

Centre Number						Candidate Number				
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For Examiner's Use	
Examiner's Initials	
Question	Mark
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TOTAL	



General Certificate of Education
Advanced Level Examination
June 2012

Physics (B): Physics in Context PHYB5

Unit 5 Energy under the microscope

Module 1 Matter Under the Microscope

Module 2 Breaking Matter Down

Module 3 Energy from the Nucleus

Monday 18 June 2012 9.00 am to 10.45 am

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.



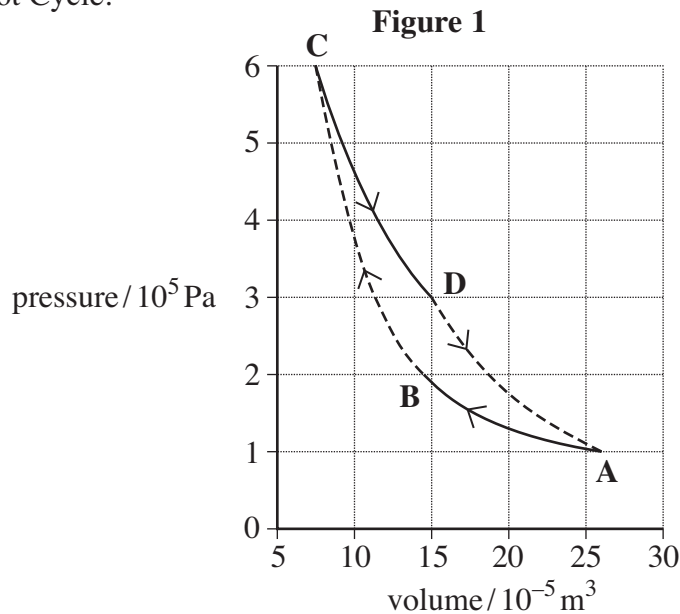
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WMP/Jun12/PHYB5

PHYB5

Answer **all** questions.

- 1 (a)** **Figure 1** shows the p - V diagram for the gas in a cylinder of an engine operating in a Carnot Cycle.



- 1 (a) (i)** In the table below tick each box that corresponds to an adiabatic change.

change	adiabatic
A → B	
B → C	
C → D	
D → A	

(2 marks)

- 1 (a) (ii)** State the quantity in the first law of thermodynamics that is zero (0) when the change is adiabatic.

.....
(1 mark)

- 1 (a) (iii)** State the quantity in the first law of thermodynamics that is zero when the change is isothermal.

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(1 mark)

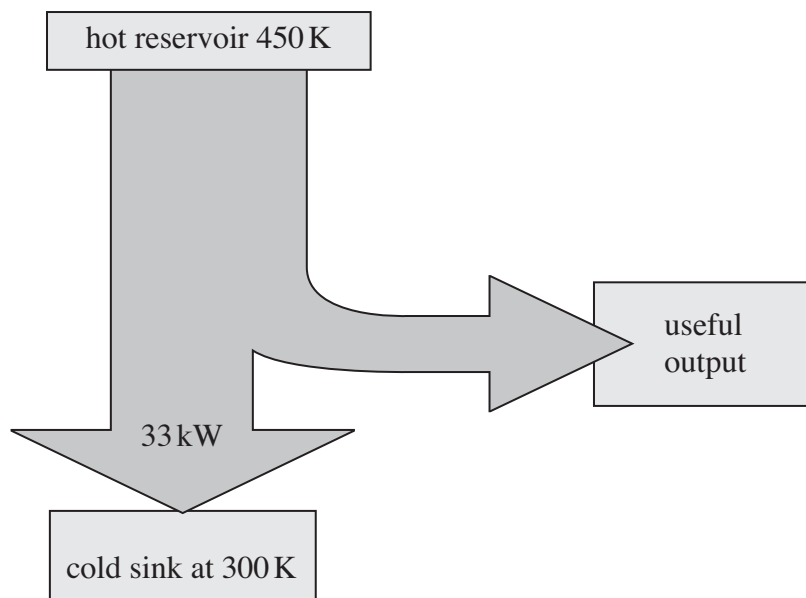
- 1 (a) (iv)** Describe how data from the p - V graph can be used to confirm that a change that takes place is an isothermal change.

.....
.....
.....
(2 marks)



- 1 (b)** An engineer designs a new engine and reports that, with a hot reservoir at a temperature of 450 K and a cold sink at a temperature of 300 K, each cylinder would deliver 33 kW to the cold sink, as shown in the Sankey diagram in **Figure 2**.

Figure 2



The engineer reported that $\frac{2}{5}$ of the energy supplied was useful energy. When drawing the Sankey diagram, the engineer forgot to include P_{hot} , the input power from the hot reservoir and P_{useful} , the useful output power of the engine.

- 1 (b) (i)** Calculate, in kW, the values for P_{hot} and P_{useful} that are consistent with the energy that the engineer recorded as passing into the cold sink.

P_{hot} kW

P_{useful} kW
(2 marks)

Turn over ►



- 1 (b) (ii)** The complete engine has 4 cylinders, each delivering 33 kW to the cold sink. Energy is transferred to the cold sink by pumping a coolant, consisting of water and antifreeze, through the engine block. The temperature of the coolant changes by 7.5 K as it passes through the block.

The specific heat capacity of the coolant is $3.1 \text{ kJ kg}^{-1} \text{ K}^{-1}$.

Calculate, in kg s^{-1} , the mass flow rate of the coolant that the designer's data would suggest.

Give your answer to an appropriate number of significant figures.

mass flow rate kg s^{-1}
(4 marks)

- 1 (c) (i)** Another engineer carries out a peer review and suggests that the reported efficiency of the cylinder is inconsistent with the temperatures that were quoted for the hot reservoir and cold sink in **Figure 2**.

Explain, with an appropriate calculation, whether or not you agree with the reviewer.

.....
.....
.....
.....
.....
.....
(4 marks)



- 1 (c) (ii)** Use your answers to part (b)(i) and data from **Figure 2** to calculate the total entropy change that would take place each second when the engine is operating.
Give an appropriate unit for your answer.

change in entropy unit
(3 marks)

- 1 (c) (iii)** Explain whether your answer to part (c)(ii) suggests that the operation of the engine has been reported correctly.

.....
.....
.....

(1 mark)

20

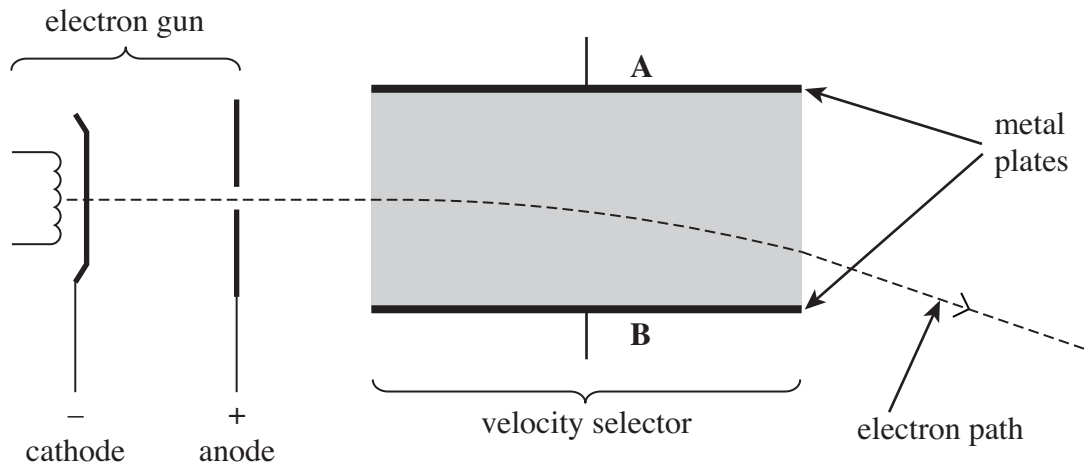
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- 2 **Figure 3** shows the path of electrons that have been accelerated in an electron gun and then pass through a velocity selector.

Figure 3



- 2 (a) (i) Electrons are produced at the cathode of the electron gun by thermionic emission. Explain what is meant by thermionic emission and why electrons produced are likely to have a range of speeds.

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(2 marks)

- 2 (a) (ii) The diagram shows the path of electrons that are moving at a speed of $4.5 \times 10^7 \text{ m s}^{-1}$. Calculate the accelerating potential difference between the cathode and anode in the electron gun that is required to produce electrons travelling at this speed. Assume that the electrons have zero velocity when they leave the cathode. Neglect the relativistic change in mass.

accelerating pd V
(3 marks)



- 2 (b)** In the shaded region shown in **Figure 3** it is possible to have either an electric field or a magnetic field, or both types of field at the same time when operating as a velocity selector.

In the situation shown in **Figure 3** there is a magnetic field but no electric field.

- 2 (b) (i)** Place a tick in the box that corresponds to the correct direction of the magnetic field.

Towards A	
Towards B	
Into the page	
Out of the page	

Explain how you decided on your answer.

.....

.....

(2 marks)

- 2 (b) (ii)** The magnetic flux density of the magnetic field is 1.4 mT.
Calculate the radius of the path of electrons that move at $4.5 \times 10^7 \text{ m s}^{-1}$.
Neglect the relativistic change in mass.

radius m
(3 marks)

Turn over ►



- 2 (c) (i)** Show that the theory of relativity predicts that the percentage change in the mass of an electron as it accelerates from rest to $4.5 \times 10^7 \text{ m s}^{-1}$ is about 1%.

percentage change in mass %
(4 marks)

- 2 (c) (ii)** State and explain the effects that the relativistic increase in mass would have on your answers for the accelerating potential difference calculated in part (a)(ii) and the radius of the path calculated in part (b)(ii).

potential difference

.....

.....

path radius

.....

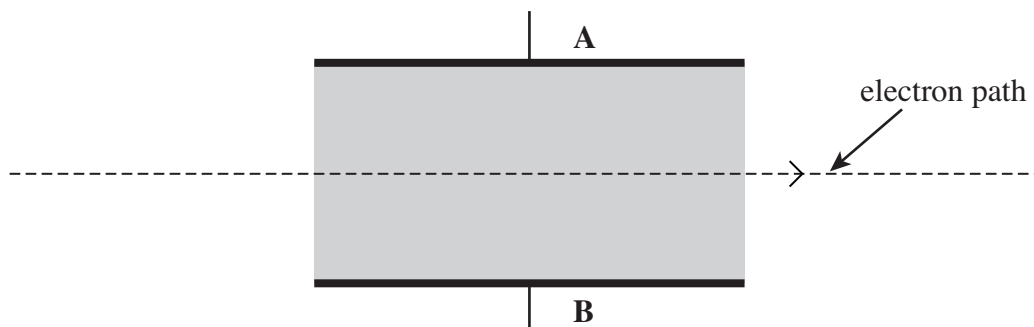
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(2 marks)



- 2 (d)** A potential difference is now applied across the gap between the plates **A** and **B**. This produces a uniform electric field in the shaded region between the metal plates in addition to the magnetic field of 1.4 mT. Electrons travelling at $4.5 \times 10^7 \text{ m s}^{-1}$ now pass straight through the velocity selector, as shown in **Figure 4**.

Figure 4



- 2 (d) (i)** State and explain which one of the metal plates **A** or **B** is positive.

.....

.....

.....

.....

(2 marks)

- 2 (d) (ii)** The metal plates are 35 mm apart.
Calculate the potential difference between the plates so that there is no deflection of the electron beam.

potential difference V
(4 marks)

22

Turn over ►



- 3** To investigate and treat an overactive thyroid gland either iodine-131($^{131}_{53}\text{I}$) or iodine-123($^{123}_{53}\text{I}$) can be used. Some properties of these nuclides are shown in the table.

nuclide	useful emissions	gamma ray energy/keV	half-life	decay constant/ s^{-1}
$^{131}_{53}\text{I}$	β^- and γ	360	8.04 days	9.98×10^{-7}
$^{123}_{53}\text{I}$	γ	160	13.0 hours	1.47×10^{-5}

Iodine-131 is produced by bombarding tellurium with neutrons in a nuclear reactor and is then transported to the hospital. Iodine-123 is produced using a cyclotron that is on-site. Iodine-123 decays by a process called electron capture in which the nucleus first captures an electron from an electron shell to form tellurium-123 which then almost immediately emits the gamma ray photon.

In one patient the biological decay constant for iodine is $4.4 \times 10^{-7} \text{ s}^{-1}$ so that the *biological half-life* is $1.6 \times 10^6 \text{ s}$.

- 3 (a) (i)** Two of the emissions from iodine-131 are shown in the table.
State the full name of the other particle that must be emitted when iodine-131 decays.

.....
(1 mark)

- 3 (a) (ii)** State the particle physics law that requires this particle to be emitted.

.....
.....
(1 mark)

- 3 (b) (i)** Explain what is meant by the biological half-life.

.....
.....
(2 marks)

- 3 (b) (ii)** Show that the effective half-life of iodine-131 when injected into the patient is about 5.6 days.

(3 marks)



3 (c) A doctor decides to administer a dose of iodine-123 to a patient. The dose must have an initial activity of 240 GBq.

3 (c) (i) Calculate the mass, in g, of iodine-123 that is required in the dose.

mass g
(4 marks)

3 (c) (ii) The effective half-life of iodine-123 can be assumed to be the same as the physical half-life.

Calculate the time taken, in hours, for the activity to fall to 15 GBq.

time hours
(2 marks)

3 (d) (i) Explain why iodine-123 has to be produced on-site whereas iodine-131 can be produced using a reactor that is some distance away.

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(2 marks)

Turn over ►



- 3 (d) (ii)** Give **two** reasons why iodine-123 might be preferred to iodine-131 for the treatment of a patient.

reason 1

.....

reason 2

.....

(2 marks)

- 3 (e)** Explain why the properties of radioactive iodine isotopes are useful for investigating whether a thyroid gland is operating normally and for treating an overactive thyroid. Include in your answer any medical or biological problems that may arise from the use of the radioactive isotopes.
The quality of your written communication will be assessed in your answer.

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(6 marks)

23



- 4** The Sun's energy is produced by the fusion of protons. Near the Sun's surface the protons have a mean kinetic energy of 0.75 eV which is too low for fusion to take place. The core, however, has a temperature of about 1.5×10^6 K and a pressure of about 1.0×10^{16} Pa. This core consists of a plasma of (mainly) protons. Within the core the density, pressure and temperature of the proton plasma are sufficiently high for nuclear fusion to occur.

The energy is thought to be produced mainly by a cycle called the hydrogen cycle. The overall effect in one cycle is that 4 protons fuse to form a helium nucleus. The total mass of hydrogen that fuses each second is 7.0×10^{11} kg of which about 5.0×10^9 kg per second is converted into energy that is radiated.

When answering the following questions assume, where necessary, that the plasma behaves like an ideal gas.

- 4 (a) (i)** Use the mean value of the kinetic energy of protons near the Sun's surface to calculate the temperature near its surface.

temperature near the Sun's surface K
(3 marks)

- 4 (a) (ii)** Calculate the closest distance of approach for two protons near the Sun's surface.

closest distance of approach m
(3 marks)

Turn over ►



4 (a) (iii) Explain why fusion cannot occur near the surface.

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(3 marks)

4 (b) (i) Calculate the number of protons in each cubic metre of the Sun's core.

number of protons
(3 marks)

4 (b) (ii) Calculate the density of the Sun's core.

density of the Sun's core kg m^{-3}
(2 marks)



- 4 (c) (i)** Show that the data given in the passage on page 13 suggest that every second, about 4×10^{38} protons fuse to form helium nuclei.

(2 marks)

- 4 (c) (ii)** The total binding energy of a helium nucleus is 4.5×10^{-12} J.
Determine with an appropriate calculation whether the mass that is converted into radiant energy, stated in the passage, is consistent with this value.

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(4 marks)

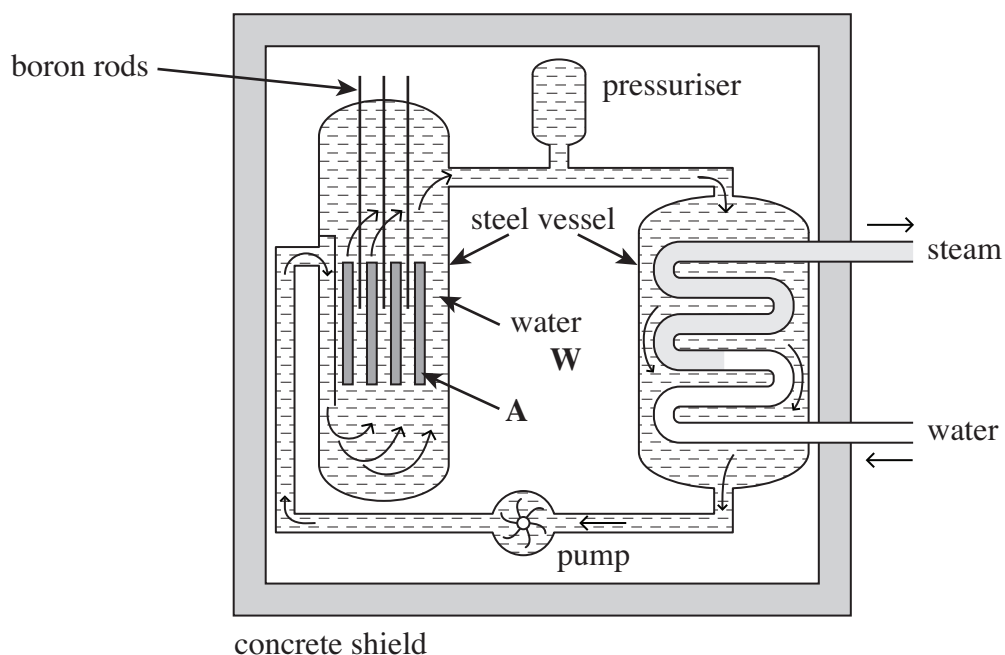
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Turn over ►



- 5 **Figure 5** shows a diagram of a nuclear reactor that is used to provide energy for a power station.

Figure 5



- 5 (a) (i) Describe the effect of raising the boron rods on the electrical power output of the power station.

.....

(1 mark)

- 5 (a) (ii) Explain why the power output is affected by the position of the boron rods.

.....

(2 marks)

- 5 (b) State the name of the component labelled **A** that is part of the reactor core.

.....

(1 mark)



- 5 (c)** The water labelled **W** has two functions. Name each function and discuss briefly the physics involved in each process.

function 1

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function 2

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.....

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(4 marks)

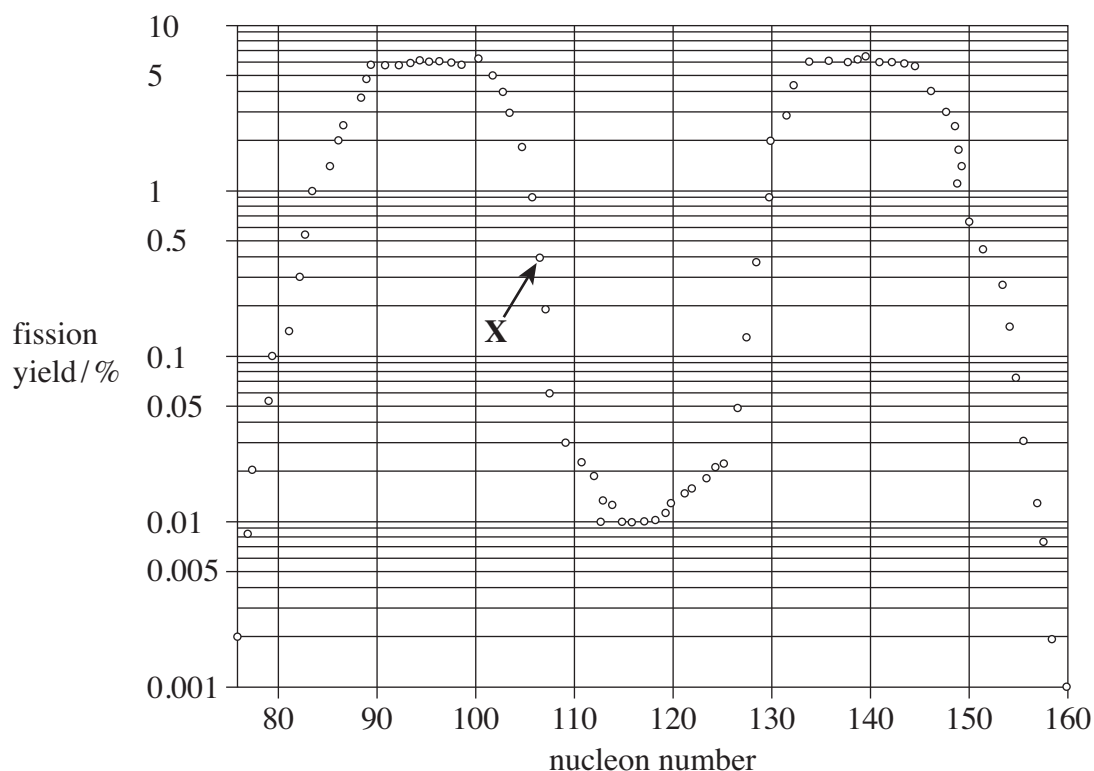
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- 5 (d)** A fission yield graph shows the relative amounts of some of the nuclei produced when neutron induced fission takes place in a nuclear reactor. The graph in **Figure 6** shows the fission yield of uranium-235. The fission yields are on the y-axis and are shown as a percentage using a logarithmic scale. About 2.9×10^{-11} J of energy is released when a nucleus undergoes fission.

Figure 6



- 5 (d) (i)** Estimate the percentage of the fission products that contains 90 nucleons.

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(1 mark)

- 5 (d) (ii)** Suggest the nucleon number of the nuclide that is likely to be produced at the same time as the nuclide labelled X on **Figure 6**.

.....
(1 mark)

- 5 (d) (iii)** Assume that when a nucleus in the reactor splits into two nuclei with the same number of nucleons, each nucleus takes half of the energy released.
Calculate the speed of the nuclei immediately after they are formed from uranium.

speed of nuclei m s^{-1}
(3 marks)

- 5 (d) (iv)** Explain why, when the nucleus splits to form two nuclei, they will have a lower speed than that calculated in part (d)(iii) and are unlikely to move in opposite directions following fission.

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(2 marks)

15

END OF QUESTIONS



There are no questions printed on this page

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ANSWER IN THE SPACES PROVIDED**

