Centre Number						Candidate Number				
Surname										
Other Names										
Candidate Signature										

For Examiner's Use	
Examiner's Initials	
Question	Mark
1	
2	
3	
4	
5	
6	
TOTAL	

General Certificate of Education
Advanced Level Examination
June 2013

Physics (B): Physics in Context PHYB4

Unit 4 Physics Inside and Out

Module 1 Experiences Out of this World
Module 2 What Goes Around Comes Around
Module 3 Imaging the Invisible

Thursday 13 June 2013 1.30 pm to 3.15 pm

For this paper you must have:
- a pencil and a ruler
- a calculator
- a Data and Formulae Booklet (enclosed).

Time allowed
- 1 hour 45 minutes

Instructions
- Use black ink or black ball-point pen. Use pencil only for drawing.
- Fill in the boxes at the top of this page.
- Answer **all** questions.
- You must answer the questions in the spaces provided. Do not write outside the box around each page or on blank pages.
- Do all rough work in this book. Cross through any work you do not want to be marked.
- Show all your working.

Information
- The marks for questions are shown in brackets.
- The maximum mark for this paper is 100.
- You are expected to use a calculator where appropriate.
- A *Data and Formulae Booklet* is provided as a loose insert.
- You will be marked on your ability to:
  – use good English
  – organise information clearly
  – use specialist vocabulary where appropriate.

Answer **all** questions in the spaces provided.

1 **Figure 1** shows (not to scale) three students, each of mass 50.0 kg, standing at different points on the Earth's surface. Student **A** is standing at the North Pole and student **B** is standing at the equator.

Figure 1

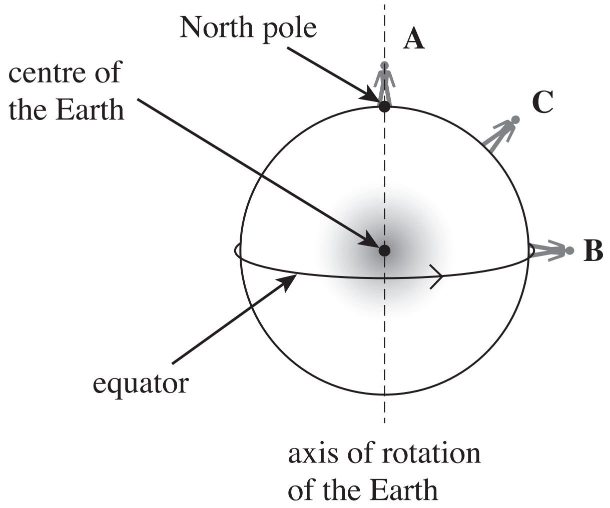
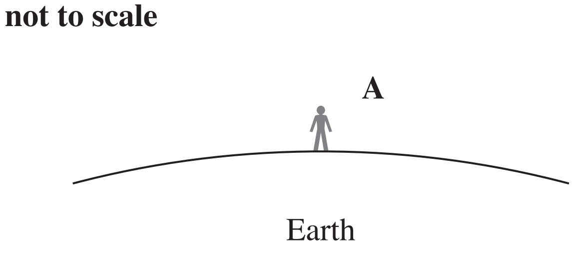


Figure 2



The radius of the Earth is 6370 km.
The mass of the Earth is 5.98×10^{24} kg.

In this question assume that the Earth is a perfect sphere.

1 (a) (i) Use Newton's gravitational law to calculate the gravitational force exerted by the Earth on a student.

force .... N
(3 marks)

1 (a) (ii) **Figure 2** shows a closer view of student **A**.
Draw, on **Figure 2**, vector arrows that represent the forces acting on student **A**.
(2 marks)

Do not write outside the box

1 (b) (i) Show that the linear speed of student **B** due to the rotation of the Earth is about $460\,\text{m}\,\text{s}^{-1}$.

(3 marks)

1 (b) (ii) Calculate the magnitude of the centripetal force required so that student **B** moves with the Earth at the rotational speed of $460\,\text{m}\,\text{s}^{-1}$.

magnitude of the force .... N

(2 marks)

1 (b) (iii) Show, on **Figure 1**, an arrow showing the direction of the centripetal force acting on student **C**.

(1 mark)

1 (c) Student **B** stands on a bathroom scale calibrated to measure weight in newton (N). If the Earth were not rotating, the weight recorded would be equal to the force calculated in part (a)(i).

State and explain how the rotation of the Earth affects the reading on the bathroom scale for student **B**.

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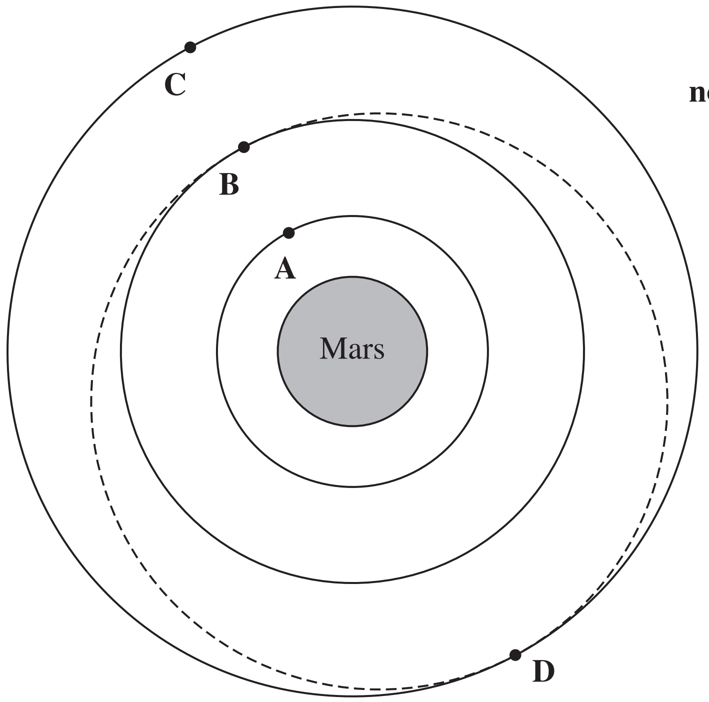
(3 marks)

14

2 **Figure 3** represents three equipotential surfaces associated with the gravitational field of the planet Mars.

Figure 3



	r / km	V / MJ kg^{-1}
A	6800	
B	10200	–4.20
C	13600	–3.16

The points labelled **A**, **B**, **C**, **D** lie on the equipotential surfaces. The table shows the distances r of these equipotential surfaces from the centre of Mars and the gravitational potential V for each surface. *The gravitational potential at the surface of Mars is* $-12.6\,MJ\,kg^{-1}$. The dotted line shows the elliptical orbit that is referred to in part (b)(ii).

2 (a) (i) State what is meant by the statement that ‘the gravitational potential at the surface of Mars is $-12.6\,\text{MJ}\,\text{kg}^{-1}$’.

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(2 marks)

2 (a) (ii) Determine the gravitational potential at point **A**.

gravitational potential at **A** .... $MJ\,kg^{-1}$

(2 marks)

2 (b) (i) An un-powered satellite in a stable orbit about the centre of Mars passes through **C** and **D**. Explain why the speed of the satellite is the same at **D** as it is at **C**.

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(1 mark)

2 (b) (ii) Another un-powered satellite of mass 850 kg passes point **D** at a speed of $1.64 \times 10^3\,m\,s^{-1}$. This satellite follows the elliptical orbit shown by the dotted line in **Figure 3**. In this orbit the radius about the centre of Mars is continually changing.

By considering the energy changes that occur, show that the speed of this satellite when it passes point **B** is about $2.2 \times 10^3\,m\,s^{-1}$.

(4 marks)

Turn over ▶

2 (b) (iii) It can be shown that the speed, v, of the satellite in the elliptical orbit is inversely proportional to r, the corresponding radius of the orbit. The moment of inertia of a satellite about the centre of Mars is equal to mr^2, where m is its mass. Show that angular momentum is conserved during the elliptical orbit.

(3 marks)

2 (b) (iv) Explain why it would be expected that the angular momentum of the satellite would not change during the orbit.

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(1 mark)

2 (c) Mars has a mass of 6.4×10^{23} kg and a radius of 3.4×10^{6} m.
The period of rotation of Mars about its axis is 24.6 h.

Suppose that a future expedition lands on Mars and wishes to set up a communications satellite, of mass 850 kg, in an orbit that has the same period as Mars.

2 (c) (i) Calculate the radius of the orbit for this communications satellite.

radius of orbit .... m
(4 marks)

2 (c) (ii) Calculate the change in gravitational potential energy of the satellite when placed into this orbit from a base on the surface of Mars.

change in gravitational potential energy .... J
(3 marks)

20

There are no questions printed on this page

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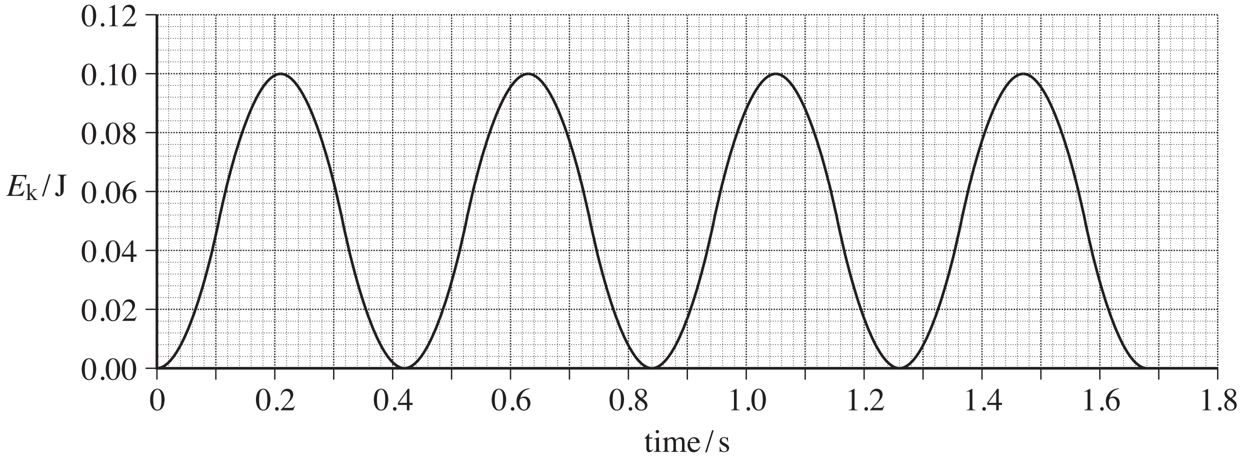
ANSWER IN THE SPACES PROVIDED

3 (a) **Figure 4** shows how the kinetic energy, E_k, of an oscillating mass varies with time when it moves with simple harmonic motion.

Figure 4



3 (a) (i) Determine the frequency of the oscillations of the mass.

frequency of oscillation .... Hz

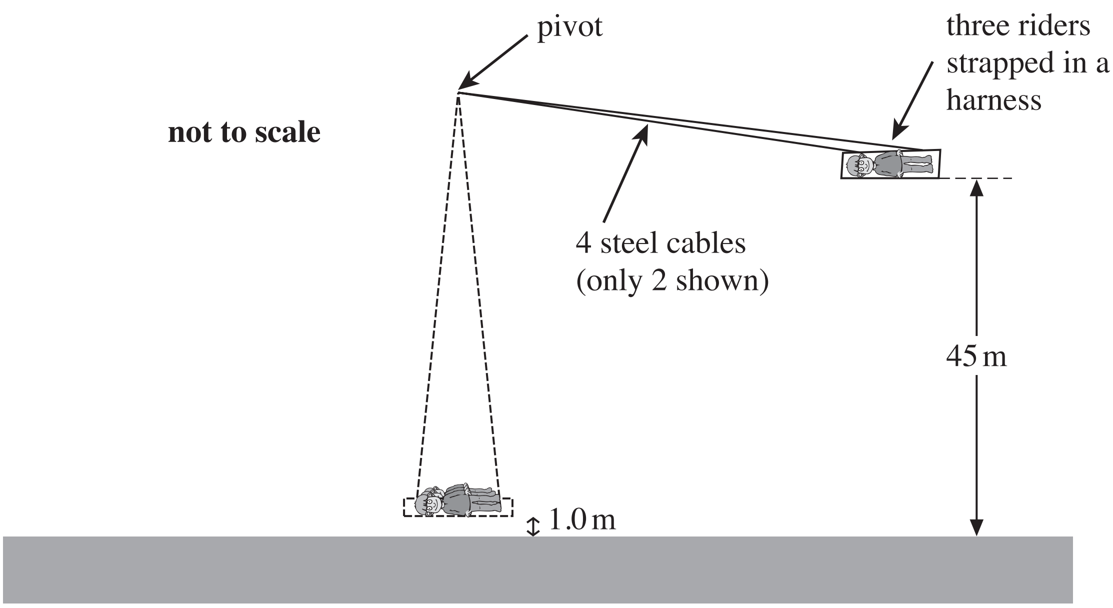
(2 marks)

3 (a) (ii) Sketch, on **Figure 4**, a graph showing how the potential energy of the mass varies with time during the first second.

(2 marks)

3 (b) **Figure 5** shows a ride called a 'jungle swing'.

Figure 5



The harness in which three riders are strapped is supported by 4 steel cables. An advert for the ride states that the riders will be released from a height of 45 m above the ground and will then swing with a period of 14.0 s. It states that they will be 1.0 m above the ground at the lowest point and that they will travel at speeds of 'up to 120 km per hour'.

3 (b) (i) Treating the ride as a simple pendulum, show that the distance between the pivot and the centre of mass of the riders is about 49 m.

(2 marks)

3 (b) (ii) The riders and their harness have a total mass of 280 kg.
Calculate the tension in each cable at the lowest point of the ride, assuming that the riders pass through this point at a speed of 120 km h^{-1}. Assume that the cables have negligible mass and are vertical at this point in the ride.

tension in each cable .... N

(4 marks)

3 (b) (iii) Show that the maximum speed stated in the advert is an exaggerated claim.
Assume that the riders are released from rest and neglect any effects of air resistance.

(4 marks)

3 (b) (iv) The riders lose 50% of the energy of the oscillation during each half oscillation. After one swing, the speed of the riders as they pass the lowest point is 20 m s^{-1}.

Calculate the speed of the riders when they pass the lowest point, travelling in the same direction after two further complete oscillations.

speed of riders .... m s^{-1}

(3 marks)

17

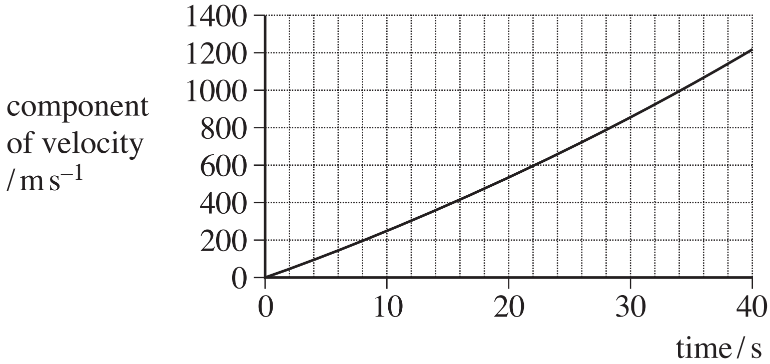
Turn over ▶

4 A spacecraft of mass 3500 kg is travelling at a speed of 4700 m s^{-1} in space. In order to change course a rocket motor fires a burst of gas at right angles to the direction in which the spacecraft is travelling initially.

The gas is ejected at a speed of 2500 m s^{-1} for 40 s. The thrust produced by the rocket motor is constant during this time.

The graph in **Figure 6** shows how the magnitude of the component of the **velocity** perpendicular to the original direction of travel varies with time during the 40 s burst.

Figure 6



4 (a) (i) Determine the final speed of the rocket. Give your answer to 3 significant figures.

final speed .... m s^{-1}

(2 marks)

4 (a) (ii) Calculate the angle between the new direction of travel of the rocket and its original direction that is produced by this burst of gas.

angle .... degrees

(2 marks)

4 (b) Show that the distance travelled perpendicular to the initial direction of motion, while the burst of gas takes place, is about 20 km.

(3 marks)

4 (c) (i) Use data from the graph and the rocket equation to determine the rate at which gas is ejected from the rocket. Give an appropriate unit for your answer.

rate of ejection of gas .... unit ....

(5 marks)

4 (c) (ii) Determine the thrust produced by the rocket motor.

thrust .... N

(2 marks)

4 (d) Explain why the graph in **Figure 6** is not a straight line.

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(4 marks)

18

Turn over for the next question

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ANSWER IN THE SPACES PROVIDED

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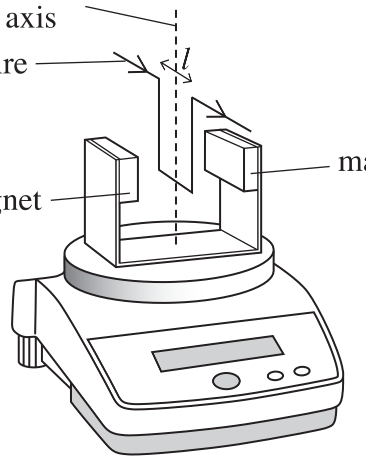
5 **Figure 7** shows one arrangement for measuring the strength of the magnetic field produced by a pair of magnets in a laboratory.

Figure 7



The wire is perpendicular to the magnetic field of the magnet and carries a current of 5.0 A in the direction shown. The length l of the wire shown in the diagram is 6.5 cm. The wire is held rigidly in place so that it cannot move. When the current is turned on, the reading on the balance increases.

5 (a) (i) Show, on **Figure 7**, the direction of the magnetic field between the magnets that produces the increase in the balance reading.

(1 mark)

5 (a) (ii) The minimum change in reading that the balance can detect is 1 mg. Calculate the smallest change in magnetic flux density that is detectable using this arrangement. Give an appropriate unit for your answer.

change in flux density .... unit ....

(3 marks)

5 (b) Magnetic flux density is a vector quantity. State and explain how the balance reading would be affected by rotating the pair of magnets about the vertical axis shown in **Figure 7**.

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(2 marks)

5 (c) Archaeologists need to detect small changes in magnetic flux density when investigating sites. This is possible using the precession of protons in a proton magnetometer.

Explain what is meant by precession. You may use a diagram to help your explanation. Go on to explain how a proton magnetometer works. Make clear in your answer what quantity is measured by a proton magnetometer to indicate changes in the magnetic flux density in the region being investigated.

The quality of your written communication will be assessed in your answer.

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(6 marks)

12

6 X-rays have been a familiar diagnostic tool in hospitals ever since their discovery. To produce the X-rays, a metal target is bombarded by electrons that have been accelerated in an electron gun. **Figure 8** shows how the intensity of the X-rays produced at the target varies with wavelength. The sharp peaks correspond to the characteristic X-rays, referred to as K_α and K_β. Characteristic X-rays depend on the energy levels for the element from which the target is made.

Figure 9 shows, using a logarithmic scale, some energy levels of electrons in a copper atom. The actual energies in eV of each level are shown. The table in **Figure 10** illustrates how photon energies of K_α radiation depend on the proton number *Z* of the element used for three different targets.

Figure 8

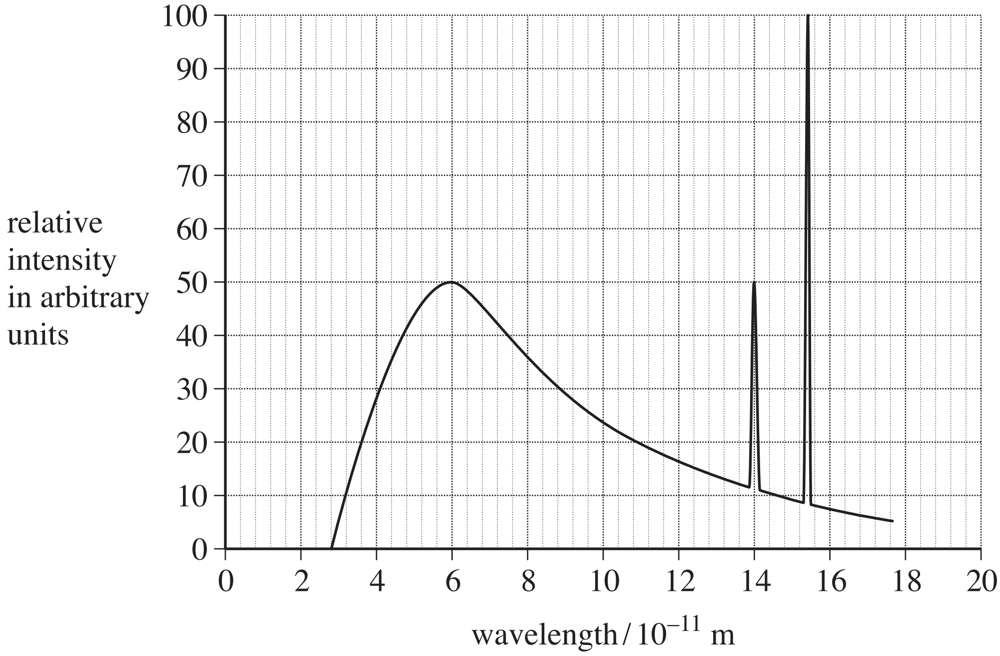

Figure 9

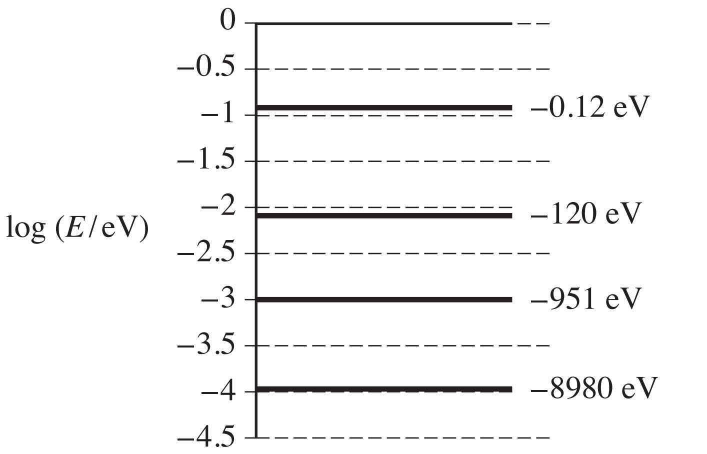

Figure 10

element	Z	K_α photon energy / keV
Chromium	24	5.40
Copper	29	8.03
Silver	47	22.10

6 (a) Show, on **Figure 9**, the electron transition that takes place when a photon of K_α radiation for copper is emitted.

(2 marks)

6 (b) Determine the potential difference that was used to accelerate the electrons that produced the X-ray spectrum shown in **Figure 8**.

potential difference V

(3 marks)

6 (c) Draw, on **Figure 8**, the spectrum that would be produced if the electrons were accelerated through a higher potential difference.

(3 marks)

6 (d) (i) Calculate the frequency of K_α radiation emitted by a silver target.

frequency .... Hz

(2 marks)

6 (d) (ii) Show that the data in **Figure 10** suggest that for different targets, the frequency of K_α radiation is directly proportional to $(Z–1)^2$.

(3 marks)

Turn over ▶

6 (e) State and explain which of the targets in **Figure 10** would produce K_α radiation that would produce the best resolution in an X-ray image of a patient.

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(2 marks)

6 (f) Describe and explain **one** method used in the design of an X-ray system used in medical diagnosis that reduces blurring of the final image.

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(2 marks)

6 (g) Ultrasound can also be used to produce images of the human body. Explain, in terms of the physical properties, the difference between the ways in which X-rays and ultrasound identify parts of the body that have different density.

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(2 marks)

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END OF QUESTIONS