Thermal 2

There are two sets of questions in this prep. Everyone must complete section A. You must complete section B if either you are unsure about the topic so far, or if you got less than an A at AS. Section C should be completed by those applying for a physical science or those that simply fancy a challenge!

Section A

1.

This question is about a detector for neutrons and other sub atomic particles which works by measuring the temperature rise of a suitable liquid.

When neutrons enter the detector their kinetic energy can be shared amongst the particles within the detector. This results in a temperature rise of the liquid.

(a) Consider using water as the liquid in the detector.

Assume that each neutron passing through the detector transfers 3.5×10^{-16} J of energy to the water.

Show that 1.2×10^{19} neutrons would need to enter the detector to raise the temperature of 1 kg of water by 1 K.

Specific thermal capacity of water = 4.2×10^{3} J kg^{-1} K^{-1}

[2]

(b) Scientists are attempting to use this process to detect a new type of particle. This particle has a kinetic energy of 3.5×10^{-16} J but only interacts with matter very rarely. It is expected that only one of these particles would be absorbed per day by 1 kg of water.

Explain why the temperature rise of water cannot be used to detect such rare happenings.

[2]

(c) A similar type of detector uses the temperature rise of very cold liquid helium-3 to detect the particles. When helium-3 is cooled to 1×10^{-4} K it has a specific thermal capacity of 7.0×10^{-8} J kg^{-1} K^{-1}.

(i) The detector uses 8.0×10^{-6} kg of helium-3 at this temperature. Show that a particle transferring 3.5×10^{-16} J to the helium-3 will give a temperature rise of 6.3×10^{-4} K.

(ii) The smallest temperature change that can be detected is 0.5×10^{-6} K. Explain why it is unlikely that any particles will be detected if helium-3 absorbs the particles at a similar rate to water. Suggest how the apparatus can be adapted to make detection more likely.

[3]

2.

13 This question is about the gravitational field around the Moon and the absence of any atmosphere around the Moon.

Fig. 13.1 shows lines representing equipotentials at different heights above the surface of the Moon.

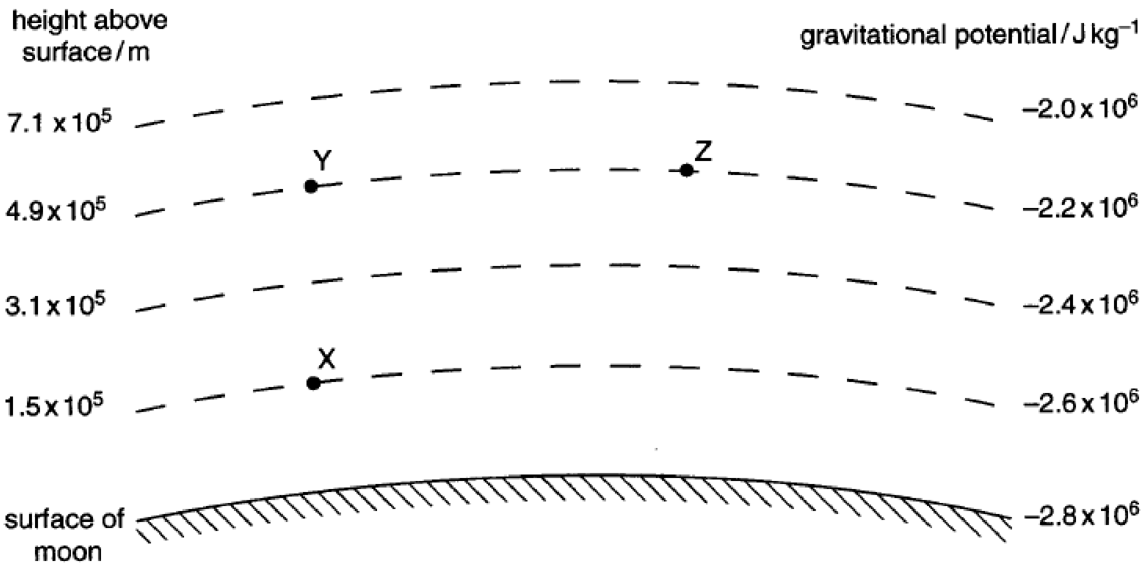


Fig. 13.1

(a) Explain why the energy required to move a mass from X to Y is the same as the energy required to move a mass from X to Z.

[2]

(b) **(i)** Show that about 78,000 J are required to move 28 gram of nitrogen molecules (one mole) from the surface of the Moon to a point far away from the surface.

[2]

Each nitrogen molecule has a mass of 4.7×10^{-26} kg. In one mole there are 6.0×10^{23} nitrogen molecules.

(ii) Show that the speed required for molecules at the surface of the planet to escape is about 2 400 m s^{-1}.

[3]

(c) Use the ideal gas law and $pV = \frac{1}{3}Nmc^2$ to show that the mean square speed of a molecule of an ideal gas at absolute temperature T is given by:

$$c^2 = \frac{3RT}{M_m}$$

where M_m is the mass of one mole of the gas.

[3]

(d) The mean surface temperature of the Moon is 290 K.

Calculate the root mean square speed of nitrogen molecules at 290 K.

[2]

(e) Explain why the moon has lost any nitrogen atmosphere it may have once possessed.

[2]

Section B: A2

3.

4.0 g of helium contains one mole (6.0×10^{23} atoms). The helium is at a pressure of 1.0×10^5 Pa and at a temperature of 300 K.

(a) Show that one mole of helium occupies a volume of about 0.025 m^3 under these conditions.

molar gas constant $R = 8.3\ J\ mol^{-1}\ K^{-1}$

[2]

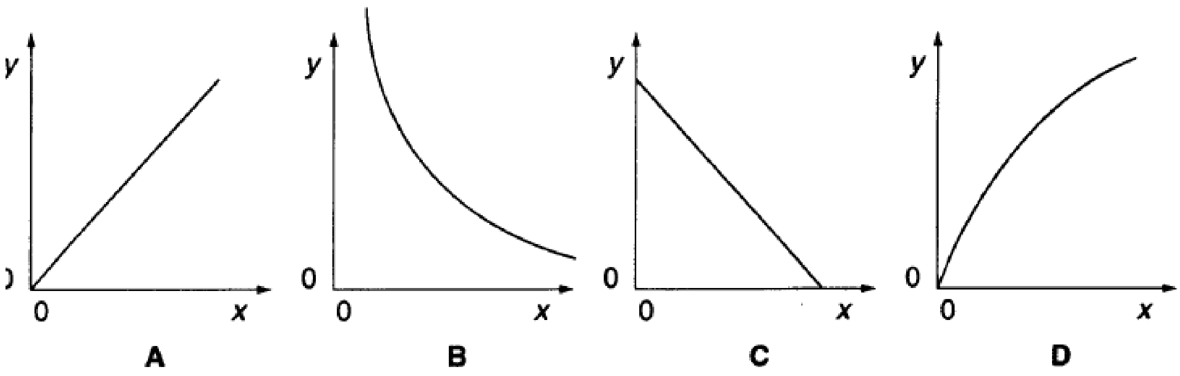
(b) The gas is compressed to a volume of 0.020 m^3. The temperature of the gas is kept constant.

Calculate the new pressure of the gas.

pressure = ... Pa [2]

4.

Study the graphs **A, B, C, D.**



(a) Which graph shows the variation in **volume** (y) of a fixed mass of ideal **gas at constant** pressure with **absolute temperature** (x) ?

answer ....

(b) Which graph shows the variation in **pressure** (y) of a fixed mass of ideal gas at constant temperature with **volume** (x) ?

answer ....

[2]

5.

A helium balloon has a volume of $5.0\,m^3$ at ground level on a summer's day. The temperature at ground level is 298 K and the pressure of the helium is 1.0×10^5 Pa.

The balloon rises to a height at which its volume is $10.8\,m^3$ and the temperature is 257 K.

Calculate the pressure of the helium in the balloon.

Assume that helium behaves as an ideal gas.

Pressure = ... Pa [3]

Section B: Extension

6.

(a) State Boyle's law.

(b) Figure 2.1 .shows a length of capillary tubing in which a column of air is trapped by a mercury column of length 100 mm. The length of the air column is 400 mm. The bottom of the tubing is sealed and the top is open to the atmosphere.

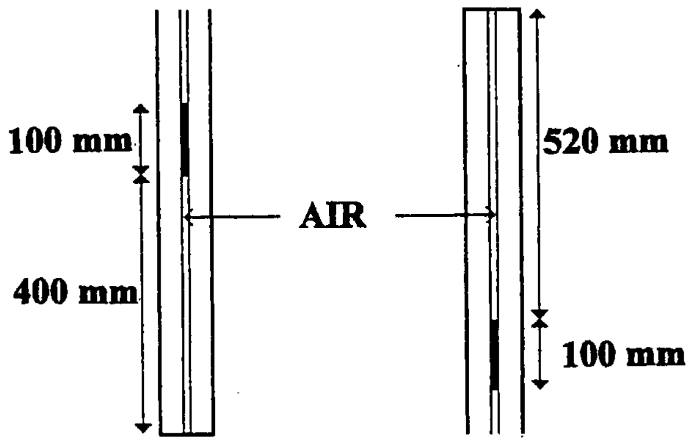


Figure 2.1 Figure 2.2

The tubing is now inverted, Figure 2.2, and the air column is seen to increase in length to 520 mm. Use this observation to calculate a value for atmospheric pressure, expressed in mm of mercury.

(c) A typical value for atmospheric pressure, expressed in SI units, is 101 kPa. The surface area A of the Earth is related to its mean radius R by the expression

$$A = 4\pi R^2,$$

where R has the value 6400 km.

Calculate

(i) the sum of the magnitudes of the forces exerted by the atmosphere on the surface of the Earth,

(ii). the mass of the Earth's atmosphere, assuming g does not vary with height above the Earth's surface.

(11 marks)

7.

A cylinder, with a weightless piston, has an internal diameter of 0.24 m. The cylinder contains water and steam at 100° C. It is situated in a constant temperature bath at 100° C, Figure 2.1. Atmospheric pressure is 1.01×10^5 Pa. The steam in the cylinder occupies a length of 0.20 m and has a mass of 0.37 g.

Figure 2.1

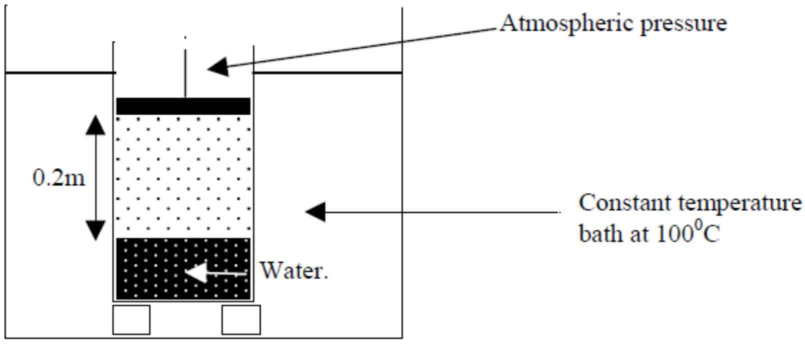


Figure 2.1

(i) What is the pressure P of the steam in the cylinder?
(ii) If the piston moves very slowly down a distance 0.10 m, how much work, W, will be done in reducing the volume of the system?
(iii) What is the final temperature, T_f, in the cylinder?
(iv) Determine the heat Q_c produced in the cylinder. [6]

8.

What must be the speed of a lead bullet if it melts when it strikes a steel slab? The initial temperature of the bullet is 27 °C. The melting point of lead is 327 °C, its latent heat of melting is 2.1×10^4 J kg^{-1} and its specific heat capacity is 126 J kg^{-1} °C^{-1}. Assume that all of the kinetic energy is converted to heat energy in the bullet.

(4 marks)

9.

Black coffee at 70.0°C, with a mass of 225 grams and specific heat capacity of 4200 J kg^{-1}°C^{-1}, is poured into a porcelain mug which is at 20.0°C, with mass 200 grams and specific heat capacity of 1200 J kg^{-1}°C^{-1}. This is followed by the addition of 15 grams of cream at 5.0 °C, with specific heat capacity of 4000 J kg^{-1}°C^{-1}. Determine the final equilibrium temperature of the white coffee assuming no heat is lost.

Explain, without any calculation, why more black coffee, at 70°C, is required to raise the equilibrium temperature of the white coffee by 1°C when it is at temperature T_1°C compared with that at temperature T_2°C, T_1 being greater than T_2. [6]