# TOPIC 11 Thermodynamics

**1** A fixed mass of gas undergoes the cycle of changes *WXYZW* (see Fig. 1). The shaded area represents the difference in magnitude between the amounts of work done during

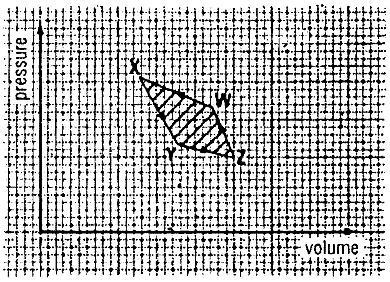



**Fig. 1**

| | | | |
|---|---|---|---|
| **A** | *WX* and *YZ*. | **D** | *ZWX* and *XYZ*. |
| **B** | *ZW* and *XY*. | **E** | *WXY* and *YZW*. |
| **C** | *WX* and *ZW*. | | |

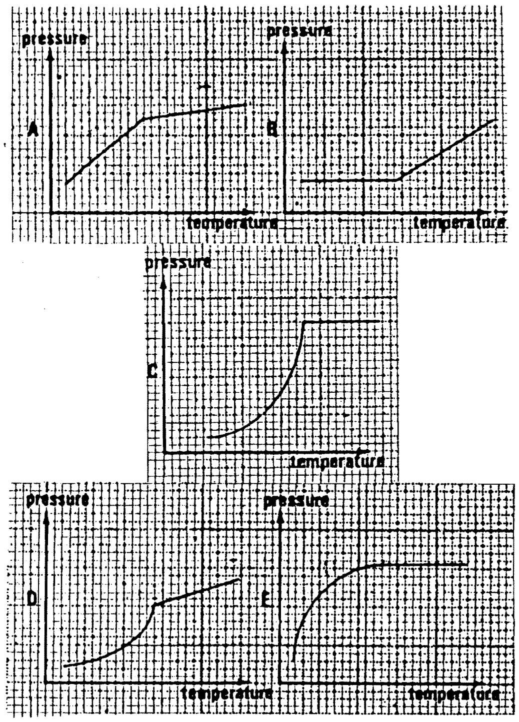
J76/II/27

**2** The first law of thermodynamics is a statement which implies that

**A** no heat enters or leaves a system.
**B** the change in internal energy equals the external work done.
**C** the temperature remains constant.
**D** all work is mechanical.
**E** energy is conserved.

J76/II/28; N91/I/24

**3** A small quantity of water, sealed into a strong metal container, was heated continuously to a temperature above that at which the last of the water evaporated. Which graph best illustrates the variation of pressure in the container with temperature?




J76/II/38

**4** A piece of brass undergoes 3 different processes involving change of energy:

P : it is lifted vertically 2 m
Q : it is heated from 15 °C to 20 °C
R : it is accelerated from rest to 10 m s$^{-1}$.

Given that the specific heat capacity of brass is 380 J K$^{-1}$ kg$^{-1}$ and that $g$ = 10 m s$^{-2}$, the processes, arranged in order of increasing energy change, are

| | | | |
|---|---|---|---|
| **A** | *PQR* | **D** | *PRQ* |
| **B** | *QPR* | **E** | *RQP* |
| **C** | *QRP* | | |

N77/II/3

**5** An immersion heater takes time $T_1$ to raise the temperature of a mass $M$ of a liquid from a temperature $t_1$ to its normal boiling point $t_2$. In a further time $T_2$, a mass $m$ of the liquid is vaporised. If the specific heat capacity of the liquid is $c$ and heat losses to the atmosphere and to the containing vessel are ignored, the specific latent heat of vaporisation is

**A** $\dfrac{Mc\,(t_2 - t_1)\,T_2}{mT_1}$  **D** $\dfrac{mT_1}{Mc\,(t_2 - t_1)\,T_2}$

**B** $\dfrac{mc\,(t_2 - t_1)\,T_2}{MT_1}$  **E** $\dfrac{mT_1}{Mct_1T_2}$

**C** $\dfrac{Mct_1T_2}{mT_1}$

N77/II/29

**6** The specific latent heat of vaporisation of water at 20 °C is appreciably greater than the value at 100 °C. This is because

**A** the specific latent heat at 20 °C includes the energy necessary to raise the temperature of one kilogram of water from 20 °C to 100 °C.
**B** more work must be done in expanding the water vapour against atmospheric pressure at 20 °C than at 100 °C.
**C** the molecules in the liquid are more tightly bound to one another at 20 °C than at 100 °C.
**D** the root mean square speed of the vapour molecules is less at 20 ° C than at 100 °C.
**E** the saturated vapour pressure of water is greater at 20 °C than at 100 °C.

N77/II/39

**7** In determining the specific heat capacity of a liquid using the constant-flow method, the experiment is normally repeated so that heat loss from the flow tube may be eliminated in the calculation. If the inlet temperature and room temperature are unchanged, which one of the following quantities must also be the same in the two experiments?

**A** the electrical power input
**B** the rate of liquid flow
**C** the period of collection of the liquid
**D** the outlet temperature
**E** the mass of liquid collected

J78/II/27

8 In the continuous flow method for determining the specific heat capacity of a liquid, the experiment is usually repeated in order to correct for heat losses. Which one of the following should be kept the same in the two experiments?

A the power dissipated by the heating coil
B the pressure 'head' causing the liquid flow
C the time for which the liquid flows
D the mass of liquid collected
E the inlet and outlet temperatures J79/II/27; J83/II/27

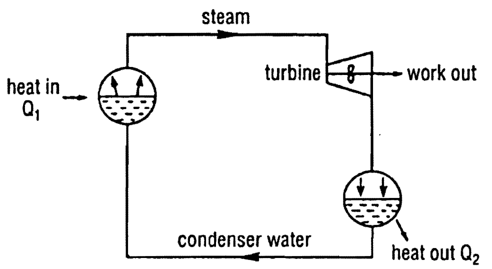
9 In a constant flow determination of the specific heat capacity of a liquid, it is important to allow for any heat losses. This can be done by repeating the experiment using the same

A temperatures, heat input and flow rate.
B temperature but different heat input and flow rate.
C flow rate but different temperatures and heat input.
D heat input but different temperatures and flow rate.
E temperatures and flow rate but different heat input.
N79/II/29; J82/II/30

10 A ideal gas, contained in a cylinder by a frictionless piston, is allowed to expand from volume $V_1$, at pressure $p_1$, to volume $V_2$, at pressure $p_2$. Its temperature is kept constant throughout. The work done by the gas is

A zero, because it obeys Boyle's Law and therefore $p_2V_2 - p_1V_1 = 0$.
B negative, because the pressure has decreased and so the force on the piston has been diminishing.
C zero, because it has been kept at constant temperature and so its internal energy is unchanged.
D positive, because the volume has increased.
E zero, because intermolecular forces are negligible in an ideal gas N78/II/28

11 A steam turbine cycle is shown diagrammatically below.




If heat only enters and leaves through the boiler and condenser, then, when the system is working steadily, heat $Q_1$ is absorbed in the boiler in the same time that heat $Q_2$ is rejected in the condenser. The fraction of heat converted into work is

A $\frac{Q_1 - Q_2}{Q_1}$
B $\frac{Q_2 - Q_1}{Q_1}$
C $\frac{Q_1 - Q_2}{Q_2}$
D $\frac{Q_1 - Q_2}{Q_1 + Q_2}$
E $\frac{Q_2}{Q_1}$

N78/II/29; J81/II/26

12 The specific latent heat of vaporisation of water is 2.25 MJ $kg^{-1}$. The relative molecular mass of water is 18. It follows that the molar latent heat of vaporisation of water is

A 40.5 MJ $mol^{-1}$
B 20.3 MJ $mol^{-1}$
C 250 kJ $mol^{-1}$
D 125 kJ $mol^{-1}$
E 40.5 kJ $mol^{-1}$ N78/II/31

13 One mole of an ideal gas is contained within a cylinder by a frictionless piston and is initially at temperature $T$. The pressure of the gas is kept constant while it is heated and its volume doubles. If $R$ is the molar gas constant, the work done by the gas in increasing its volume is

A $RT\ln 2$
B $\frac{1}{2}RT$
C $RT$
D $\frac{3}{2}RT$
E $2RT$ N79/II/27

14 A fixed mass of gas undergoes changes of pressure and volume as shown in Fig. 2.

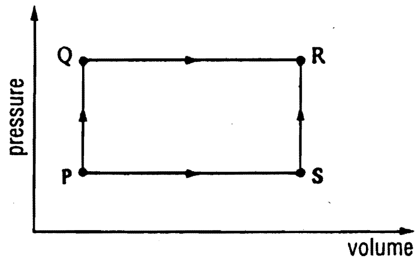



**Fig. 2**

When the gas is taken from state P to state R by the stages PQ and QR, 8 J of heat are absorbed by it and 3 J of work are done by it. When the same resultant change is achieved by stages PS and SR, 1 J of work is done by the gas. In this case,

A 12 J of heat are rejected.
B 10 J of heat are absorbed.
C 8 J of heat are absorbed.
D 6 J of heat are absorbed.
E 4 J of heat are rejected. N79/II/31; J83/II/29

15 Latent heat of vaporisation is the energy required to

A separate the molecules of the liquid.
B force back the atmosphere to make space for the vapour.
C increase the average molecular speed in the liquid phase to that in the gas phase.
D separate the molecules and to force back the atmosphere.
E separate the molecules and to increase their average molecular speed to that in the gas phase.
N79/II/32; N82/II/39

16 The internal energy of a fixed mass of an ideal gas depends on

A pressure, but not volume or temperature.
B temperature, but not pressure or volume.
C volume, but not pressure or temperature.
D pressure and temperature, but not volume.

J80/II/31; N83/II/29; N94/I/24

17 One mole of an ideal gas undergoes an isothermal change at a temperature $T$ so that its volume $V$ is doubled. With $R$ as the molar gas constant, the work done by the gas during this change is

A $RTV$
B $RT\ln V$
C $2RT$
D $RT\ln 2$
E $RT\ln(2V)$

J80/II/32

18 Neglecting surface tension effects and taking the specific latent heat of vaporisation of water as $l$ and its density as $\rho$, the heat energy required to evaporate a spherical drop of water so that its radius changes from $r$ to $(r - \delta r)$ is

A $\frac{4}{3}\pi r^3 \rho l \delta r$
B $4\pi r^2 \rho l \delta r$
C $\frac{4}{3}\pi(\delta r)^3 \rho l$
D $4\pi(\delta r)^2 \rho l$
E $8\pi r \rho l \delta r$

J80/II/35

19 A solid object of mass $M$ is made from material of specific heat capacity $c$, of specific latent heat of fusion $l$ and of very high thermal conductivity. When the object enters the atmosphere from outer space, its temperature is below its melting point by $\Delta T$. Because of atmospheric friction, it absorbs energy at a constant net rate of $R$. The time before the solid becomes completely molten is given by

A $\dfrac{M(c + l)\,\Delta T}{R}$
B $\dfrac{M(c\Delta T + l)}{R}$
C $M(c+l)\Delta TR$
D $\dfrac{R}{M\Delta T\,(c + l)}$
E $\dfrac{R}{M(c\Delta T + l)}$

N80/II/31

20 An ideal gas of volume $1.5 \times 10^{-3}$ m$^3$ and at pressure $1.0 \times 10^5$ Pa is supplied with 70 J of energy. The volume increases to $1.7 \times 10^{-3}$ m$^3$, the pressure remaining constant. The internal energy of the gas is

A increased by 90 J
B increased by 70 J
C increased by 50 J
D decreased by 50 J
E decreased by 80 J

N80/II/33

21 When using a simple constant flow calorimeter, the result calculated from one set of readings might be better than the result after subtracting two sets to eliminate heat loss. This is because

A the increased effect of random errors when subtracting might outweigh the elimination of the systematic heat loss error.
B the mercury thermometers used in simple apparatus have a scale which differs from the ideal gas scale.
C the rate of flow might be different in the two experiments.
D the systematic error of heat loss doubles as the experiment is repeated.
E the power supplied might not be the same in the two experiments.

J81/II/27

22 The first law of thermodynamics can be stated in the form

$$\Delta U = \Delta Q + \Delta W,$$

where $\Delta U$ is the increase in the internal energy of the system,
$\Delta Q$ is the heat supplied to the system,
$\Delta W$ is the external work done on the system.

Which of $\Delta U$, $\Delta Q$ and $\Delta W$ are necessarily zero for an ideal gas which undergoes an adiabatic change?

A only $\Delta U$
B only $\Delta Q$
C only $\Delta W$
D none of $\Delta U$, $\Delta Q$ and $\Delta W$
E all of $\Delta U$, $\Delta Q$ and $\Delta W$

J81/II/31

23 A sample of an ideal gas initially having internal energy $U_1$ is allowed to expand adiabatically performing external work $W$. Heat $Q$ is then supplied to it, keeping the volume constant at its new value, until the pressure rises to its original value. The internal energy is then $U_2$. (See Fig. 3.)

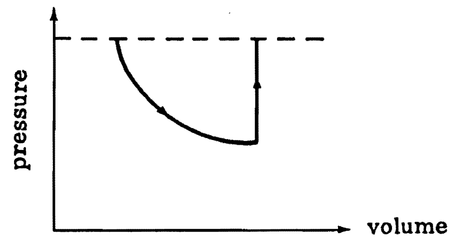



Fig. 3

The increase in internal energy, $U_2 - U_1$ is equal to

A zero
B $W$
C $Q$
D $Q - W$
E $W - Q$

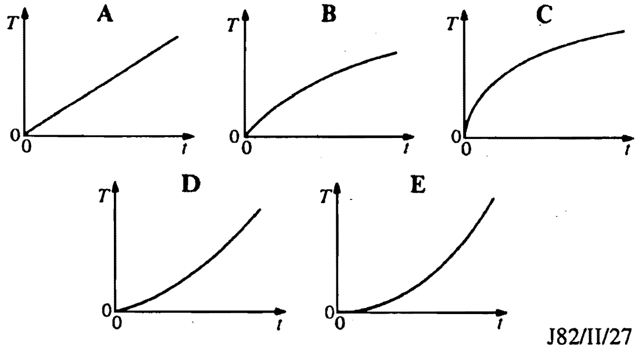
N81/II/27

24 If a block of ice is ejected into space from a spacecraft and remains distant from any other matter, the ice block will

A maintain its original temperature and mass.
B vaporise instantaneously and completely.
C vaporise at a constant rate and without change in temperature until it is completely vaporised.
D vaporise at a constant rate until its temperature has fallen to 0 K.
E vaporise at a progressively slower rate as its temperature falls.

N81/II/32

**25** The heat capacities of some solids at temperatures close to 0 K are given by an equation of the form $C = aT^3$, where $T$ is the temperature and $a$ is a constant characteristic of the solid. If heat is supplied to such a solid at a steady rate, which one of the following graphs best represents the variation of its temperature $T$ with time $t$?




J82/II/27

**26** When a monatomic ideal gas undergoes an isothermal change,

**A** the number of degrees of freedom of the molecules changes.
**B** the temperature changes.
**C** there is no change of internal energy.
**D** there is no exchange of heat with the surroundings.
**E** no external work is done. J82/II/28

**27** Two equal masses of an ideal gas initially at s.t.p. are compressed to half of their initial volumes, one of them isothermally, and the other while thermally isolated from its surroundings. Which one of the following is the same for both samples of gas?

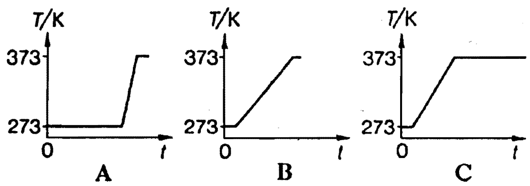
**A** the heat given out during compression
**B** the temperature of the compressed gas
**C** the internal energy of the compressed gas
**D** the density of the compressed gas
**E** the work done on the gas during compression

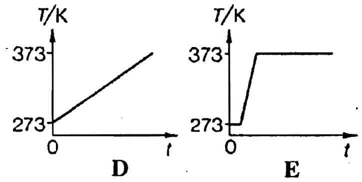
N82/II/30; J85/I/25

**28** A constant power supply is used to melt 1 kg of ice, to heat the water produced, and finally to turn all the water to steam.

| | |
|---|---|
| specific heat capacity of water | $= 4 \times 10^3$ J kg$^{-1}$ K$^{-1}$ |
| specific latent heat of fusion of ice | $= 3 \times 10^5$ J kg$^{-1}$ |
| specific latent heat of vaporisation of water | $= 2 \times 10^6$ J kg$^{-1}$ |

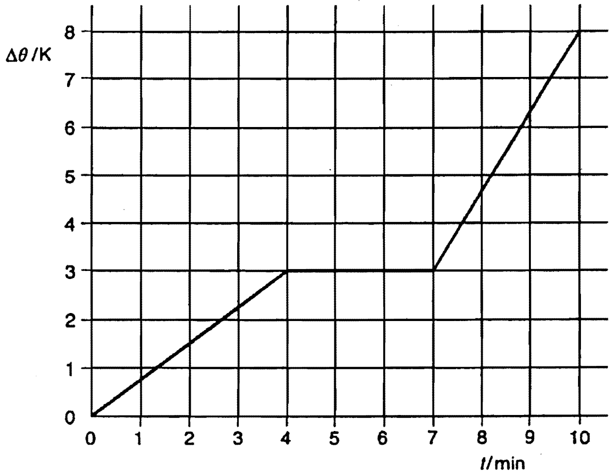
Which graph best shows how the thermodynamic temperature $T$ varies with time $t$ for this sequence?




J83/II/32; J91/I/25

**29** The graph shows the variation of temperature change $\Delta\theta$ with time $t$ for 1 kg of a substance, initially solid at room temperature. The substance is heated at a uniform rate of 2000 J min$^{-1}$.




What can be deduced from this graph?

**A** After 4 min of heating, the substance is all liquid.
**B** After 10 min of heating the substance is all gaseous.
**C** The specific heat capacity of the substance is greater when liquid than when solid.
**D** The specific latent heat of fusion of the substance is 6000 J kg$^{-1}$. N92/I/23; J98/I/24

**30** A fixed mass of gas undergoes the cycle of changes represented by PQRSP as shown in Fig. 4 below. In some of the changes, work is done on the gas and, in others, work is done by the gas.

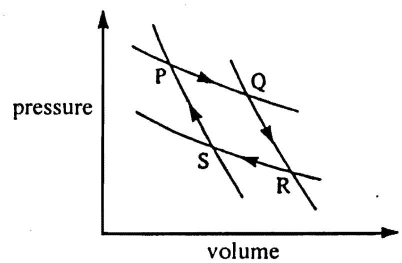



**Fig. 4**

In which pair of the changes is work done on the gas?

**A** PQ and RS
**B** PQ and QR
**C** QR and RS
**D** QR and SP
**E** RS and SP J84/II/30

**31** A fixed mass of gas in a thermally insulated container is compressed. After compression, the temperature of the gas will have

A fallen, since more molecules bombard the container and so they must be moving slower.

B fallen, since the molecules collide more frequently with one another and so their average speed is lower.

C remained constant if the compression is very slow.

D risen, since doing work on the gas increases the kinetic energy of the molecules.

E risen, since there are more intermolecular collisions and so more heat is produced by them. J84/II/31

**32** The molar heat capacity of chromium at room temperature is 24 J $K^{-1}$ $mol^{-1}$ and its relative atomic mass is 52. What is the specific heat capacity of chromium?

**A** 0.46 J $K^{-1}$ $kg^{-1}$ **D** 460 J $K^{-1}$ $kg^{-1}$
**B** 1.2 J $K^{-1}$ $kg^{-1}$ **E** 1200 J $K^{-1}$ $kg^{-1}$
**C** 2.2 J $K^{-1}$ $kg^{-1}$ N84/II/27

**33** A fixed mass of an ideal gas undergoes the changes represented by XYZX below (Fig. 5).

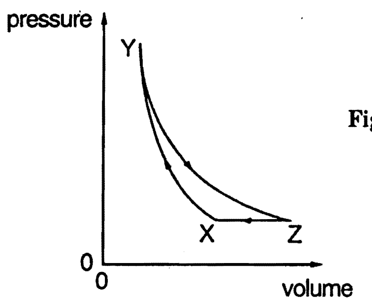



**Fig. 5**

Which one of the following sets could describe this set of changes?

| | XY | YZ | ZX |
|---|---|---|---|
| **A** | isothermal expansion | adiabatic compression | compression at constant pressure |
| **B** | adiabatic expansion | isothermal compression | pressure reduction at constant volume |
| **C** | isothermal compression | adiabatic expansion | compression at constant pressure |
| **D** | adiabatic compression | isothermal expansion | pressure reduction at constant volume |
| **E** | adiabatic compression | isothermal expansion | compression at constant pressure |

N84/II/28

**34** The first law of thermodynamics states that $\Delta U$ the change of internal energy of a system is related to $\Delta Q$ the heat supplied to it and $\Delta W$ the work done on it by the equation

$$\Delta U = \Delta Q + \Delta W.$$

What are $\Delta Q$, $\Delta U$ and $\Delta W$ for a constant mass of ideal gas which is cooled at constant pressure?

| | $\Delta U$ | $\Delta Q$ | $\Delta W$ |
|---|---|---|---|
| **A** | negative | negative | positive |
| **B** | negative | negative | zero |
| **C** | zero | negative | positive |
| **D** | negative | zero | negative |
| **E** | positive | zero | positive |

J85/I/24

**35** A sample of an ideal gas may (i) expand adiabatically, or (ii) expand isothermally. The net flow of heat into the gas from the exterior is

**A** positive in each case.
**B** negative for (i) and positive for (ii).
**C** positive for (i) and negative for (ii).
**D** zero in each case.
**E** zero in (i) and positive for (ii). N85/I/25

**36** A fixed mass of an ideal gas slowly absorbs 1000 J of heat and as a result expands slowly, at a constant pressure of $2.0 \times 10^4$ Pa, from a volume of 0.050 $m^3$ to a volume of 0.075 $m^3$. What is the effect on the internal energy of the gas?

**A** It decreases by 1000 J. **D** It increases by 500 J.
**B** It decreases by 500 J. **E** It increases by 1000 J.
**C** It is unchanged. J86/I/25; N90/I/24

**37** A fixed mass of an ideal gas absorbs 1000 J of heat and expands under a constant pressure of 20 kPa from a volume of $25 \times 10^{-3}$ $m^3$ to a volume of $50 \times 10^{-3}$ $m^3$.

What is the change in internal energy of the gas?

**A** −1000 J **D** +500 J
**B** −500 J **E** +1000 J
**C** zero N93/I/23

**38** With the usual notation, the first law of thermodynamics applied to one mole of an ideal gas can be written in the following form.

$$C_V \Delta T = \Delta Q - p\Delta V$$

In a change for which Boyle's law is obeyed, which of the following would necessarily be zero?

**A** $\Delta Q$ **D** $p$
**B** $C_V$ **E** $\Delta V$
**C** $\Delta T$ N86/I/24

**39** Which one of the following statements expresses the first law of thermodynamics as applied to a gas?

| | | | | | |
|---|---|---|---|---|---|
| **A** | the increase in its internal energy | = | the heat supplied to a gas | + | the work done on the gas |
| **B** | the increase in its internal energy | = | the heat supplied to a gas | + | the work done by the gas |
| **C** | the heat supplied to a gas | = | the increase in it internal energy | + | the work done on the gas |
| **D** | the work done by a gas | = | the increase in its internal energy | + | the heat supplied to the gas |
| **E** | the work done by a gas | = | the increase in its internal energy | + | the heat extracted from the gas |

J87/I/24

**40** The first law of thermodynamics can be stated in the form:

$$\Delta U = \Delta Q + \Delta W$$

$\Delta U$ is the *increase* in the internal energy of the system;
$\Delta Q$ is the heat supplied *to* the system;
$\Delta W$ is the external work done *on* the system.

Which of the quantities $\Delta U$, $\Delta Q$ and $\Delta W$ are necessarily zero when the system is an ideal gas that undergoes a change at constant temperature?

**A** $\Delta U$ only
**B** $\Delta Q$ only
**C** $\Delta W$ only
**D** none of $\Delta U$, $\Delta Q$, $\Delta W$
**E** all of $\Delta U$, $\Delta Q$, $\Delta W$

N87/I/23

**41** The first law of thermodynamics may be written

$$\Delta U = Q + W$$

where $\Delta U$ is the increase in internal energy of the system, $Q$ is the heat transfer to the system and $W$ is the external work done on the system.

Which of the following is correct for the case of an isothermal expansion of an ideal gas?

**A** $W > 0$
**B** $W = 0$
**C** $\Delta U = 0$
**D** $\Delta U > 0$
**E** $Q = 0$

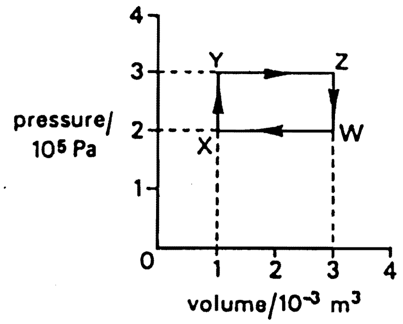
N88/I/25

**42** Air is injected from a cylinder of compressed air into a balloon of volume $V$, causing its diameter to double. What is the work done against the pressure $p$ of the atmosphere?

**A** $pV$ **B** $3pV$ **C** $4pV$ **D** $7pV$ **E** $8pV$

J89/I/5

**43** A gas undergoes the cycle of pressure and volume changes W→X→Y→Z→W shown in the diagram.




What is the net work done *by* the gas?

**A** −600 J
**B** −200 J
**C** 0 J
**D** 200 J
**E** 600 J

N89/I/3

**44** When a frictionless and well-insulated bicycle pump is used to pump up a tyre, the air in the tyre becomes hotter than the surrounding air. Which of the following statements best explains this observation?

**A** After compression the air molecules collide more frequently.

**B** Thermal energy is supplied to the air during the pumping action but the internal energy remains unchanged.

**C** Work is done on the air and the internal energy remains unchanged.

**D** Work is done on the air and since little thermal energy escapes the internal energy increases.

**E** The internal energy increases because thermal energy is supplied and work is done on the air.

N89/I/25

**45** Which statement describes the internal energy of a system?

**A** The maximum amount of work that can be extracted from the system.

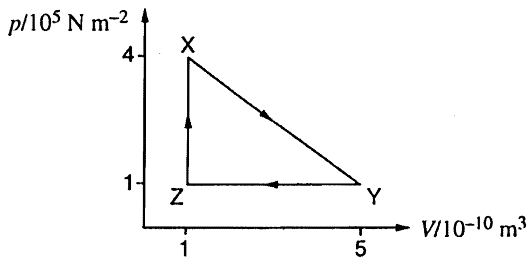
**B** The sum of the kinetic and potential energies of the particles in the system.

**C** The total amount of work which has been done on the system.

**D** The thermal energy needed to raise the temperature of the system by one kelvin.

J90/I/25; N97/I/24

**46** A mass of an ideal gas of volume $V$ at pressure $p$ undergoes the cycle of changes shown in the graph.




At which points is the gas coolest and hottest?

| | *coolest* | *hottest* |
|---|---|---|
| **A** | X | Y |
| **B** | Y | X |
| **C** | Y | Z |
| **D** | Z | X |
| **E** | Z | Y |

J90/I/26

**47** Cooling water enters the heat exchanger in the turbine hall of a nuclear power station at 6.0 °C and leaves at 14.0 °C. The rate of heat removal by the water is $6.7 \times 10^9$ J per minute.

The specific heat capacity of water is 4200 J kg$^{-1}$ K$^{-1}$.

What is the rate of water flow?

**A** $\dfrac{6.7 \times 10^9 \times 60}{4200 \times 8}$ kg s$^{-1}$

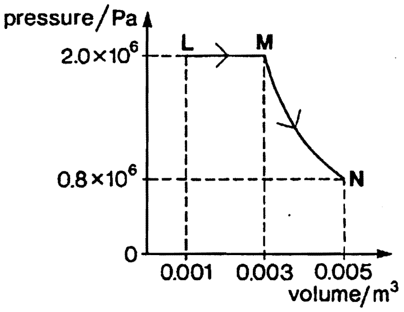
**B** $\dfrac{6.7 \times 10^9}{4200 \times 8 \times 60}$ kg s$^{-1}$

**C** $\dfrac{4200 \times 8}{6.7 \times 10^9 \times 60}$ kg s$^{-1}$

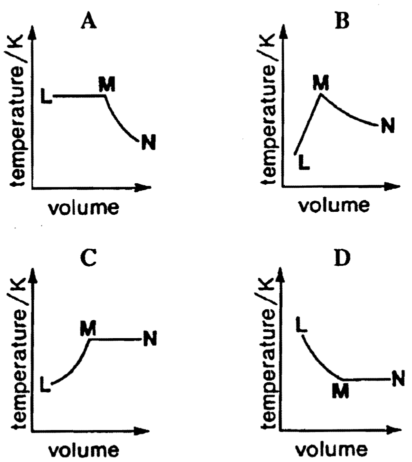
**D** $\dfrac{4200 \times 8 \times 60}{6.7 \times 10^9}$ kg s$^{-1}$

J92/I/25; N95/I/23; N98/I/24

48 A fixed mass of ideal gas undergoes changes of pressure and volume starting at **L**, as shown.




Which graph shows how temperature (measured in kelvin) changes with volume?




N92/I/24; J95/I/25

49 In a heating experiment, energy is supplied at a constant rate to a liquid in a beaker of negligible heat capacity. The temperature of the liquid rises at 4.0 K per minute just before it begins to boil. After 40 minutes all the liquid has boiled away.

For this liquid, what is the ratio $\dfrac{\text{specific heat capacity}}{\text{specific latent heat of vaporisation}}$ ?

**A** $\frac{1}{10}\,\text{K}^{-1}$ **B** $\frac{1}{40}\,\text{K}^{-1}$ **C** $\frac{1}{160}\,\text{K}^{-1}$ **D** $\frac{1}{640}\,\text{K}^{-1}$

J93/I/24; J2000/I/25

50 Which statement about the evaporation and boiling of a liquid is correct?

**A** Boiling always occurs at a higher temperature than evaporation.

**B** Evaporation occurs at any temperature, but the boiling point depends on the external pressure.

**C** Evaporation results in the loss of the most energetic molecules from a liquid but, in boiling, all molecules have the same energy.

**D** The rates of evaporation and boiling are unaffected by changes in the surface area of the liquid.

J94/I/21; N98/I/21

51 An airgun pellet, mass $m$ and specific heat capacity $c$, hits a steel plate at speed $v$. During the impact, 50% of the pellet's kinetic energy is converted to thermal energy in the pellet.

What is the rise in temperature of the pellet?

**A** $\dfrac{v^2}{2c}$ **C** $\dfrac{mv^2}{2c}$

**B** $\dfrac{v^2}{4c}$ **D** $\dfrac{mv^2}{4c}$ J94/I/24

52 A metal ball-bearing of specific heat capacity $c$, moving with speed $v$, is brought to rest. All its kinetic energy is converted into thermal energy which it absorbs, causing a temperature rise $\Delta\theta$.

What was the value of $v$?

**A** $\frac{1}{2}c\,\Delta\theta$ **B** $2c\,\Delta\theta$ **C** $\sqrt{c\,\Delta\theta}$ **D** $\sqrt{2c\,\Delta\theta}$

J95/I/24

53 A small quantity, mass $m$, of water at a temperature $\theta$ (in °C) is poured on to a large mass $M$ of ice which is at its melting point.

If $c$ is the specific heat capacity of water and $L$ the specific latent heat of fusion of ice, then the mass of ice melted is given by

**A** $\dfrac{ML}{mc\theta}$ **C** $\dfrac{Mc\theta}{L}$

**B** $\dfrac{mc\theta}{ML}$ **D** $\dfrac{mc\theta}{L}$ J96/I/24

54 A solar furnace made from a concave mirror of area 0.40 $m^2$ is used to heat water. The radiant energy from the Sun arrives at the mirror's surface at a rate of 1400 $W m^{-2}$. The specific heat capacity of water is 4200 J $kg^{-1}$ $K^{-1}$.

What is the best estimate of the least time that the furnace takes to heat 1.0 kg of water from 20 °C to 50 °C?

**A** 0.6 min **B** 4 min **C** 36 min **D** 230 min

N96/I/24; N99/I/24

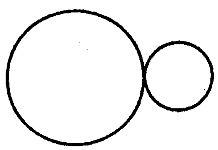
55 An electric kettle contains 1.5 kg of water at 100 °C and is powered by a 2.0 kW electric element.

If the thermostat of the kettle fails to operate, approximately how long will the kettle take to boil dry? [Take the specific latent heat of vaporisation of water as 2000 kJ $kg^{-1}$.]

**A** 500 s **C** 1500 s

**B** 1000 s **D** 3000 s J97/I/24

56 Two metal spheres of different radii are in thermal contact in a vacuum as shown.



The spheres are at the same temperature.

Which statement **must** be correct?

A Each sphere has the same internal energy.

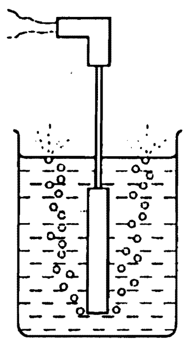
B There is no net transfer of thermal energy between the spheres.

C Both spheres radiate electromagnetic energy at the same rate.

D The larger sphere has a greater mean internal energy per atom than the smaller sphere.

J97/I/26

**57** In an experiment to find its specific latent heat of vaporisation, water is vaporised using an immersion heater as shown.



Two sources of error in this experiment are:

error 1 water splashing out of the container;
error 2 vapour condensing on the handle of the heater and dripping back into the container.

What is the effect of these two experimental errors on the calculated value for the specific latent heat?

| | error 1 | error 2 |
|---|---|---|
| A | decrease | decrease |
| B | decrease | increase |
| C | increase | decrease |
| D | increase | increase |

J99/I/24

**58** The temperature of a hot liquid in a container of negligible heat capacity falls at a rate of 2 K per minute just before it begins to solidify. The temperature then remains steady for 20 minutes by which time the liquid has all solidified.

What is the value of the ratio $\frac{\text{specific heat capacity of liquid}}{\text{specific latent heat of fusion}}$ ?

A $\frac{1}{40}$ K$^{-1}$ C 10 K$^{-1}$

B $\frac{1}{10}$ K$^{-1}$ D 40 K$^{-1}$ N2000/I/25

**59** *(a)* State the *first law of thermodynamics.*

*(b)* Give **one** practical example of each of the following:

(i) a process in which heat is supplied to a system without causing an increase in temperature,

(ii) a process in which no heat enters or leaves a system but the temperature changes.

J78/I/10

**60** At a temperature of 100 °C and a pressure of $1.01 \times 10^5$ Pa, 1.00 kg of steam occupies 1.67 m$^3$ but the same mass of water occupies only $1.04 \times 10^{-3}$ m$^3$. The specific latent heat of vaporisation of water at 100 °C is $2.26 \times 10^6$ J kg$^{-1}$. For a system consisting of 1.00 kg of water changing to steam at 100 °C and $1.01 \times 10^5$ Pa, find

*(a)* the heat supplied to the system,

*(b)* the work done by the system,

*(c)* the increase in internal energy of the system.

J79/I/10

**61**

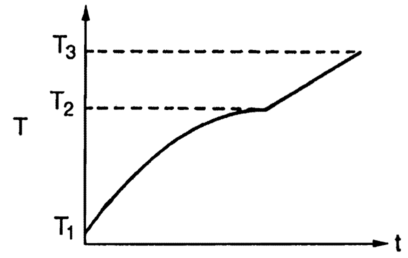



**Fig. 6**

Electrical power was supplied at a constant rate $P$ to a heating coil wrapped around an alloy sample of mass $m$ under conditions such that heat losses were negligible. The way in which the temperature $T$ of the sample changed with time $t$ is shown in Fig. 6

*(a)* Explain how the specific heat capacity $c$ of the alloy at any temperature could be deduced from the graph.

*(b)* Sketch a graph to show how $c$ varies with temperature $T$ for this alloy. Label the temperature $T_1$, $T_2$ and $T_3$ in your sketch. N81/I/10

**62** The specific heat capacity at constant volume of a certain ideal gas is $6.0 \times 10^2$ JK$^{-1}$ and is independent of temperature. Find the internal energy of $5.0 \times 10^{-3}$ kg of the gas at 27 °C.

N82/I/9

**63** A piece of copper of mass 0.275 kg is heated from 14.0 °C to 100.0 °C. By how much does its internal energy increase? *What is the mass of this additional energy?

(Specific heat capacity of copper = 380 J kg$^{-1}$ K$^{-1}$.) N84/I/9

**64** When water changes to steam at 100 °C, heat (the latent heat of vaporisation) must be supplied to the system. Is work done on or by the system as the water vaporises? Taking into account the fact that the temperature remains constant during the change of phase, state whether or not the internal energy changes, giving the reason for your answer. N85/II/5

**65** One mole of an ideal monatomic gas is confined in a cylinder fitted with a frictionless piston. When 63 J of heat are supplied and the gas is allowed to expand at constant pressure, the temperature rises by 3.0 K. What heat input would be required to raise the temperature of the same mass of gas through the same interval when the piston is fixed, so as to maintain a constant volume? J87/II/5 (part)

**66** A heat pump is a device which works by changing the state of a gas through the cycle of operations such as A → B → C → D → A shown in Fig. 7. Between A and B the gas absorbs heat from the atmosphere, and between C and D it delivers heat to the inside of a building. For a certain heat pump, the heat supplied to the gas during each part of the cycle and the corresponding work done on the gas are given in the table. The cycle is completed 20 times per second.

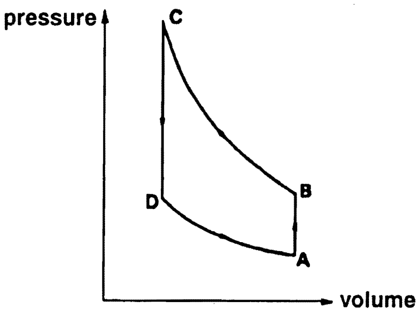



**Fig. 7**

| *section of cycle* | *heat supplied of gas /J* | *work done on gas /J* |
|---|---|---|
| A → B | 280 | 0 |
| B → C | 0 | 190 |
| C → D | –400 | 0 |
| D → A | 0 | –70 |

(i) What is the minimum average power of the motor required to run the pump?

(ii) What is the average rate of supply of heat by the pump?

J89/II/4

**67** *(a)* State in words the first law of thermodynamics.

*(b)* An adiabatic change is one in which no heat is supplied or extracted.

(i) Write down an expression for the first law when related to an adiabatic change in the state of an ideal gas in which the gas does 600 J of work.

(ii) Deduce the change in the internal energy of the gas.

(iii) What can you deduce about the temperature of the gas? [5]

N89/II/4

**68** Fig. 8 shows some details concerning the behaviour of a fixed mass of a gas (assumed to be ideal) in a petrol engine. The gas starts at A with a volume of $5.00 \times 10^{-4}$ $m^3$, a temperature of 300 K and a pressure of $1.00 \times 10^5$ Pa. In the change A to B it is compressed to a volume of $7.00 \times 10^{-5}$ $m^3$; the pressure rises to $1.50 \times 10^6$ Pa and the temperature to 630 K.

*(a)* Use the equation of state for an ideal gas to find the number of moles in the fixed mass of gas. [3]

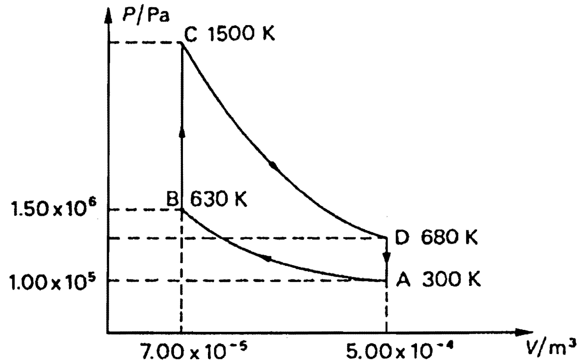



**Fig. 8**

*(b)* In the change from B to C the temperature of the gas rises from 630 K to 1500 K. The molar heat capacity at constant volume of the gas is 21 J $K^{-1}$ $mol^{-1}$. Calculate the thermal energy supplied in this change. [3]

*(c)* How much work is done by the gas in the change B to C? [1]

*(d)* In the change from C to D the gas expands to its original volume. The temperature at D is 680 K. Calculate the pressure at D. [3]

N91/II/4

**69** Some gas, assumed to behave ideally, is contained within a cylinder which is surrounded by insulation to prevent loss of heat, as shown in Fig. 9.

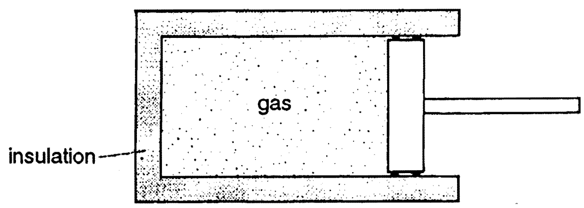



**Fig. 9**

Initially the volume of gas is $2.9 \times 10^{-4}$ $m^3$, its pressure is $1.04 \times 10^5$ Pa and its temperature is 314 K.

*(a)* Use the equation of state for an ideal gas to find the amount, in moles, of gas in the cylinder. [2]

*(b)* The gas is then compressed to a volume of $2.9 \times 10^{-5}$ $m^3$ and its temperature rises to 790 K. Calculate the pressure of the gas after this compression. [2]

*(c)* The work done on the gas during the compression is 91 J. Use the first law of thermodynamics to find the increase in the internal energy of the gas during the compression. [2]

*(d)* Explain the meaning of *internal energy*, as applied to this system, and use your result in *(c)* to explain why a rise in the temperature of the gas takes place during the compression. [2]

J92/II/6

70 *(a)* Write down in words an expression for the first law of thermodynamics. [2]

*(b)* (i) The densities of water and steam at 100°C and $1.01 \times 10^5$ Pa are 1000 kg $m^{-3}$ and 0.590 kg $m^{-3}$ respectively. Calculate the change in volume which occurs when 1.00 kg of water evaporates at 100 °C and atmospheric pressure of $1.01 \times 10^5$ Pa. [2]

(ii) Calculate the work done against the atmosphere to produce the change in volume found in (i). [2]

(iii) The specific latent heat of vaporisation of water at 100 °C is $2.26 \times 10^6$ $Jkg^{-1}$. Use the first law of thermodynamics to calculate the increase in internal energy of the molecules when 1.00 kg of water evaporates. [2]

(iv) State, with a reason, the increase in the potential energy of the molecules. [2] N92/II/5

71 A fixed mass of gas in a heat pump undergoes a cycle of changes of pressure, volume and temperature as illustrated in the graph, Fig. 10. The gas is assumed to be ideal.

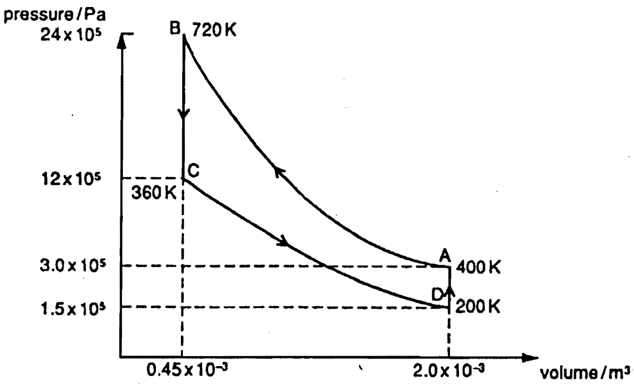



**Fig. 10**

The table below shows the increase in internal energy which takes place during each of the changes A to B, B to C and C to D. It also shows that in both of sections A to B and C to D, no heat is supplied to the gas.

| | *Increase in internal energy* /J | *Heat supplied to gas* /J | *Work done on gas* /J |
|---|---|---|---|
| A to B | 1200 | 0 | 1200 |
| B to C | −1350 | | 0 |
| C to D | −600 | 0 | |
| D to A | | | 0 |

*(a)* Using the first law of thermodynamics and necessary data from the graph, complete the table. You will find it helpful to proceed in the following order.

(i) work done on gas for A to B and C to D

(ii) work done on gas for B to C and D to A

(iii) heat supplied to gas for B to C

(iv) increase in internal energy for D to A

(v) heat supplied to gas for D to A [6]

*(b)* Calculate $P$, the coefficient of performance of the heat pump, given that

$$P = \frac{\text{Heat delivered by gas (during change B to C)}}{\text{Net work done on gas}}. \quad [1]$$

J94/II/5

72 *(a)* The specific latent heat of vaporisation of water at 28 °C is $2.3 \times 10^6$ J $kg^{-1}$. It has been estimated that $1.2 \times 10^{12}$ $m^3$ of water is evaporated per day from the Earth's surface.

(i) State what is meant by *specific latent heat of vaporisation.*

(ii) Given that the density of water is $1.0 \times 10^3$ kg $m^{-3}$, calculate the energy required to evaporate this volume of water. [4]

N94/II/7 (part)

73 *(a)* By considering differences in structure, state how the density change which takes place when a solid changes to a liquid compares with the density change when a liquid changes to a gas. [3]

*(b)* State one similarity and one difference between evaporation and boiling. [2]

*(c)* What is meant by the *internal energy* of a system? [2]

*(d)* Use the first law of thermodynamics to calculate the difference between the internal energy of 1.00 kg of water at 100 °C and 1.00 kg of steam at 100 °C at a pressure of $1.01 \times 10^5$ Pa. [A mass of 1.00 kg of steam at this pressure and temperature occupies 1.67 $m^3$ and the specific latent heat of vaporisation of water is $2.26 \times 10^6$ J $kg^{-1}$.]

internal energy difference = ................................ J [4]

J98/II/6

74 An electric kettle, rated 230 V 8.0 A, contains some water. It is placed on a balance, as illustrated in Fig. 11.

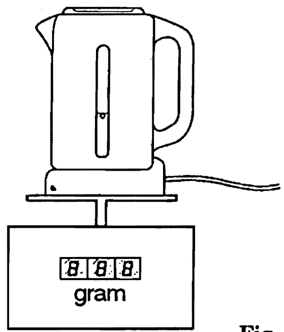



**Fig. 11**

The kettle is switched on and, when the water is boiling, the reading on the balance is found to decrease by 8.1 g in 10 s.

*(a)* Calculate

(i) the power rating of the kettle,

power rating = .................. W

(ii) the specific latent heat of vaporisation of water.

specific latent heat = .............. [4]

*(b)* (i) State one source of error in this determination of the specific latent heat of vaporisation.

(ii) Suggest briefly how this error may be reduced. [2]

N99/II/6

**75** *(a)* (i) State what is meant by the *internal energy* of a system.

(ii) Explain why the internal energy of an ideal gas is proportional to the mean-square speed $<c^2>$ of its atoms. [4]

*(b)* The first law of thermodynamics may be expressed as

*gain in internal energy* = $q + w$.

Explain the symbol

(i) $q$, ..........................................................................

(ii) $w$ .. ..................................................................... [3]

N2000/II/7

## *Long Questions*

**76** What is meant by *internal energy*? State the quantitative relationship between changes of internal energy of a system, the work done on the system, and the heat supplied to it.

The following suggestions have been made for energy saving in the use of a thermostatically-controlled immersion heater fitted to a lagged hot-water tank.

(i) The heater should be left switched on all the time, rather than be used to heat water from cold only when required.

(ii) the thermostat should be set to a high temperature, so that in running a bath, only a small amount of hot water is taken from the tank to be mixed with cold water in the bath.

Discuss whether these suggestions would lead to economy.

J77/I/15 (part)

**77** A thermally-insulated tube through which a gas may be passed at constant pressure contains an electric heater and thermometers for measuring the temperature of the gas as it enters and as it leaves the tube. $3.0 \times 10^{-3}$ m$^3$ of gas of density 1.8 kg m$^{-3}$ flows into the tube in 90 s and, when electrical power is supplied to the heat at a rate of 0.16 W, the temperature difference between the outlet and inlet is 2.5 K.

*(a)* Calculate a value for the specific heat capacity of the gas at constant pressure.

*(b)* In what way would your result have been different if the viscous drag on the gas had been significant?

*(c)* What features of the constant-flow method make it particularly suitable for the accurate determination of the specific heat capacities of fluids?

J78/I/15 (part)

**78** Explain what is meant by an *isothermal* change. How may an isothermal compression of a gas be achieved in practice? Explain why, in the isothermal compression of an ideal gas, the internal energy is unchanged even though mechanical work is done.

A cylinder fitted with a frictionless piston contains an initial volume of $5.0 \times 10^{-4}$ m$^3$ of an ideal gas at a pressure of $1.0 \times 10^5$ Pa and a temperature of 300 K. The gas is (i) heated at constant pressure to 450 K, and then (ii) cooled at constant volume to the original temperature of 300 K. The heat extracted from the gas during stage (ii) is 63 J.

*(a)* Illustrate these change on a $p$-$V$ diagram labelled with the appropriate values of pressure and volume.

*(b)* How much work does the gas do in pushing back the piston in stage (i)?

*(c)* What is the total heat input in stage (i)?

N78/I/15 (part)

**79** The first law of thermodynamics relates the external work $W$ done on a system, the heat $Q$ supplied to it and the change of internal energy, $\Delta U$. Write down the equation relating $W$, $Q$ and $\Delta U$, and explain the sign convention you use.

For a system consisting of a real gas,

*(a)* give an example of a way in which external work may be done on the system,

*(b)* explain in molecular terms what forms the internal energy takes.

N79/I/15 (part)

**80** Write down an equation representing the first law of thermodynamics, defining your symbols carefully. Identify the 'heat' and 'work' terms in the law as applied to the vaporisation of water to form steam at constant temperature. Why does the internal energy change in this change of phase, although the temperature remains constant?

When 1.00 kg of ice melts at 0 °C and $1.01 \times 10^5$ Pa, $3.34 \times 10^5$ J (the specific latent heat of fusion) must be supplied.

*(b)* When water turns to steam, a significant fraction of the latent heat of vaporisation is used in pushing back the atmosphere. Discuss quantitatively whether similar considerations apply when ice melts to form water.

[ Densities at 0 °C; ice, $0.92 \times 10^3$ kg m$^{-3}$; water, $1.00 \times 10^3$ kg m$^{-3}$. ]

*(c)* The relative molecular mass of water is 18. How many water molecules are there is 1.0 kg of ice?

*(d)* Assuming that, in ice, each water molecule is closely bonded to four neighbours, estimate the energy required to modify each bond to the arrangement that applies in the liquid phase. N83/I/18 (part)

**81** Fig. 12 gives data in graphical form concerning the pressure, volume and temperature of a fixed mass of gas. On each curve, the pressure is plotted against the volume at a fixed temperature and reference is made to values of pressure, volume and temperature by use of capital letters. You are expected to take quantitative readings from the graph when necessary.

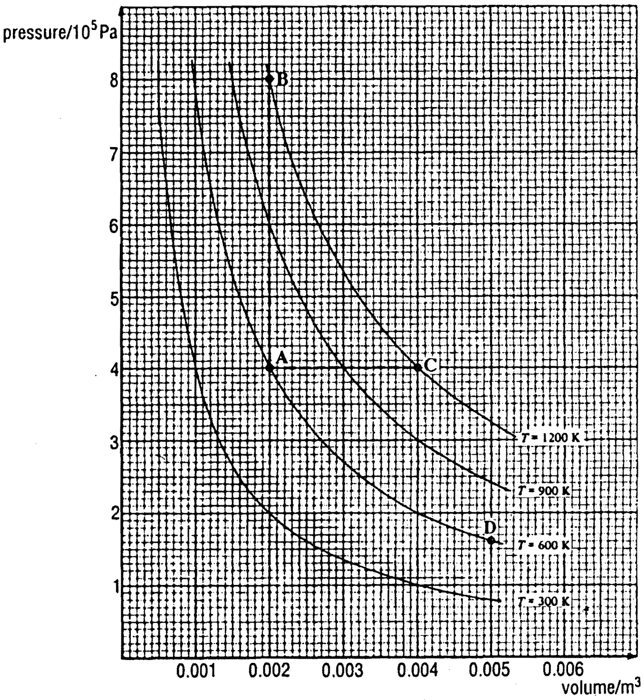



**Fig. 12**

*(a)* Suggest how the curve at a temperature of 300 K could be obtained experimentally. [4]

*(b)* State the *First Law of Thermodynamics.* [2]

*(c)* Write down the ideal gas equation and use it to find the number of moles of gas. [3]

*(d)* Show that the data of the graph are consistent with the gas behaving as an ideal gas over the range of temperature from 300 K to 1200 K. [3]

*(e)* The gas has a heat capacity of 3.33 J $K^{-1}$ at constant volume and 4.66 J $K^{-1}$ at constant pressure.

Calculate the quantity of heat required to take the gas

(i) from A to B along the line AB.

(ii) from A to C along the line AC. [3]

*(f)* The internal energy of the gas at A is 2000 J. Find the internal energy at B and at C. [3]

*(g)* How much work is done by the gas if an expansion at constant pressure takes place from A to C? [2]

*(h)* Explain why the internal energy of the gas at D is also 2000 J. [2] J88/II/10

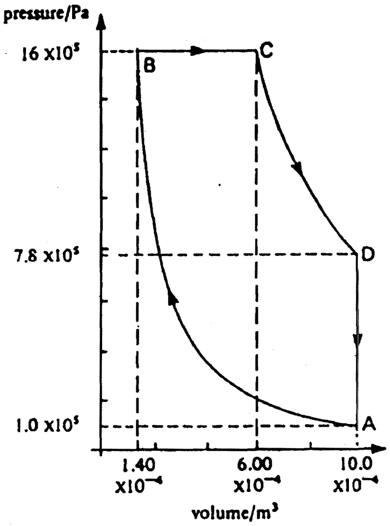
**82** *(a)* (i) Explain what is meant by the terms

*internal energy of a gas,*
*ideal gas.* [4]

(ii) State, in words, the relation between the increase in the internal energy of a gas, the work done on the gas, and the heat supplied to the gas. [1]

*(b)* The gas in the cylinder of a diesel engine can be considered to undergo a cycle of changes of pressure, volume and temperature. One such cycle, for an ideal gas, is shown on the graph, Fig. 13.

**Fig. 13**




(i) The temperature of the gas at A and B are 300 K and 660 K respectively. Use the ideal gas equation and data from the graph to find the temperatures at C and D. [4]

(ii) During each of the four sections of the cycle, changes are being made to the internal energy of the gas. Some of the factors affecting these changes are given the table below.

| Section of cycle | Heat supplied to gas/J | Work done on gas/J | Increase in internal; energy of gas/J |
|---|---|---|---|
| A to B | 0 | 300 | |
| B to C | 2580 | –740 | |
| C to D | 0 | –440 | |
| D to A | –1700 | | |

Explain why the work done on the gas is sometimes negative and find the work done on the gas in section D to A.

Deduce the values of the "increase in internal energy of the gas" for each section and list them. [7]

(iii) Explain why the total change in the internal energy of the gas during a complete cycle must be zero.

(iv) What is the net work output during a complete cycle? [2]

(v) Assuming that the efficiency of a heat engine is defined as the ratio of work output to heat input, calculate the efficiency of this engine. [2]

N88/II/10

**83** *(a)* (i) Explain why is meant by the *internal energy* of a system.

(ii) Use the molecular model of matter to explain why evaporation of a liquid is accompanied by cooling, unless heat is supplied to the liquid. [5]

*(b)* A thermally insulated vessel containing liquid water and water vapour is connected to a vacuum pump which removes water vapour continuously. When the temperature reaches 0 °C, the vessel contains 110 g of liquid water. What mass of ice has been formed when no liquid remains? [5]

(Specific latent heat of fusion of water = $3.40 \times 10^5$ J $kg^{-1}$, Specific latent heat of vaporisation of water = $2.52 \times 10^6$ J $kg^{-1}$.)

J90/III/3 (part)

**84** *(a)* Explain what is meant by the terms *internal energy* and *molar heat capacity.* [3]

*(c)* What additional fact may be stated about the internal energy of a gas if the gas is ideal? [1]

*(d)* (i) A quantity of 0.200 mol of air enters a diesel engine at a pressure of $1.04 \times 10^5$ Pa and at a temperature of 297 K. Assuming that air behaves as an ideal gas find the volume of this quantity of air. [2]

(ii) The air is then compressed to one twentieth of this volume, the pressure having risen to $6.89 \times 10^6$ Pa. Find the new temperature. [2]

(iii) Heating of the air then takes place by burning a small quantity of fuel in it to supply 6150J. This is done at a constant pressure of $6.89 \times 10^6$ Pa as the volume of air increases and the temperature rises to 2040 K.

Find

(1) the molar heat capacity of air at constant pressure,

(2) the volume of air after burning the fuel,

(3) the work done by the air during this expansion,

(4) the change in the internal energy of the air during this expansion. [8]

J91/III/5 (part)

**85** *(a)* Describe in molecular terms the process of *melting*. Your answer should make reference to the spacing, ordering, motion and energies of the molecules. [6]

*(b)* Define *specific latent heat of fusion.* [2]

*(c)* A heating coil is placed in a large funnel and surrounded by lumps of melting ice as shown in Fig. 14.

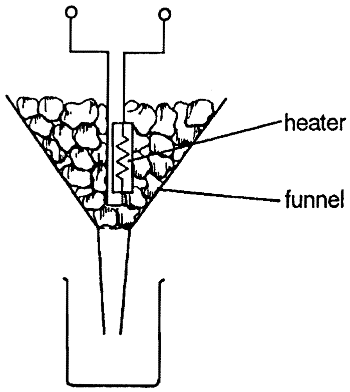



**Fig. 14**

The coil is connected to a power supply.

(i) Briefly outline how the apparatus may be used to determine *L*, the specific latent heat of fusion of ice.

(ii) Show how the readings you would take may be used to calculate *L*. [6]

*(d)* The first law of thermodynamics may be expressed in terms of the equation

$$\Delta U = q + w.$$

(i) Identify each of the terms in this equation.

(ii) Some solids contract and some solids expand when they melt. Copy Fig. 15 on to your answer paper.

| | Solid which *contracts* on melting | Solid which *expands* on melting |
|---|---|---|
| $\Delta U$ | | |
| $q$ | | |
| $w$ | | |

**Fig. 15**

Complete the table with the symbols + or – to indicate the *signs* of the thermodynamic quantities for each of the two types of solid when the solids melt at constant pressure. [6]

N93/III/5

**86** *(e)* Explain, in terms of the energies of atoms, conditions under which it is possible to increase the total energy of the atoms of a substance without any change of temperature of that substance. [3]

J94/III/6 (part)

**87** *(a)* What is meant, in molecular terms, by the *internal energy* of a gas? [2]

*(b)* State qualitatively and explain in molecular terms, what happens to the internal energy of a fixed mass of an ideal gas when, separately,

(i) the temperature of the gas is raised,

(ii) the volume is decreased at constant temperature,

(iii) the gas as a whole is moving at a certain speed. [6]

*(c)* The quantity of gas in an engine is $5.2 \times 10^{-3}$ mol. It has volume $5.0 \times 10^{-5}$ m$^3$ and pressure $6.0 \times 10^5$ Pa. Assume the gas to be ideal.

(i) Calculate the temperature of the gas. [3]

(ii) The gas is then heated at constant volume, so raising its temperature by 800 K. This is done by supplying 85 J of energy to the gas. Calculate

1. the molar heat capacity of the gas at constant volume,
2. the final pressure of the gas. [5]

(iii) During the power stroke of the engine, the gas expands, doing 62 J of work, but no thermal energy enters or leaves the gas.

1. State the first law of thermodynamics.
2. By applying the law to this process, find the change in the internal energy of the gas during the power stroke. [4]

J95/III/5

**88** *(a)* What is meant by the term *internal energy* of a system? Give your answer in terms of the molecules within the system. [1]

*(b)* (i) State two physical quantities which affect the internal energy of any system.

(ii) State a physical quantity which does not affect the internal energy of any system. [3]

*(c)* The pressure $p$ exerted by an ideal gas is given by the equation

$$p = \tfrac{1}{3}\rho <c^2>$$

What do the symbols $\rho$ and $<c^2>$ represent? [3]

*(d)* Use the equation given in *(c)* to derive an expression for the total internal kinetic energy of the molecules of an ideal gas of volume $V$ and pressure $p$. [3]

*(e)* (i) Calculate the internal energy of an ideal gas of volume $3.4 \times 10^{-4}$ m$^3$ when its pressure is 100 kPa. State the property of the molecules of an ideal gas which enables you to do this calculation. [3]

(ii) Calculate the increase in the internal energy which takes place in this gas if it then expands at constant pressure to a volume of $8.8 \times 10^{-4}$ m$^3$. [2]

(iii) How much work is done by the gas during this expansion? [2]

(iv) Use the first law of thermodynamics to calculate how much energy has to be supplied in heating the gas so as to enable the expansion at constant pressure to take place. [3]

N96/III/5

**89** *(a)* (i) Define *specific latent heat of vaporisation* of a liquid.

(ii) By reference to the first law of thermodynamics explain why, when a liquid is boiling, thermal energy is being supplied although the temperature of the liquid does not change. [6]

*(b)* A student has been asked to determine the specific latent heat of vaporisation of water by an electrical method. He has available a 12V supply and a heater marked "9V, 75W". The heater is used to boil water and, when the water is boiling, the mass of water vapour produced per minute is measured at two different powers for the heater. The results are shown in Fig. 16.

| *power of heater/W* | *mass of water vaporised per minute /g* |
|---|---|
| 75 | 1.80 |
| 20 | 0.34 |

**Fig. 16**

(i) Draw and label a diagram of an electrical circuit so that the heater may be used correctly with the 12 V supply.

(ii) Calculate the current in the heater when the heater is operating at 75 W.

(iii) Suggest why the student repeated the experiment using a different power for the heater.

(iv) Calculate a value for the specific latent heat of vaporisation of water. [9]

*(c)* In one particular make of electric kettle, the minimum volume of water required to immerse the heater is 600 cm$^3$. It is a safety requirement that, when water is being heated, the heater must be totally immersed. The kettle is used five times each day in order to make, on each occasion, a single cup of coffee. The density and specific heat capacity of water are $1.0 \times 10^3$ kg m$^{-3}$ and $4.2 \times 10^3$ J kg$^{-1}$ K$^{-1}$ respectively, and electrical energy costs 6 p per kWh. Making suggestions for the volume of a cup of coffee and the initial temperature of the water in the kettle, estimate the expenditure per year to heat water which is not actually used to make coffee. [5]

N97/III/5

**90** *(c)* In a certain waterfall, water falls through a vertical distance of 24 m, as illustrated in Fig. 17.

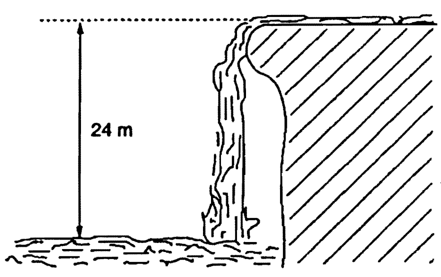



**Fig. 17**

The water is brought to rest at the base of the waterfall. Calculate

(i) the change in gravitational potential energy of 18 kg of water when it descends the waterfall,

(ii) the difference in temperature between the top and the bottom of the waterfall if all of the potential energy is converted into thermal energy. The specific heat capacity of water is 4.2 kJ $kg^{-1}$ $K^{-1}$. [3]

*(d)* The mass of one mole of water molecules is 0.018 kg.

(i) Calculate the number of water molecules in 18 kg of water.

(ii) Assuming that all of the potential energy lost by the water as it descends the waterfall in *(c)* is converted into random kinetic energy of water molecules, calculate the average increase in kinetic energy of a water molecule. [3]

*(e)* (i) Use your answer to *(d)*(ii) and the equation

$$\text{average change in kinetic energy per molecule} = \frac{3}{2}k\Delta T$$

to calculate a value for the quantity $\Delta T$.

(ii) Suggest why your answers to *(e)*(i) and *(c)*(ii) are not in agreement. [3]

J98/III/5 (part)

**91** Use the following physical data for ice, water and steam when necessary in answering this question.

| | ice | water | water | steam |
|---|---|---|---|---|
| temperature | 0 °C | 0 °C | 100 °C | 100 °C |
| volume occupied by 1 kg at standard pressure/$m^3$ | 0.00109 | 0.00100 | 0.00104 | 1.67 |
| kinetic energy of all the molecules in 1 kg/$10^5$J | 1.89 | 1.89 | 2.58 | 2.58 |
| potential energy of all the molecules in1 kg (referred to ice at 0°C)/$10^5$J | 0 | 3.36 | 3.41 | 24.3 |
| internal energy of 1 kg/$10^5$J | 1.89 | 5.25 | 5.99 | 26.9 |

*(a)* In terms of the spacing of molecules, account qualitatively for the changes in volume which take place when 1 kg of ice is heated until it becomes 1 kg of steam. [4]

*(b)* Explain why there is no change in the kinetic energy of the molecules when ice at 0 °C changes to water at 0 °C. [2]

*(c)* What determines the internal energy of 1 kg of the substance? [2]

*(d)* Determine the specific latent heat of fusion of ice. [2]

*(e)* Calculate how much work has to be done by 1 kg of water in order to change to steam at 100 °C and at atmospheric pressure of $1.01 \times 10^5$ Pa. [3]

*(f)* Use the first law of thermodynamics to calculate the specific latent heat of vaporisation of water. [3]

*(g)* Outline an electrical method to determine the specific latent heat of vaporisation of water. [4]

N98/III/5

**92** *(d)* Fig. 18 shows data for ethanol.

| | |
|---|---|
| density | 0.79 g $cm^{-3}$ |
| specific heat capacity of liquid ethanol | 2.4 J $g^{-1}$ $K^{-1}$ |
| specific latent heat of fusion | 110 J $g^{-1}$, |
| specific latent heat of vaporisation | 840 J $g^{-1}$ |
| melting point | –120 °C |
| boiling point | 78 °C |

**Fig. 18**

Use the data in Fig. 18 to calculate the thermal energy required to convert 1.0 $cm^3$ of ethanol at 20 °C into vapour at its normal boiling point. [6]

*(e)* (i) State the *first law of thermodynamics.*

(ii) Suggest why there is a considerable difference in magnitude between the specific latent heats of fusion and vaporisation. [5]

J99/III/2 (part)

**93** *(a)* (i) Distinguish between the processes of evaporation and of boiling.

(ii) Use the first law of thermodynamics to explain why, when a liquid evaporates or boils, thermal energy must be supplied to the liquid in order to maintain constant temperature. [6]

J2000/III/5 (part)