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Thermal Physics, Physics 224 **Final Exam** **Thursday March 21, 2002**
Winter 2002
Instructor David Cobden 7 printed sides

Time allowed: 1hr and 50 minutes = 110 minutes. Begin and end on the buzzer.
Attempt all four questions. Remember that each has an equal weight in the final reckoning.
Be careful not to spend more than 20-25 minutes on each question initially – you can come back to the more difficult parts at the end. Also, make sure you take into account how many marks a part is worth and don't spend a disproportionate amount of time on it.

Write all your working on the question sheets.
Please write your name on each page.
This is a closed book exam.
You are allowed three pages of notes.
You are allowed a calculator but it is not essential.

Question 1 [33] – Pressure in the atmosphere, adiabaticity, heat flow, Bernoulli

(a) [9] Estimate the pressure p_{top}, at the top of a mountain ridge h = 2000 m above sea level, assuming that the atmosphere (on average) has a constant temperature of T = 7 C.

(b) [9] A wind blows up the mountain from the west, and just after passing over the ridge it is at T_{top} = 2° C, which is somewhat colder and denser than the rest of the atmosphere at that height. As a result, it then sinks down into the valley to the east, whose floor is close to sea level. Assuming the air is adiabatically compressed during this process, so that pV^{γ} = const, deduce the relation between T and p as it sinks, and hence estimate the temperature T_{valley} reached at the valley floor.

(c) [5] One reason the wind coming down on the east is warmer than the wind going up on the west at the same height is because on the way up the water vapour condenses and precipitates out. Why does it condense, and why does this make the air warmer than it would be otherwise?

(d) [5] Another reason is that the flow is not completely adiabatic. List the factors that determine and influence the flow of heat into the rising air.

(e) [5] Why does the wind sink down into the valley at a roughly constant velocity, rather than speeding up rapidly as it flows downhill? (hint: consider Bernoulli's equation)

Question 2 [33] – Heat capacities, First Law

(a) The internal energy of an ideal gas is given by $E_{int} = nqRT/2$. Explain what q is in this equation. [3]

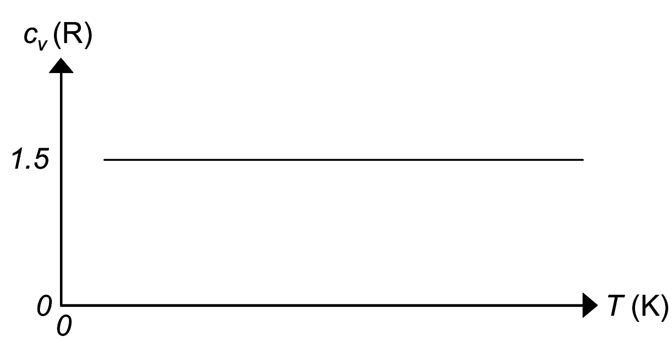
Calculate the heat Q_v absorbed by n moles of the gas when its temperature is increased by ΔT isovolumetrically. [3]

Now calculate the heat Q_p absorbed if the same temperature is instead increased isobarically. [5]

Hence show that $c_p = c_v + R$. [4]

Shown below are sketches of the temperature dependence of the molar heat capacity at constant volume for four different common substances. In each case, deduce the nature of the substance (eg, 'margarine' or 'diatomic gas'), and explain each of the features that is seen.

(a) [3]



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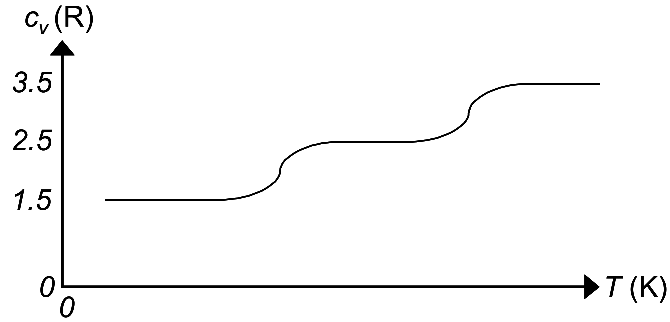
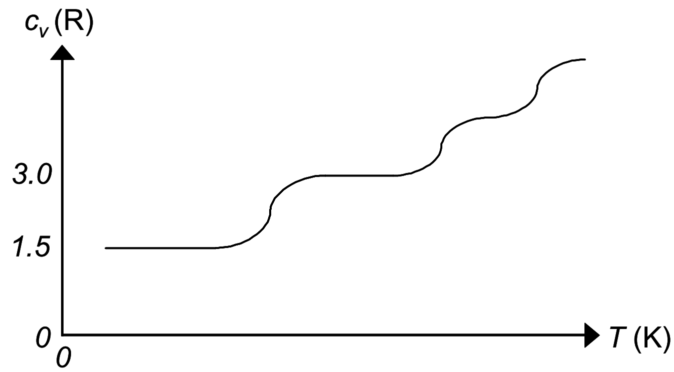
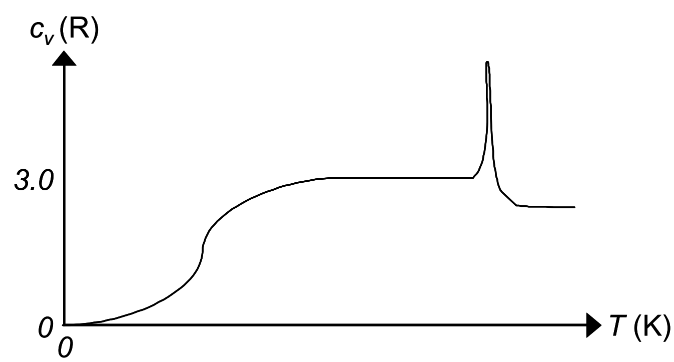
(b) [4]



(c) [4]



(d) [5]



What property of the substance is the area under the spike in (d) equal to? [2]

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Question 3 [33] Refrigerators and Entropy

(a) [6] Draw a schematic energy flow diagram for a heat pump (ie, refrigerator) working between two reservoirs at temperatures T_H and T_L, and define the coefficient of performance K in terms of W, Q_H and Q_L.

(b) [4] State the second law of thermodynamics in the form (Clausius) that applies to a heat pump.

(c) [8] Show that the second law implies $K_c \leq T_L/(T_H-T_L)$ for any real heat pump, by considering driving the heat pump with a Carnot engine.

(d) [8] A heat pump keeps the inside of a house at a temperature $T_H = 22^\circ$ C. For the second reservoir it has two optional settings. It can use either (1) a point deep in the ground, at a constant temperature of 7° C throughout the year, or (2) the outside air, which is at an average temperature of -3° C during the winter and $+10^\circ$ C during the summer. Which is the better setting in summer, and which is better in winter?

(e) [7] The heat pump (which is *real*!) runs with $K = 5$ when using the underground reservoir. What is then the rate of increase of the entropy of the universe due to the heat pump if it takes 1 kW of electric power?

Question 4 [30]

(a) [10] Determine the rms speeds of H_2 and O_2 molecules in the earth's atmosphere at 300 K and 1 atm pressure. (R = 8.3 J/K)

(b) [10] The escape velocity of particles on the earth is 11 km/sec. Explain, using the Maxwell speed distribution, why hydrogen can eventually escape the earth's atmosphere, while oxygen almost never does.

(c) [10] Estimate the mean free path λ of oxygen molecules in the atmosphere at $T = 300$ K and sea level. Assume that the diameters of oxygen and nitrogen molecules, which are the main components of air, are both about $d = 2 \times 10^{-10}$ m. How does λ vary with altitude above the earth's surface?