1)

(a)		molecules have negligible volume collisions are elastic the gas cannot be liquified there are no interactions between molecules (except during collisions) the gas obeys the (ideal) gas law / obeys Boyles law etc. at all temperatures/pressures any two lines ✓✓	2	a gas laws may be given as a formula
(b)	(i)	n (= PV / RT) = $1.60 \times 10^6 \times 0.200$ / $(8.31 \times (273 + 22))$ ✓ = 130 or 131 mol ✓ (130.5 mol)	2	
(b)	(ii)	mass = 130.5×0.043 = 5.6 (kg) ✓ (5.61kg) density (= mass/volume) = 5.61 / 0.200 = 28 ✓ (28.1 kg m^{-3}) kg m^{-3} ✓	3	allow ecf from bi a numerical answer without working can gain the first two marks
(b)	(iii)	($V_2 = P_1 V_1 T_2 / P_2 T_1$) $V_2 = 1.6 \times 10^6 \times .200 \times (273 - 50) / 3.6 \times 10^4 \times (273 + 22)$ or 6.7(2) (m^3)✓ mass remaining = 5.61 × 0.20 / 6.72 = 0.17 (kg) ✓ (0.167 kg) or n = (PV / RT = $3.6 \times 10^4 \times 0.200$ / $(8.31 \times (273 - 50))$ = 3.88(5) (mol) ✓ mass remaining = $3.885 \times 4.3 \times 10^{-2}$ = 0.17 (kg) ✓ 2 sig figs ✓	3	allow ecf from bii **[reminder must see bii]** look out for any 2 sf answer gets the mark

2)

(b)(i)	• The motion of molecules is random. • Collisions between molecules (or molecules and the wall of the container) are elastic. • The time taken for a collision is negligible (compared to the time between collisions) • Newtonian mechanics apply (or the motion is non-relativistic). • The effect of gravity is ignored or molecules move in straight lines (at constant speed) between collisions. ✓✓ any two	If more than 2 answers are given each wrong statement cancels a correct mark.	2
b)(ii) Escalate if the numbers used are 4000, 5000 and 6000 giving 25666666 o			
(b)(ii)	mean square speed (= $(2000^2 + 3000^2 + 7000^2) / 3$ = 20.7×10^6) = 2.1×10^7 ($m^2 s^{-2}$)	common correct answers 20.7×10^6 21×10^6 2.07×10^7 2.1×10^7 20 700 000 21 000 000 **Possible escalation**	1

(c)	(using meanKE = $3RT/2N_A$) $T = 2N_A \times$ meanKE / $3R$ $=2\times6.02\times10^{23}\times6.6\times10^{-21}/3\times8.31$ ✓ = 320 (K) ✓ (318.8 K) Or (meanKE = $3kT/2$) $T = 2 \times$ meanKE $/3k$ $=2\times 6.6\times10^{-21} / 3\times 1.38\times10^{-23}$ ✓ = 320 (K) ✓ (318.8 K)	first mark for substitution into an equation second mark for answer **Possible escalation** Answer only can gain 2 marks	2

3)

3 (a)	the number of atoms in 12g of carbon-12 or the number of particles/atoms/molecules in one mole of substance ✓	Not – N_A quoted as a number	1	
3 (b)(i)	mean kinetic energy (= 3/2 kT) = $3/2 \times 1.38 \times 10^{-23} \times (273 + 22)$ $= 6.1 \times 10^{-21}$ (J) ✓	6×10^{-21} J is not given mark	1	
3 (b)(ii)	mass of krypton atom $= 0.084 / 6.02 \times 10^{+23}$ ✓ $(= 1.4 \times 10^{-25}$ kg) $\overline{c^2}$ (= 2 × mean kinetic energy / mass $= 2 \times 6.1 \times 10^{-21} / 1.4 \times 10^{-25}$) $= 8.7 - 8.8 \times 10^4$ ✓ $m^2 s^{-2}$ or J kg^{-1} ✓	1st mark is for the substitution which will normally be seen within a larger calculation. Allow CE from (b)(i) Working must be shown for a CE otherwise full marks can be given for correct answer only. No calculation marks if mass has a physics error i.e. no division by N_A note for CE answer = (b)(i) $\times 1.43 \times 10^{25}$	3	
3 (c)	(at the same temperature) the	1st mark requires the word	2	
	mean kinetic energy is the same Or Gases have equal $\frac{1}{2}mc_{rms}^2$ Or mass is inversely proportional to mean square speed / m $\propto 1/\overline{c^2}$ ✓ $\overline{c^2}$ or mean square speed of krypton is less ✓	mean/average or equivalent in an algebraic term 2nd mark 'It' will be taken to mean krypton. So, 'It is less' can gain a mark Allow 'heavier' to mean more massive' Allow vague statements like speed is less for 2nd mark but not in the first mark		

4)

4(a)	1. fixed mass or fixed number of molecules/moles √ 2. constant temperature √	Allow alternatives to fixed mass such as 'sealed vessel' or 'closed system'. Not amount of gas as this is ambiguous. The temperature must not be specific.	2
4(b)(i)	$(V_2 = \frac{P_1}{P_2} \times V_1 \times \frac{T_2}{T_1})$ $V_2 = \frac{1.0 \times 10^5}{4.4 \times 10^5} \times 0.0016 \times \frac{350}{290}$ or $(V = \frac{nRT}{P})$ V = 0.067 x 8.31 x 350 / (4.4 x 10^{-4}) √ = 0.00044 (m^3) √ (4.39 × 10^{-4} m^3)	1st mark comes from use of valid equation with substitutions. In the alternative look out for 0.067 = 1 /15 = (0.0016 / 0.024) And $R = N_A k$ Correct answer gains full marks If no other answer is seen then 1 sig fig is wrong.	2
4(b)(ii)	(proportion of a mole of trapped air = volume of cylinder / volume of mole) = 0.0016 / 0.024 = 0.067 (mol) √ (0.0667) or (use of $n = pV/RT$) = 1.0 × 10^5 × 0.0016 / (8.31 × 290) = 0.066 (mol) √ (0.0664) or = 4.4 × 10^5 × 0.00044 / (8.31 × 350) = 0.067 (mol) √ (0.0666)	Answers range between 0.066 – 0.067 mol depending on the volume carried forward. (answer alone gains mark) Working must be shown for a CE Ans = V_2 × 151	1
4(b)(iii)	(mass = molar mass × number of moles) mass = 0.029 × 0.0667 √ (0.00193 kg) (density = mass / volume) density = 0.00193 / 0.0016 = 1.2(1) kg m^{-3} √ (no continuation errors within this question but allow simple powers of 10 arithmetic errors which will lose one mark)	CE mass = 0.029 × (b)(ii) CE density = (0.029 × (b)(ii)) / 0.0016 or (18.1 × (b)(ii)	2
4(c)	the (average/mean/mean-square) speed of molecules		2
	increases (with absolute temperature) √ as the mean kinetic energy is proportional to the (absolute) temperature Or Reference to KE_{mean} = 3/2 kT √ but mean or rms must feature in the answer somewhere.		

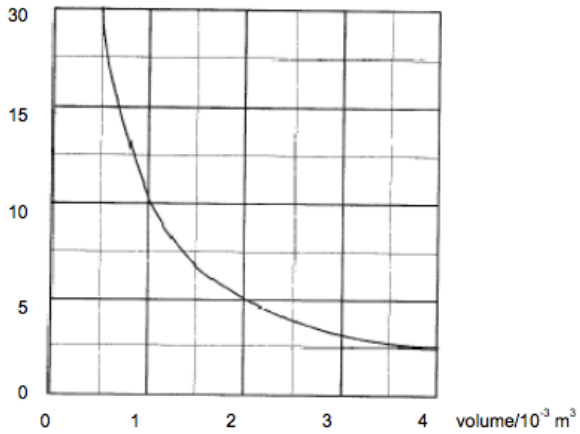
5)

The mark scheme for this part of the question includes an overall assessment for the Quality of Written Communication (QWC).		
Descriptor	**Mark**	
High Level – Good to Excellent An experiment with results and interpretation must be given leading to the measurement of absolute zero. The student refers to 5 or 6 points given below. However each individual point must stand alone and be clear. *The information presented as a whole should be well organised using appropriate specialist vocabulary. There should only be one or two spelling or grammatical errors for this mark.*	5-6	6 clear points = 6 marks 5 clear points = 5 marks
Intermediate Level – Modest to Adequate An experiment must be given and appropriate measurements must be suggested. For 3 marks the type of results expected must be given. 4 marks can only be obtained if the method of obtaining absolute zero is given. *The grammar and spelling may have a few shortcomings but the ideas must be clear.*	3-4	4 clear points = 4 marks 3 clear points = 3 marks
Low Level – Poor to Limited One mark may be given for any of the six points given below. For 2 marks an experiment must be chosen and some appropriate results suggested even if the details are vague. Any 2 of the six points can be given to get the marks. *There may be many grammatical and spelling errors and the information may be poorly organised.*	1 - 2	2 clear points = 2 marks Any one point = 1 mark

The description expected in a competent answer should include:
 	
1. Constant mass of gas (may come from the experiment if it is clear that the gas is trapped) and constant volume (or constant pressure).
 	
2. Record pressure (or volume) for a range of temperatures.
(the experiment must involve changing the temperature with pressure or volume being the dependent variable)
 	
3. How the temperature is maintained/changed/controlled. (The gas must be heated uniformly by a temperature bath or oven – so not an electric fire or lamp)
 	
4. Describe or show a graph of pressure against temperature (or volume against temperature) that is linear. The linear relationship may come from a diagram/graph or a reference to the Pressure Law or Charles' Law
(line of best fit is continued on implies a linear graph)
		for (point 1) amount/quantity/moles of gas is acceptable
		
		for (point 2) no specific details of the apparatus are needed. Also the temperature recording may not be explicitly stated eg. record the pressure at different temperatures is condoned
		
		for (points 4 and 5) the graphs referred to can use a different variable to pressure or volume but its relationship to *V* or *P* must be explicit

5. Use the results in a graph of pressure against temperature (or volume against temperature) which can be extrapolated to lower temperatures which has zero pressure (or volume) at absolute zero, which is at 0 K or -273 °C (a reference to crossing the temperature axis implies zero pressure or volume) 6. Absolute zero is obtained using any gas (providedit is ideal or not at high pressures or close to liquification) **Or** Absolute temperature is the temperature at which the volume (or pressure or mean kinetic energy of molecules) is zero./or when the particles are not moving Discount any point that are vague or unclear		in (point 5) the graph can be described or drawn (second part of point 6) must be stated not just implied from a graph

6)

(a)	pressure/10^4 Pa  curve with decreasing negative gradient that passes through the given point which does not touch the x axis ✓ designated points pressure/10^4 Pa / volume/10^{-3} m^3 10 / 1.0 5.0 / 2.0 4.0 / 2.5 2.5 / 4.0 2 of the designated points ✓✓ (one mark each)	**3**
(b) (i)	$N = PV/kT = 5 \times 10^4 \times 2 \times 10^{-3}/1.38 \times 10^{-23} \times 290$ ✓ [or alternative use of $PV = nRT$ $5 \times 10^4 \times 2.0 \times 10^{-3}/8.31 \times 290 = 0.0415$ moles] $= 2.50 \times 10^{22}$ molecules ✓	**2**
(b) (ii)	(mean) kinetic energy of a molecule $= \frac{3}{2}kT = \frac{3}{2} \times 1.38 \times 10^{-23} \times 290$ ✓ $(= 6.00 \times 10^{-21}$ J) (total kinetic energy = mean kinetic energy × N) $= 6.00 \times 10^{-21} \times 2.50 \times 10^{22}$ ✓ = 150 (J) ✓	**3**

(c)	all molecules/atoms are identical molecules/atoms are in random motion Newtonian mechanics apply gas contains a large number of molecules the volume of gas molecules is negligible (compared to the volume occupied by the gas) or reference to point masses no force act between molecules except during collisions or the speed/velocity is constant between collisions or motion is in a straight line between collisions collisions are elastic or **kinetic** energy is conserved and of negligible duration any 4 ✓✓✓✓	**max 4**
	Total	**12**

7)

a	graph passes through given point 2.2×10^{-3} m^3 at 0°C straight line with positive gradient ✓ (straight) line to aim or pass through –273°C at zero volume ✓	**2**
b	(use of $n = PV/RT$) $1.00 \times 10^5 \times 2.20 \times 10^{-3}/8.31 \times 273$ ✓ $n = 0.0970$ (moles) ✓	**2**
c	(use of mean kinetic energy = 3/2 K T) $= 3/2 \times 1.38 \times 10^{-23} \times 323$ ✓ 6.69×10^{-21} (J) ✓ 3 sfs ✓	**3**
d	total internal energy = $6.69 \times 10^{-21} \times 0.0970 \times 6.02 \times 10^{23} = 390$ (J) ✓	**1**
e	**The candidate's writing should be legible and the spelling, punctuation and grammar should be sufficiently accurate for the meaning to be clear.** The candidate's answer will be assessed holistically. The answer will be assigned to one of three levels according to the following criteria. **High Level (Good to excellent): 5 or 6 marks** The information conveyed by the answer is clearly organised, logical and coherent, using appropriate specialist vocabulary correctly. The form and style of writing is appropriate to answer the question. The candidate provides a comprehensive and coherent sequence of ideas linking the motion of molecules to the pressure they exert on a container. At least three of the first four points listed below must be given in a logical order. The description should also show awareness of how a balance is maintained between the increase in speed and shortening of the time interval between collisions with the wall to maintain a constant pressure. To be in this band, reference must be made to force being the rate of change of momentum or how, in detail, the volume compensates for the increase in temperature. **Intermediate Level (Modest to adequate): 3 or 4 marks** The information conveyed by the answer may be less well organised and not fully coherent. There is less use of specialist vocabulary, or specialist vocabulary may be used incorrectly. The form and style of writing is less appropriate. The candidate provides a comprehensive list of ideas linking the motion of molecules to the pressure they exert on a container. At least three of the first four points listed below are given. The candidate also knows than the mean square speed of molecules is proportional to temperature. Using this knowledge, an attempt is made to explain how the pressure is constant.	**max 6**

	Low Level (Poor to limited): 1 or 2 marks The information conveyed by the answer is poorly organised and may not be relevant or coherent. There is little correct use of specialist vocabulary. The form and style of writing may be only partly appropriate. The candidate attempts the question and refers to at least two of the points listed below. **Incorrect, inappropriate of no response: 0 marks** No answer or answer refers to unrelated, incorrect or inappropriate physics. **Statements expected in a competent answer should include some of the following marking points.** molecules are in rapid random motion/many molecules are involved molecules change their momentum or accelerate on collision with the walls reference to Newton's 2nd law either $F = ma$ or F = rate of change of momentum reference to Newton's 3rd law between molecule and wall relate pressure to force $P = F/A$ mean square speed of molecules is proportional to temperature as temperature increases so does change of momentum or change in velocity compensated for by longer time between collisions as the temperature increases as the volume increases the surface area increases which reduces the pressure	
	Total	**14**

8)

a	i	$n = PV/RT = 3.2 \times 10^5 \times 1.9 \times 10^{-3}/8.31 \times 285$ $n = 0.26$ mol ✓ (0.257 mol)	1

a	ii	$P_2 = \frac{T_2}{T_1} \times P_1 = \frac{295}{285} \times 3.20 \times 10^5$ ✓ 3.31×10^5 Pa ✓(allow 3.30-3.35 × 10^5 Pa) 3 sig figs ✓sig fig mark stands alone even with incorrect answer	3

b		similar -(rapid) **random** motion - range of speeds different - **mean** kinetic energy - root **mean** square speed - **frequency** of collisions	2