

**Thermal Physics 224**  
**Autumn 2007**

**Second midterm 9.30 am, Monday November 19, 2007**  
Instructor: David Cobden

Do not turn this page until the buzzer goes at 9.30. You must hand your exam to me by the time I leave the room at 10.25.

Attempt all the questions.

Please write your name on every page and your SID on the first page.

Write all your working on these question sheets. Use this front page for extra working. It is important to show your calculation or derivation. Some of the marks are given for showing clear and accurate working and reasoning.

Watch the blackboard for corrections or clarifications during the exam.

This is a closed book exam. *No books, notes or calculators allowed.*

The generalized thermodynamic identity is

$$dU = TdS - pdV + \mu dN. \quad (\text{i})$$

The Sackur-Tetrode equation for the entropy of an ideal monatomic gas is

$$S = Nk \left[ \ln \left\{ \frac{V}{N} \left( \frac{4\pi mU}{3Nh^2} \right)^{\frac{3}{2}} \right\} + \frac{5}{2} \right]. \quad (\text{ii})$$

1. [5] What is meant by a *quasistatic* process?
2. [5] An ideal gas of  $N$  atoms initially at temperature  $T_1$  and volume  $V_1$  is expanded to volume  $V_2$ . What is the change  $\Delta S$  in its entropy  $S$  if the expansion is adiabatic and quasistatic, and why?
3. [5] What if the expansion is adiabatic but not quasistatic, and why?
4. [10] What if the expansion is isothermal?
5. [10] What if it is a free expansion, ie, into vacuum?
6. [3] Is equation (i) valid for quasistatic processes only, or for any process that leads to a change in  $U, S, V$  and  $N$ ?

7. [10] Derive from equation (i) the expression for the pressure  $p$  which is most natural from the point of view of statistical mechanics. Show, using entropy, that this expression is a quantity that must be equal for two systems in thermal equilibrium which are able to exchange volume (eg, portions of gas on either side of a moveable partition.)

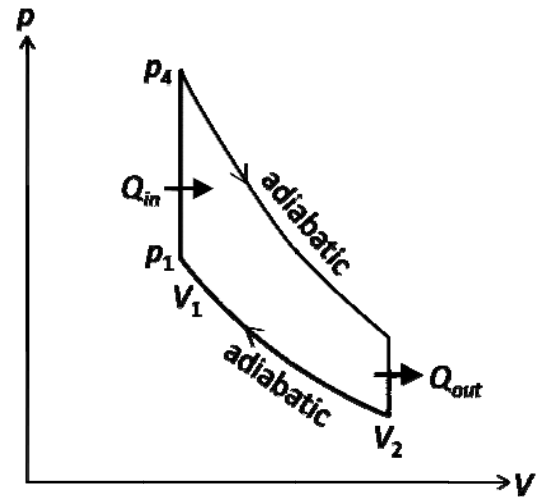
8. [8] Use this expression for  $p$  combined with equation (ii) to deduce the ideal gas law.

9. [10] Derive from equation (i) an expression for  $p$  in terms of  $U$  and  $V$  which is more natural from the point of view of classical thermodynamics. Explain why it is so, using the relationships between heat and entropy, and between volume and work, for a quasistatic process.

10. [10] State the definition of temperature  $T$  in statistical mechanics, which also can be deduced from equation (i), and use it to deduce the internal energy of an ideal monatomic gas at temperature  $T$ .

11. [8] A heat engine consists of some ideal gas which is taken quasistatically around the cycle shown. Heat  $Q_{in}$  comes from the hot reservoir which is at  $T_h$ , and heat  $Q_{out}$  is dumped into the cold reservoir at  $T_c$ . The efficiency is  $e = \frac{W}{Q_{in}}$ , where  $W$  is the work done by the gas during the cycle.

First, write  $e$  in terms of  $Q_{in}$  and  $Q_{out}$ .



12. [6] Give or find an expression for  $U$  in terms of  $p$  and  $V$  for an ideal gas.

13. [10] Find  $Q_{in}$  and  $Q_{out}$ , making use of the First Law, and hence show that  $e = 1 - \left(\frac{V_2}{V_1}\right)^a$ , where you should determine the parameter  $a$  in terms of  $\gamma$ .

14. [5] Why must this engine be less efficient than a Carnot Engine? Why is the cycle not reversible?