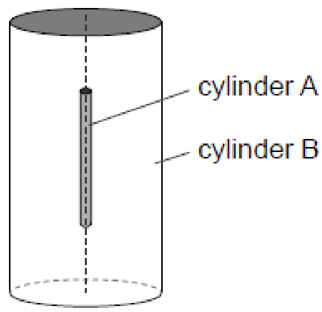
HL Paper 2

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).

At the start of the experiment, Rutherford and Royds put 6.2 x 10^{-4} mol of pure radium-226 in a small closed cylinder A. Cylinder A is fixed in the centre of a larger closed cylinder B.



The experiment lasted for 6 days. The decay constant of radium-226 is 1.4 x 10^{-11} s^{-1}.

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.

a. Write down the nuclear equation for this decay. [2]

b.i. Deduce that the activity of the radium-226 is almost constant during the experiment. [2]

b.ii. Show that about 3 x 10^{15} alpha particles are emitted by the radium-226 in 6 days. [3]

c.i. The wall of cylinder A is made from glass. Outline why this glass wall had to be very thin. [1]

c.ii. The experiment was carried out at a temperature of 18 °C. The volume of cylinder B was 1.3 x 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 over the 6 day period. Helium is a monatomic gas. [3]

Markscheme

a. $^{4}_{2}\alpha$

OR

$^{4}_{2}\mathrm{He}$

$^{222}_{86}\mathrm{Rn}$

*These **must** be seen on the right-hand side of the equation.*

b.i. ***ALTERNATIVE 1***

6 days is 5.18 x 10^5 s

activity after 6 days is $A_0 e^{-1.4\times10^{-11}\times5.8\times10^5} \approx A_0$

OR

A = 0.9999927 A_0 ***or*** 0.9999927 λN_0

OR

states that index of e is so small that $\frac{A}{A_0}$ is ≈ 1

OR

$A - A_0 \approx 10^{-15}$ «s^{-1}»

ALTERNATIVE 2

shows half-life of the order of 10^{11} s or 5.0 x 10^{10} s

converts this to year «1600 y» or days and states half-life much longer than experiment compared to experiment

*Award **[1 max]** if calculations/substitutions have numerical slips but would lead to correct deduction.*

eg: failure to convert 6 days to seconds but correct substitution into equation will give MP2.

Allow working in days, but for MP1 must see conversion of λ or half-life to day^{-1}.

b.ii ***ALTERNATIVE 1***

use of $A = \lambda N_0$

conversion to number of molecules = nN_A = 3.7 x 10^{20}

OR

initial activity = 5.2 x 10^9 «s^{-1}»

number emitted = (6 x 24 x 3600) x 1.4 x 10^{-11} x 3.7 x 10^{20} ***or*** 2.7 x 10^{15} alpha particles

ALTERNATIVE 2

use of $N = N_0 e^{-\lambda t}$

$N_0 = n \times N_A$ = 3.7 x 10^{20}

alpha particles emitted «= number of atoms disintegrated = $N - N_0$ =» $N_0\left(1 - e^{-\lambda\times6\times24\times3600}\right)$ ***or*** 2.7 x 10^{15} alpha particles

Must see correct substitution or answer to 2+ sf for MP3

c.i. alpha particles highly ionizing

OR

alpha particles have a low penetration power

OR

thin glass increases probability of alpha crossing glass

OR

decreases probability of alpha striking atom/nucleus/molecule

Do not allow reference to tunnelling.

c.ii.conversion of temperature to 291 K

p = 4.5 x 10^{-9} x 8.31 x «$\frac{291}{1.3\times10^{-5}}$»

OR

p = 2.7 x 10^{15} x 1.3 x 10^{-23} x «$\frac{291}{1.3\times10^{-5}}$»

0.83 ***or*** 0.84 «Pa»

Allow ECF for 2.7 x 10^{15} from (b)(ii).

Examiners report

a. [N/A]
b.i. [N/A]
b.ii. [N/A]
c.i. [N/A]
c.ii. [N/A]

A closed box of fixed volume 0.15 m^3 contains 3.0 mol of an ideal monatomic gas. The temperature of the gas is 290 K.

When the gas is supplied with 0.86 kJ of energy, its temperature increases by 23 K. The specific heat capacity of the gas is 3.1 kJ kg^{-1} K^{-1}.

Determine, in kJ, the total kinetic energy of the particles of the gas.

Markscheme

ALTERNATIVE 1

average kinetic energy = $\frac{3}{2}$1.38 × 10^{-23} × 313 = 6.5 × 10^{-21} «J»

number of particles = 3.0 × 6.02 × 10^{23} = 1.8 × 10^{24}

total kinetic energy = 1.8 × 10^{24} × 6.5 × 10^{-21} = 12 «kJ»

ALTERNATIVE 2

ideal gas so $U = KE$

KE = $\frac{3}{2}$8.31 × 131 × 3

total kinetic energy = 12 «kJ»

[3 marks]

Examiners report

[N/A]

0.46 mole of an ideal monatomic gas is trapped in a cylinder. The gas has a volume of 21 m^3 and a pressure of 1.4 Pa.

(i) State how the internal energy of an ideal gas differs from that of a real gas.

(ii) Determine, in kelvin, the temperature of the gas in the cylinder.

(iii) The kinetic theory of ideal gases is one example of a scientific model. Identify **two** reasons why scientists find such models useful.

Markscheme

i

«intermolecular» potential energy/PE of an ideal gas is zero/negligible

ii
THIS IS FOR USE WITH AN ENGLISH SCRIPT ONLY
use of $T = \frac{PV}{nR}$ ***or*** $T = \frac{1.4 \times 21}{0.46 \times 8.31}$
Award mark for correct re-arrangement as shown here not for quotation of Data Booklet version.
*Award **[2]** for a bald correct answer in K.*
*Award **[2 max]** if correct 7.7 K seen followed by –265°C and mark BOD. However, if only –265°C seen, award **[1 max]**.*

7.7K
Do not penalise use of "°K"

ii
THIS IS FOR USE WITH A SPANISH SCRIPT ONLY
$T = \frac{PV}{nR}$
Award mark for correct re-arrangement as shown here not for quotation of Data Booklet version.

$T = \frac{1.4 \times 2.1 \times 10^{-6}}{0.46 \times 8.31}$
Uses correct unit conversion for volume

T = 7.7×10^{-6}K
*Award **[2]** for a bald correct answer in K. Finds solution. Allow an ECF from MP2 if unit not converted, ie candidate uses 21m3 and obtains 7.7 K*
Do not penalise use of "°K"

iii
«models used to»
predict/hypothesize / lead to further theories
*Response needs to identify **two** different reasons. (**N.B.** only one in SL).*

explain / help with understanding / help to visualize
Do not allow any response that is gas specific. The question is couched in general, nature of science terms and must be answered as such.

simulate
simplify/approximate

Examiners report

[N/A]

This question is about an ideal gas.

a. Describe how the ideal gas constant R is defined. [2]

b. Calculate the temperature of 0.100 mol of an ideal gas kept in a cylinder of volume 1.40×10^{-3} m^3 at a pressure of 2.32×10^5 Pa. [1]

c. The gas in (b) is kept in the cylinder by a freely moving piston. The gas is now heated at constant pressure until the volume occupied by the gas is 3.60×10^{-3} m^3. The increase in internal energy of the gas is 760 J. Determine the thermal energy given to the gas. [2]

d. After heating, the gas is compressed rapidly to its original volume in (b). Outline why this compression approximates to an adiabatic change of state of the gas. [2]

Markscheme

a. defined from the equation of state of an ideal gas *PV=nRT*;

all symbols (*PVnT*) correctly identified;

b. 390/391 K;

c. work done$= \left(P\Delta V = 2.32 \times 10^5 \times 2.20 \times 10^{-3} =\right) 510\text{J};$

thermal energy$= (760 + 510 =)\, 1.27 \times 10^3\text{J};$

*Award **[1 max]** if volume is taken as 3.6×10^{-3}, giving an answer of 1600 J.*

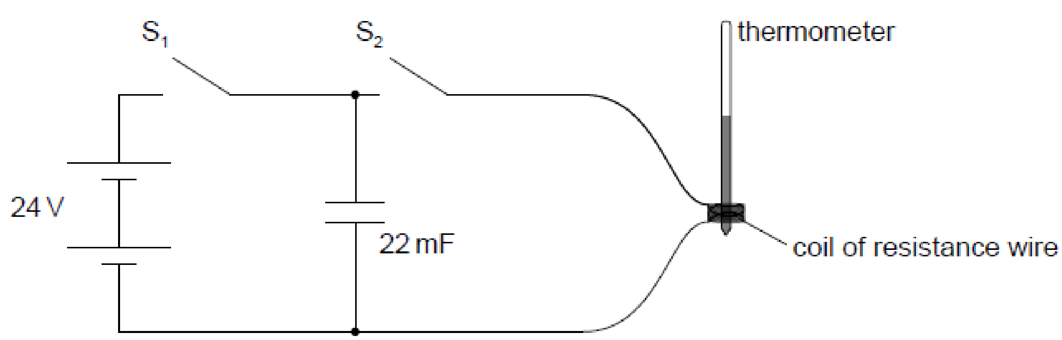
d. an adiabatic change is one in which no (thermal/heat) energy is transferred between system and surroundings / no energy enters/leaves system;

a rapid compression means that there is insufficient time (for energy transfer) / *OWTTE*;

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]

The electrical circuit shown is used to investigate the temperature change in a wire that is wrapped around a mercury-in-glass thermometer.



A power supply of emf (electromotive force) 24 V and of negligible internal resistance is connected to a capacitor and to a coil of resistance wire using an arrangement of two switches. Switch S_1 is closed and, a few seconds later, opened. Then switch S_2 is closed.

a. The capacitance of the capacitor is 22 mF. Calculate the energy stored in the capacitor when it is fully charged. [1]

b. The resistance of the wire is 8.0 Ω. Determine the time taken for the capacitor to discharge through the resistance wire. Assume that the capacitor is completely discharged when the potential difference across it has fallen to 0.24 V. [3]

c.i. The mass of the resistance wire is 0.61 g and its observed temperature rise is 28 K. Estimate the specific heat capacity of the wire. Include an appropriate unit for your answer. [2]

c.ii. Suggest **one** other energy loss in the experiment and the effect it will have on the value for the specific heat capacity of the wire. [2]

Markscheme

a. «$\frac{1}{2}CV^2 = \frac{1}{2} \times 0.22 \times 24^2$» = «J»

b. $\frac{1}{100} = e^{-\frac{t}{8.0 \times 0.022}}$

$\ln 0.01 = -\frac{t}{8.0 \times 0.022}$

0.81 «s»

c.i. $c = \frac{Q}{m \times \Delta T}$

OR

$\frac{6.3}{0.00061 \times 28}$

370 J kg^{-1} K^{-1}

Allow ECF from 3(a) for energy transferred.

Correct answer only to include correct unit that matches answer power of ten.

Allow use of g and kJ in unit but must match numerical answer, eg: 0.37 J kg^{-1} K^{-1} receives ***[1]***

c.ii. ***ALTERNATIVE 1***

some thermal energy will be transferred to surroundings/along connecting wires/to thermometer

estimate «of specific heat capacity by student» will be larger «than accepted value»

ALTERNATIVE 2

not all energy transferred as capacitor did not fully discharge

so estimate «of specific heat capacity by student» will be larger «than accepted value»

Examiners report

a. [N/A]

b. [N/A]

c.i. [N/A]

[N/A]

c.ii.

This question is about internal energy.

Humans generate internal energy when moving, while their core temperature remains approximately constant.

Distinguish between the concepts of internal energy and temperature.

Markscheme

internal energy:

total energy of component particles (in the human);

comprises potential energy + (random) kinetic energy;

temperature:
measure of average kinetic energy of particles;
indicates direction of (natural) flow of thermal energy;
internal energy measured in J and temperature measured in K/°C ; *(both needed)* {*(accept alternative suitable units)*

Examiners report

[N/A]

Part 2 Properties of a gas

a. With respect to a gas, explain the meaning of the terms thermal energy and internal energy. [2]

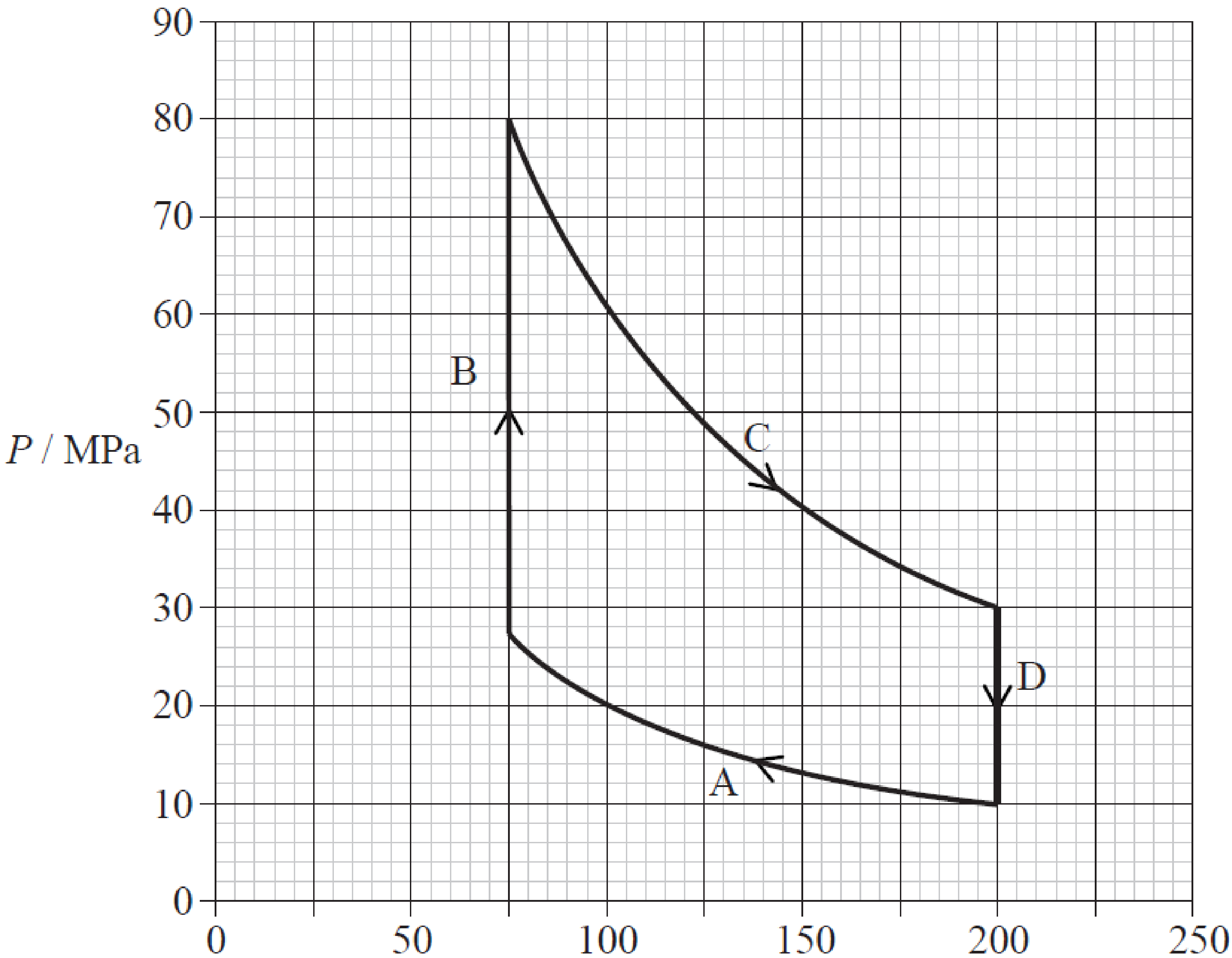
Thermal energy: . . . .

. . . .

Internal energy: . . . .

. . . .

b. The graph shows how the pressure *P* of a sample of a fixed mass of an ideal gas varies with volume *V*. The gas is taken through a cycle **ABCD.** [10]



V / 10^{-6} m^3

(i) Estimate the net work done during the cycle.

(ii) Explain whether the net work is done on the gas or by the gas.

(iii) Deduce, using the data from the graph, that the change **C** is isothermal.

(iv) Isothermal change **A** occurs at a temperature of 450 K. Calculate the temperature at which isothermal change **C** occurs.

(v) Describe the changes **B** and **D**.

Markscheme

a. *(Q)* energy transferred between two objects (at different temperatures);

(U) (total) potential energy and (random) kinetic energy of the molecules/particles (of the gas);

b. (i) use of area within cycle;

each large square has work value of 250 (J);

estimate (16 x 250=)4000 (J); (allow 3600 – 4100)

*Award **[3]** for same outcome with small squares of area 10 (J).*

(ii) (work is done by the gas because) area under expansion is greater than that under compression/pressure during expansion is greater than during compression;

(iii) clear attempt to compare two *PV* values;
evaluate two *PV* values correctly *eg* 75 x 80= 6000 and 200 x 30= 6000;

(iv) use of *PV* =*nRT* or equivalent;
1350/1330 (K);

(v) both changes are isochoric/isovolumetric/constant volume changes;
B: temperature/internal energy increases, D: temperature/internal energy decreases;
B: thermal energy/heat input (to system), D: thermal energy/heat output (from system);
B: pressure increases, D: pressure decreases;

Examiners report

a. Few candidates were able to explain thermal energy was the energy transfer between two objects at different temperatures. Many knew the definition of internal energy but a high percentage omitted to mention the potential energy (probably assuming that the gas was ideal).

b. (i) Many candidates appeared to attempt to calculate area without actually saying what they were doing; although this was obvious when they referred to the area of a square, in many case it was not obvious and marks were lost when the candidates technique produced an answer out of tolerance. In examples like this there will be a reasonable tolerance for the area and it is not expected that candidates will waste considerable time in counting the small squares.

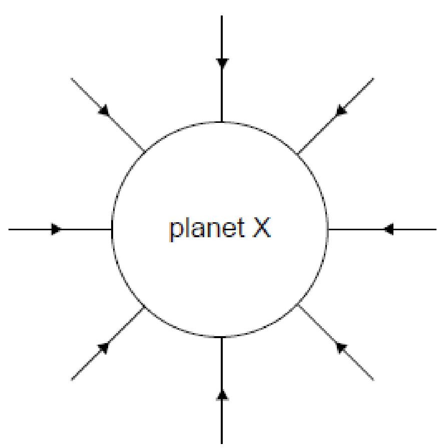
(ii) Although some candidates were aware that a clockwise cycle applies to net work done by the gas, this does not explain the choice. Simply saying that the area under the expansion was greater than the area under the compression was all that was needed.

(iii) This part was mostly well done by candidates. It is accepted, in line with SL A1, that showing constancy of two PV values does not prove that the change is isothermal; however in terms of deducing that the change is isothermal this technique is fine – that is, the candidates are told that it is isothermal and they are simply illustrating that this is the case. Often examiners will expect three values to be taken in questions such as this.

(iv) This part was well done by those many candidates who used any appropriate variant of the ideal gas equation to calculate the temperature.

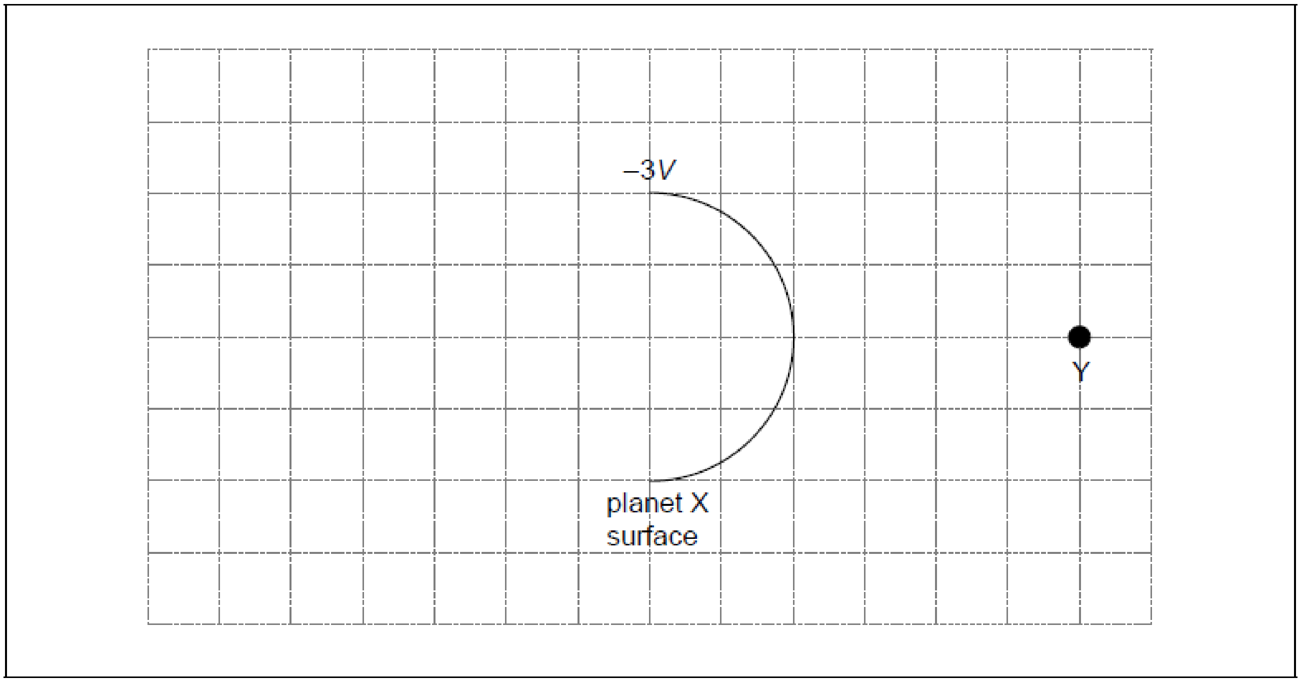
(v) The large majority of candidates did well here although a minority were deducted marks when they used contradictory statements such as isochoric and compression or expansion.

The diagram shows the gravitational field lines of planet X.



a. Outline how this diagram shows that the gravitational field strength of planet X decreases with distance from the surface. [1]

b. The diagram shows part of the surface of planet X. The gravitational potential at the surface of planet X is –3*V* and the gravitational potential at point Y is –*V*. [2]



Sketch on the grid the equipotential surface corresponding to a gravitational potential of −2*V*.

c. A meteorite, very far from planet X begins to fall to the surface with a negligibly small initial speed. The mass of planet X is 3.1 × 10^{21} kg and its radius is 1.2 × 10^{6} m. The planet has no atmosphere. Calculate the speed at which the meteorite will hit the surface. [3]

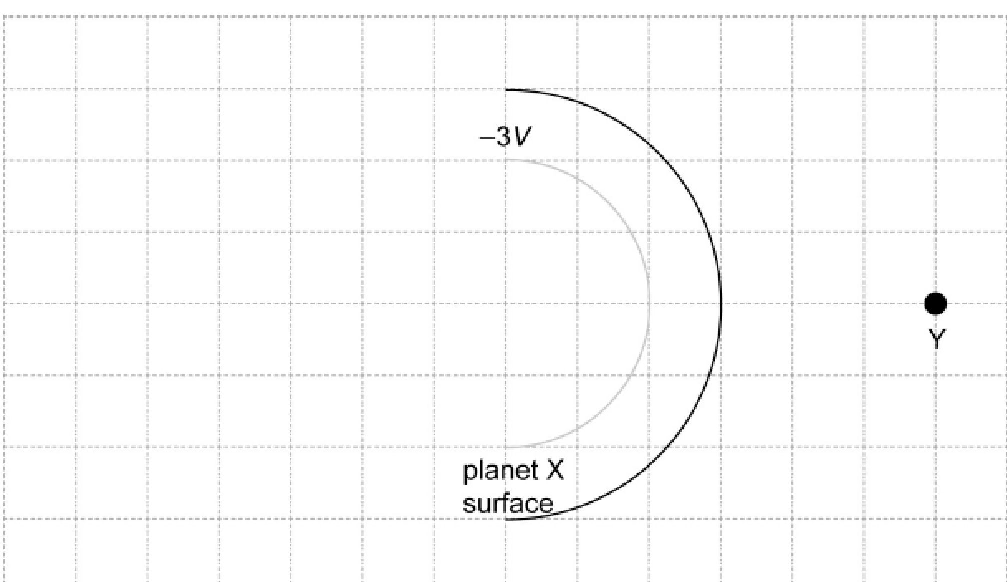
d. At the instant of impact the meteorite which is made of ice has a temperature of 0 °C. Assume that all the kinetic energy at impact gets transferred into internal energy in the meteorite. Calculate the percentage of the meteorite's mass that melts. The specific latent heat of fusion of ice is 3.3 × 10^{5} J kg^{-1}. [2]

Markscheme

a. the field lines/arrows are further apart at greater distances from the surface

b. circle centred on Planet X

three units from Planet X centre



c. loss in gravitational potential = $\frac{6.67\times10^{-11}\times3.1\times10^{21}}{1.2\times10^{6}}$

«= 1.72 × 10^5 JKg^{-1}»

equate to $\frac{1}{2}v^2$

v = 590 «m s^{-1}»

Allow ECF from MP1.

d. available energy to melt one kg 1.72 × 10^5 «J»

fraction that melts is $\frac{1.72\times10^{5}}{3.3\times10^{5}}$ = 0.52 ***OR*** 52%

Allow ECF from MP1.

Allow 53% from use of 590 ms^{-1}.

Examiners report

a. [N/A]
b. [N/A]
c. [N/A]
d. [N/A]