1(a). A flute is a musical instrument made from a long tube that is open at both ends.

A stationary sound wave in the tube produces a musical note.

The lowest frequency note that a standard flute produces in air is 262 Hz.

The speed of sound in air at a temperature of 20°C is 340 m s^{-1}.

Show that a standard flute has an approximate length of 0.65 m.

[3]

(b). In an ideal gas, the speed *v* of sound is given by

$$v = \left(\frac{\gamma RT}{M}\right)^{1/2}$$

where

γ is a dimensionless constant that depends on the gas

R is the molar gas constant

T is the absolute temperature

M is the molar mass of the gas.

The table below shows values of γ and *M* for both air and helium.

Gas	**γ**	***M*/g mol^{-1}**
Air	1.40	29.0
Helium	1.67	4.00

i. The kinetic model of an ideal gas assumes that there are a large number of particles in rapid, random motion.

State **two** further assumptions for the kinetic model of an ideal gas.

1 ______________________________

____

2 ______________________________

______________________________ **[2]**

ii. A standard flute is placed inside a sealed chamber.

The chamber is filled with helium at a temperature of −10°C.

Calculate the lowest frequency that the flute could produce inside the chamber.

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

2(a).

i. Define the internal energy of an ideal gas.

____

____

____ **[1]**

ii. Use the formulae below to show that the average kinetic energy of a particle of an ideal gas is directly proportional to the absolute temperature of the gas.

$pV = \frac{1}{3}Nm\overline{c^2}$ $pV = NkT$

[2]

(b). The velocities of four gas particles at 290 K are given below in m s^{-1}.

310 370 440 550

i. Show that the root-mean-square (r.m.s.) speed of the sample is about 430 m s^{-1}.

[2]

ii. Calculate the molar mass of the gas assuming an absolute temperature of 290 K and r.m.s. speed of 430 m s^{-1}.

molar mass = ... kg mol^{-1} **[3]**

(c). Spherical filament lamps are manufactured by a process where they are filled with a gas at 290 K and low pressure.

When the filament lamp is switched on, the filament reaches a constant temperature of 2400 K. At this temperature, the pressure inside the filament lamp is 120 kPa.

i. Explain, in terms of energy transfers, why the temperature of the filament does **not** increase beyond 2400 K. You are **not** expected to refer to the electrical characteristics of the filament lamp.

[3]

ii. Calculate the pressure of the gas within the filament lamp during manufacture.

pressure = ... kPa **[2]**

3. Which row in the table shows two equivalent physical quantities?

A	0 °C	−273.15 K
B	1 kg m s^{-1}	1000 N s
C	10 kW	10 000 N m
D	1.0 mPa	0.0010 N m^{-2}

Your answer ☐ **[1]**

4. A 3D printer can manufacture small objects.

Some 3D printers use polylactic acid (PLA). PLA is supplied in the form of long filaments. The 3D printer melts the PLA and builds up the shape of the desired object in layers.

The electrical supply to the heater in the printer has an e.m.f., ε, of 12 V. The power of the heater is 40 W.

The specific latent heat of fusion of PLA is 9.4×10^4 J kg^{-1} and its melting point is 160°C.

i. Define **specific latent heat of fusion**.

[1]

ii. Calculate the **maximum** mass *m* of PLA that the heater could melt in one minute.

m = ... kg **[2]**

iii. Explain why the printing process is slower in practice than your answer to **(ii)** suggests.

[2]

iv. **Fig. 6.1** shows the initial and final temperature of the PLA during the printing process.

Initially (point **A**), the solid PLA is at 20°C and is just entering the heater. Later (point **B**), the PLA has been added to the object and is solid again.

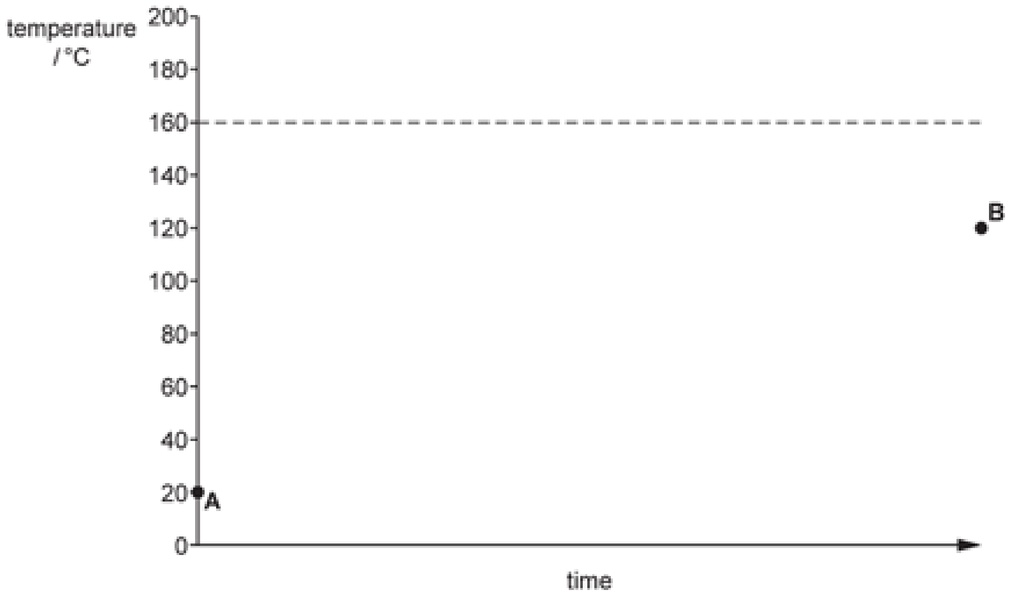


Fig. 6.1

Complete **Fig. 6.1** to show how the temperature of the PLA changes between **A** and **B**.
You are **not** required to label the time axis.

[3]

5. The Hipparcos space telescope used stellar parallax with a precision of 9.7×10^{-4} arcseconds to determine the distance to stars.

One of the stars studied was Polaris A. Data about this star is in the table below.

Parallax angle	7.5×10^{-3} arcseconds
Radius	2.1×10^{10} m
Mass	1.1×10^{31} kg
Surface temperature	6000 K
Temperature of the atmosphere of the star	4.0×10^{6} K

A continuous stream of particles called a solar wind flows from the surface of the star into the surrounding space.

These particles include helium nuclei of mass 6.6×10^{-27} kg.

Assume that the atmosphere is modelled as an ideal gas.

i. Show that the typical kinetic energy of a helium nucleus in the atmosphere is about 10^{-16} J.

[2]

ii. The gravitational potential energy of a helium nucleus in the outer layer of the star is -2.3×10^{-16} J.

Calculate the gravitational potential energy U at the maximum distance from the star that a helium nucleus could reach.

U = ... J **[1]**

iii. Calculate the distance from the centre of the star reached by this helium nucleus.

distance = ... m **[3]**

iv. Explain why the star has a solar wind that reaches a much greater distance from the star than found in **(iii)**.

____ **[1]**

6(a).

A sealed container contains *n* moles of an ideal gas. The gas has pressure *p*, absolute temperature *T* and occupies volume *V*.

The mass of one mole of the gas is *M*.

Use an ideal gas equation to show that the density *ρ* of the gas is given by the expression $\rho = \frac{pM}{RT}$.

[3]

(b). An airship has a cabin suspended underneath a gasbag inflated with helium.

The airship is floating above the ground and is stationary.

The volume of the gasbag is 12 000 m^3.
The temperature of the helium and the surrounding air is 20°C.
Atmospheric pressure is 1.0×10^5 Pa.
The molar mass of air is 0.029 kg mol^{-1}.
The volume of the cabin is negligible compared to the volume of the gasbag.

i. Show that the density of air under the conditions described is about 1.2 kg m^{-3}.

[1]

ii. Calculate the weight of air displaced by the airship.

weight of air .... N **[2]**

iii. Explain why the weight of air displaced by the airship has the same magnitude as the weight of the airship and its contents.

[2]

iv. The pressure of the helium in the gasbag is maintained at a value only slightly greater than atmospheric pressure.
Suggest why a larger pressure is not used.

[2]

(c). The airship engine drives a fan which moves 7.8 kg of air per second at a relative speed of 45 m s^{-1}, so the airship starts to move.

All other conditions given in **(b)** remain the same.

Calculate the thrust that the engine produces.

thrust ....N **[2]**

(d). The airship has a higher maximum speed at high altitudes, but also produces less thrust from the engine.

Explain these observations.

[2]

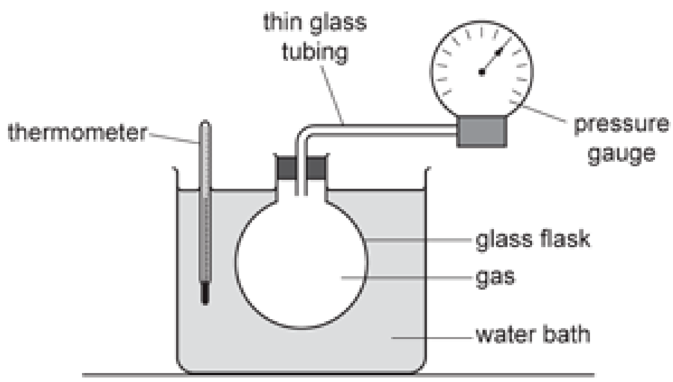
7. During cold weather salt is spread on roads causing ice to melt without changing its temperature.

Which statement correctly describes the energy of the water particles during this process?

A Potential and kinetic energies increase
B No energy changes occur
C Only kinetic energy increases
D Only potential energy increases

Your answer ☐ **[1]**

8. An experiment is carried out to estimate the value of absolute zero using the variation of gas pressure with temperature. The apparatus is shown below.



Which variable must be controlled during the experiment?

A Pressure of the gas
B Temperature of the gas
C Volume of the gas
D None of the above

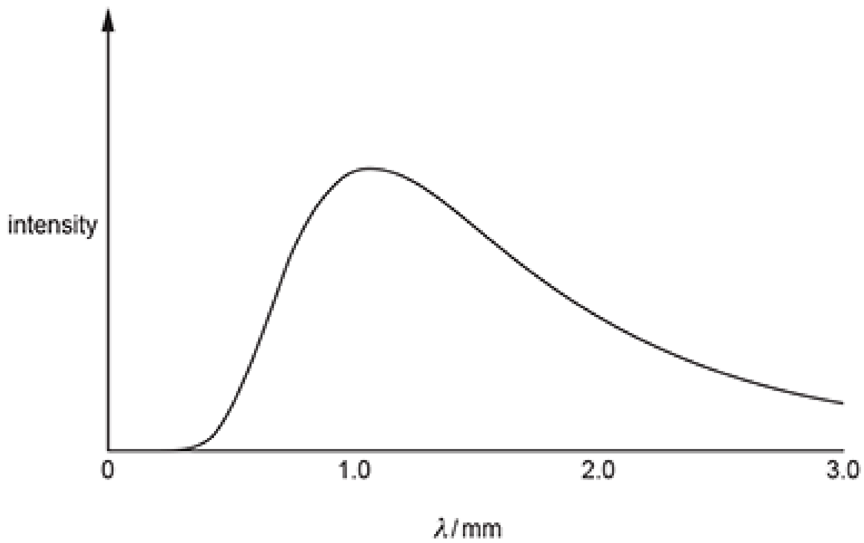
Your answer [1]

9. Astronomers can detect microwave background radiation coming from space in every direction.

The temperature of this microwave radiation is 2.7 K and its **total** intensity is about 3×10^{-6} W m^{-2}.

The figure below shows how the intensity of the microwave background radiation varies with its wavelength λ.

The **peak** intensity is at a wavelength of 1.1 mm.



This spectrum of microwave background radiation changes with temperature according to Wien's displacement law.

i. Suggest and explain how the spectrum might have looked in the distant past. You may draw on the figure to support your answer.

____

____

____

____ **[2]**

ii. Calculate the energy of a photon which has a wavelength of 1.1 mm.

energy = ... J **[2]**

iii. Estimate the number of photons of microwave background radiation incident per second on the back of your hand.

Assume that all emitted photons have the energy calculated in **(ii)**, and that the back of your hand has a surface area of 150 cm^2.

number of photons per second = ...s^{-1} **[2]**

iv. A scientist suggests that the microwave background radiation could be used as an energy source.

The scientist proposes using large tanks of water to absorb the microwave radiation.

Estimate the maximum rise in temperature that could be produced per second for a large cylindrical tank of depth 5.0 m. Assume that all microwave radiation incident on the top of the tank is absorbed.

density of water = 1000 kg m^{-3}
specific heat capacity of water = 4200 J kg^{-1} K^{-1}

maximum rise in temperature per second = ...°C s^{-1} **[3]**

10(a).

A nebula is a giant cloud of gas and dust in space. A nebula **X** is modelled as a sphere of gas and dust particles of diameter 6.4 pc.
The nebula has 1.0×10^{12} gas and dust particles per m^3 and a temperature of 250 K. The nebula behaves like an ideal gas.

i. Show that the volume of the nebula is 4.1×10^{51} m^3.

1 pc = 3.1×10^{16} m

[2]

ii. Calculate the **total** kinetic energy E_k of the gas and dust particles in the nebula.

E_k= .... J **[3]**

(b). The nebula that formed the Sun is estimated to have a diameter of 3.0 pc and had a similar composition to nebula **X** in **(b)**.

The mass of the nebula **X** is **much greate r** than the mass of the Sun.

i. Calculate the ratio $\frac{\text{mass of nebula X}}{\text{mass of the Sun}}$

ratio = ... **[2]**

ii. After a long time, nebula **X** will form a stable star.

Describe the eventual evolution of this star.

[4]

11(a).

A fixed mass of nitrogen changes phase from liquid to gas at a constant temperature.

Explain the change in the total internal energy of nitrogen.

[2]

(b). In a factory, nitrogen gas is added to packets of food to keep it fresh for longer.
In 1.0 hour, the factory uses 15 m^3 of nitrogen at pressure 100 kPa and temperature 23 °C.

i. Show that the number of moles *n*, of nitrogen used per hour is about 600.

[3]

ii. Calculate the mass of nitrogen gas used in one hour.

molar mass of nitrogen = 0.028 kg mol^{-1}

mass = ... kg **[1]**

iii. The volume of nitrogen being used cannot be changed.

State how the rate of mass of nitrogen used can be reduced.

[1]

iv. The nitrogen at the factory is stored as a liquid.
The liquid expands at constant temperature to form gas in a short section of pipe.

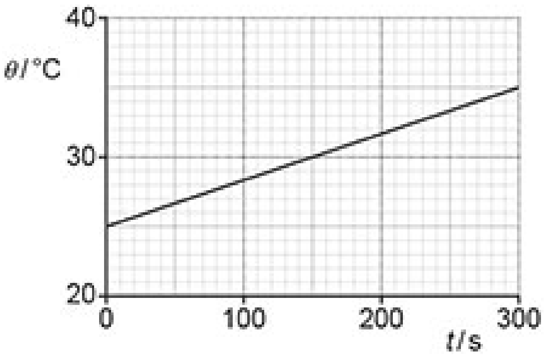
When the air temperature is 0 °C, a thick layer of ice forms on the outside of the pipe from water vapour in the air. In 1.0 hour, the mass of ice formed is 1.3 kg at a temperature of 0 °C.

Use the data below and your answer to **(b)(ii)**, to estimate the specific latent heat of vaporisation *L* of nitrogen.

- specific latent heat of fusion of ice = 3.34×10^5 J kg^{-1}
- specific latent heat of vaporisation of water = 2.26×10^6 J kg^{-1}

L = ... J kg^{-1} **[4]**

12. A metal block of mass *m* is heated by an electric heater.
The graph of temperature *θ* against time *t* for this block is shown below.



The power of the heater is *P*. The gradient of the straight-line graph is *G*.
What is the correct expression for the specific heat capacity *c* of the metal?

A c = G

B $c = \frac{PG}{m}$

C $c = \frac{mP}{G}$

D $c = \frac{P}{mG}$

Your answer

[1]

13. Which statement(s) below are implied by the assumptions of the kinetic theory model of gases?

1 A gas is mostly empty space.
2 Gas particles spend more time between collisions than time during collisions.
3 There are always forces between the gas particles.

A Only 1 and 2
B Only 1 and 3
C Only 2 and 3
D 1, 2 and 3

Your answer ☐ **[1]**

14. A container has 1.0 mole of gas at pressure 100 kPa.
The root mean square (r.m.s.) speed of the gas particles is 500 ms^{-1}. The mass of each gas particle is 4.7×10^{-26} kg.

What is the volume of the container?

A 3.9×10^{-26} m^3
B 4.7×10^{-5} m^3
C 2.4×10^{-2} m^3
D 4.7×10^{-2} m^3

Your answer ☐ **[1]**

END OF QUESTION PAPER