator or linac may be used for accelerating **protons** or **positrons**.
A particular linac consists of a source of charged particles and a series of cylindrical electrodes. These electrodes are attached alternately to the terminals of a source of alternating potential difference so that the particles accelerate each time they cross the gap between two electrodes. When they cross the gap the p.d. is 40 kV.

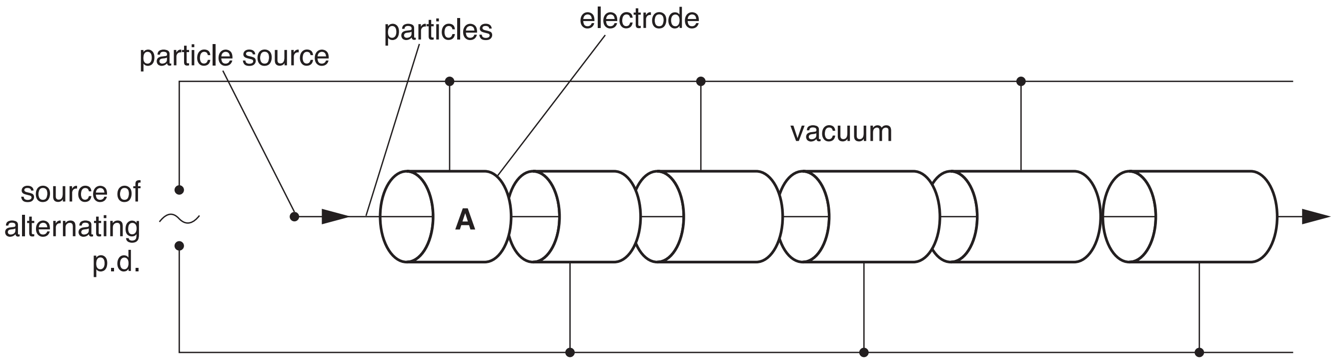

Fig. 4.1

Fig. 4.1 shows the first part of such a linac.

(a) **Protons** from the particle source enter electrode **A** with 50 keV of energy.

(i) State the energy of one of these protons after being accelerated 10 times.

energy = ... keV **[1]**

(ii) Calculate the speed of this proton.

speed = ... m s^{-1} **[3]**

(b) In a different linac, **positrons** are accelerated to the same energy. A student carries out a similar calculation to find the speed of these positrons. He calculates their speed to be $4.0 \times 10^8\,\text{m}\,\text{s}^{-1}$.

(i) Explain why his answer cannot be correct.

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.... **[2]**

(ii) The lengths of the electrodes in a **proton** linac increase along the path of the particles (see Fig. 4.1). However a high-energy positron linac has electrodes which are all of the same length. Suggest why this is so.

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.... **[3]**

(c) A 0.85 MeV positron collides with a stationary electron. The two particles are annihilated and two γ-photons of equal energies are produced. Calculate the frequency of one of these photons.

frequency = ... Hz **[4]**

[Total: 13]

5 **(a)** Fig. 5.1 shows four particles and three classes of particle.

	hadron	baryon	lepton
neutron			
proton			
electron			
neutrino			

Fig. 5.1

Indicate, using ticks, the class or classes to which each particle belongs. **[2]**

(b) The neutron can decay, producing particles which include a proton and an electron.

(i) State the approximate half-life of this process.

.... **[1]**

(ii) Write a **quark** equation for this reaction.

....

.... **[2]**

(iii) Write number equations which show that charge and baryon number are conserved in this quark reaction.

charge ....

....

baryon number ....

.... **[2]**

(c) Fig. 5.2 illustrates the paths of the neutron, proton and electron only in a decay process of the kind described in **(b)**.

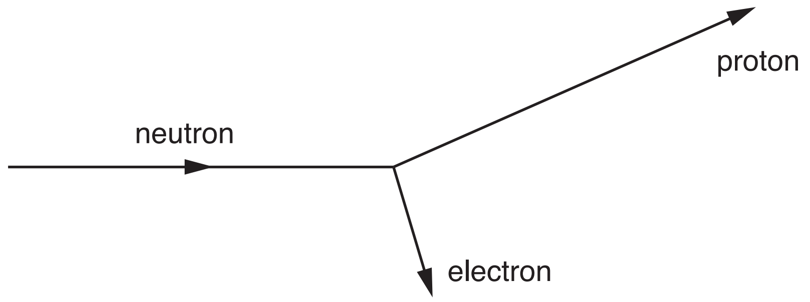

Fig. 5.2

Fig. 5.3 is a vector diagram in which p_n represents the momentum of the neutron **before** the decay. p_p and p_e represent the momenta of the proton and the electron **after** the decay.

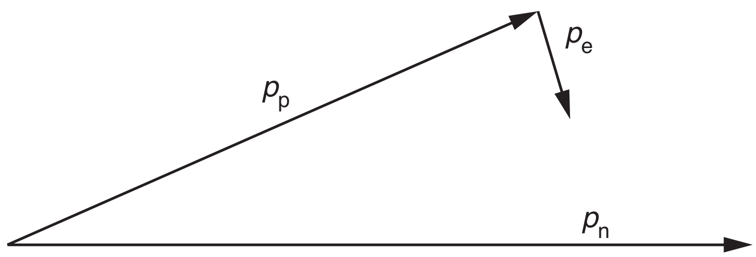

Fig. 5.3

(i) Draw and label a line on Fig. 5.3 which represents the resultant p_r of vectors p_p and p_e. **[1]**

(ii) According to the law of conservation of momentum, the total momentum of an isolated system remains constant.

Explain in as much detail as you can, why the momentum p_r is **not** the same as p_n .

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.... **[3]**

[Total: 11]

6 This question is about two isotopes of plutonium.

(a) State briefly (without nuclear equations) how plutonium-239 can be produced.

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.... **[2]**

(b) (i) State what particle is emitted when plutonium-239 decays.

.... **[1]**

(ii) Write a nuclear equation for the decay of plutonium-239 ($^{239}_{94}Pu$).

....

.... **[2]**

(c) A sample contains 5.00×10^{20} atoms of plutonium-239 and 40.0×10^{20} atoms of plutonium-240.

(i) State the half-life of plutonium-239.

.... **[1]**

(ii) Show that, after 9000 years there will be 3.85×10^{20} atoms of plutonium-239 left in the mixture.

[2]

(iii) After 9000 years there will be 15.4×10^{20} atoms of plutonium-240 left in the mixture.

1 State the ratio

$$\frac{\text{number of atoms of plutonium-240}}{\text{number of atoms of plutonium-239}} \quad \text{after 9000 years.}$$

ratio = ... to two significant figures only **[1]**

2 Use this ratio, together with the ratio of the numbers of atoms in the original mixture, to deduce the **total** time (from the start) before the number of atoms of plutonium-239 and plutonium-240 are **equal**.

time = ... years **[3]**

[Total: 12]

7 This question is about a cliff railway that is entirely powered by water. The rail line links a town at the top of a hill with another town at the bottom of the hill. The railway has two carriages running on parallel tracks. They are connected by a continuous cable running around two pulley wheels mounted at the top and bottom of the track bed (see Fig. 7.1). Brakes can be applied to the lower pulley wheel to control the speed of the carriages.

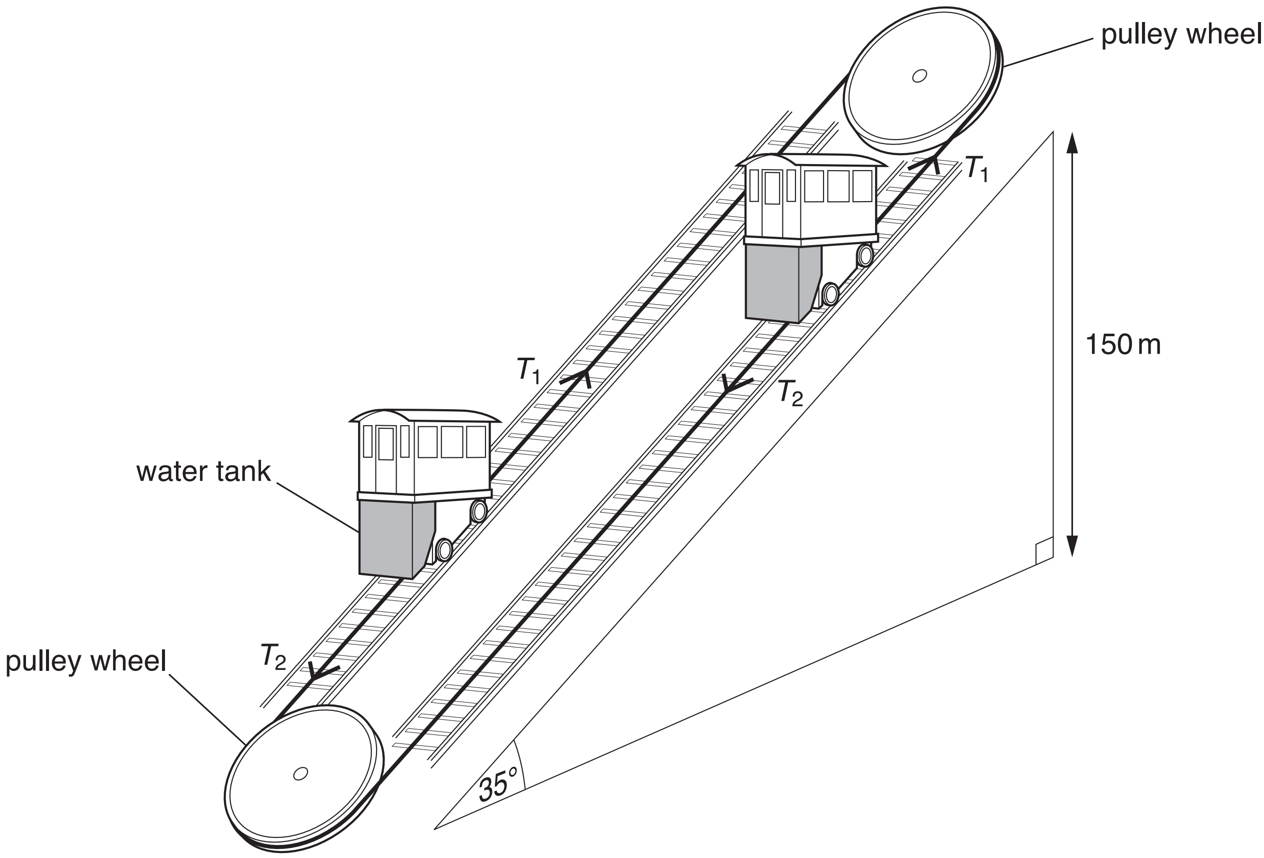

Fig. 7.1

Each carriage has a tank beneath the passenger compartment which can hold 5.0 m^3 of water. Before the start of each journey both tanks are full of water. When the passengers are aboard, water is released from the lower carriage until the weight of the lower carriage is less than that of the upper carriage. The brakes on the pulley wheel are released and the carriages accelerate toward the other station. When the speed of the carriages reaches 6.6 m s^{-1}, the brakes are partially applied to maintain a constant speed.

When the carriages reach the stations the brakes are fully applied and the carriages slow down and stop. While the passengers leave, the water tank beneath the carriage at the top station is refilled with water from a river. Passengers board both lower and upper carriages and the whole process is repeated.

Data: mass of each carriage fully loaded (including a full tank of water) = 10 000 kg
volume of water tank = 5.0 m^3
length of rails = 260 m
vertical height from lower station to the top station = 150 m
angle of inclination of rails = 35°
density of water = 1000 kg m^{-3}
mass of each brake block = 25 kg

(a) Describe the energy changes that occur when the lower carriage is lifted to the upper station while the upper carriage moves to the lower station.

....

....

....

.... **[3]**

(b) Just before the water tank in the lower carriage begins to drain, both carriages are carrying their full load and the tension T_2 in the lower cable is small enough to be ignored.

Show that the tension T_1 in the upper cable is about 5.5×10^4 N when both carriages are fully loaded.

[2]

(c) When the brakes are released, the acceleration of both cars is $1.5\,\text{m}\,\text{s}^{-2}$ and there is a resultant force of 8.7×10^3 N parallel to the track acting on the lower carriage.

(i) Calculate the volume of water which has been released from the lower carriage.

volume = ... m^3 **[4]**

(ii) Calculate the time taken from the moment the lower carriage leaves the station to the point when it reaches its maximum speed of $6.6\,\mathrm{m\,s^{-1}}$.

time = ... s **[2]**

(iii) Calculate the distance travelled during this time. Assume the acceleration remains constant.

distance = ... m **[2]**

(d) At the start of one particular journey both carriages are fully loaded. 3800 kg of water is released from the lower carriage.

(i) Show that the net change in potential energy of the system is about 5.5 MJ.

[2]

Six iron brake blocks, each of mass 25 kg, apply a force against the lower pulley wheel. This maintains the constant speed during the journey and then, following an increase in this force, brings the carriages to a halt.

(ii) Calculate the rise in temperature of the brake blocks in this journey if the brake blocks absorb all of the potential energy change calculated in **(i)**.

The specific heat capacity of iron is $4.7 \times 10^2\,\mathrm{J\,kg^{-1}\,K^{-1}}$.

rise in temperature = ... K **[3]**

(iii) In practice the rise in temperature of the brake blocks is much less than the value calculated in **(ii)**. Discuss reasons why.

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.... **[2]**

[Total: 20]

END OF QUESTION PAPER

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