NAME__WAITZ SOLUTIONS_____

Unified Quiz 1: Thermodynamics

October 3, 2003

One 8 1/2" x 11" sheet (two sides) of notes
Calculators allowed.
No books allowed.

- **Put your name on each page of the exam.**
- **Read all questions carefully.**
- **Do all work for each problem on the pages provided.**
- **Show intermediate results.**
- **Explain your work --- don't just write equations.**
- **Partial credit will be given (unless otherwise noted), but only when the intermediate results and explanations are clear.**
- **Please be neat. It will be easier to identify correct or partially correct responses when the response is neat.**
- **Show appropriate units with your final answers.**
- **Box your final answers.**

Exam Scoring

#1 (40%)	
#2 (16%)	
#3 (24%)	
#4 (20%)	
Total	

1) (40%, 8 parts * 5% each -- partial credit given)

    a) What does it mean for a process to be quasi-equilibrium? (LO# 4, 5)

    A process is quasi-equilibrium if the time rate of change of the process is slow relative to the time it takes for the system to reach thermodynamic equilibrium.

    b) Why is it necessary that a system be quasi-equilibrium (i.e. quasi-static) before applying many of the thermodynamics relations to that system? (LO# 4, 5)

    If the system is not in equilibrium, then different parts of the system exist at different states at the same time and it is not possible to define one "state" of the system. Since many of the thermodynamic relations relate to the state of the system, it is necessary that a state can be defined for the system before applying them.

    c) For a system composed of a small mass of gas passing through a rocket nozzle, describe the physical implications of an adiabatic, quasi-equilibrium (i.e. quasi-static) process. (LO# 4, 5)

    Such an assumption would imply that the mass of gas passes through the nozzle too fast for significant heat transfer to occur, but at a rate which is slow compared to the time it takes the small mass of gas to come to thermodynamic equilibrium.

    d) For a thermodynamic cycle involving an ideal gas, what is the relationship between work, shaft (or external) work and flow work when these quantities are calculated for the cycle as a whole? (LO# 1, 4)

    $w = w_s + w_f$
    $w_f = R(\Delta T)$, only a function of the state of the system. Since the system returns to its initial state when completing one loop around the cycle, then $w_f=0$ for a cycle and $w=w_s$ for a cycle.

1) **Continued (40%, 8 parts * 5% each -- partial credit given)**

   e) For a thermodynamic cycle involving an ideal gas, what is the relationship between heat and work when calculated for the cycle as a whole? (LO# 1, 4)

   $\Delta u = q - w$

   u is a property and a function of the state of the system. Therefore $\Delta u_{cycle} = 0$ since the system returns to its initial state when completing one loop around the cycle. So $w_{cycle} = q_{cycle}$

   f) What is the physical meaning of enthalpy and for what kinds of systems is it useful and why? (LO# 1, 4)

   Enthalpy is the amount of energy that is transferred across a system boundary by a moving flow. This energy is composed of two parts: the internal energy of the fluid (u) and the flow work (pv) associated with pushing the mass of fluid across the system boundary. Because enthalpy is a measure of the energy that is transferred across a system boundary by a flow, it is most useful for flow processes involving open systems, e.g. applications of the steady flow energy equation.

   g) Which terms in the first law of thermodynamics depend on path? Explain why the dependence on path is important for the design of heat engines. (LO# 5)

   Heat and work are path dependent. Energy is not path dependent, it is a function of the state of the system. The implication of path dependence for heat engines is that it is possible take a system from one thermodynamic state to another via different paths (i.e. processes). These processes , which are defined by the engineer, have different amounts of heat and work, and thus result in difference performance for the heat engine.

   h) Explain the difference between heat and temperature. (LO# 1)
   Heat is the transfer of energy across a system boundary by virtue of a temperature difference only. It is measured in Joules.   Temperature is a thermodynamic property and a function of the state of the system. It is measured in Kelvin.

2) (16%, partial credit given)
Explain how a refrigerator works in terms of energy, heat and work. (LO# 2, 3)

The objective of a refrigerator is to lower the internal energy of a body at low temperature (the food) and transfer that energy to the higher temperature surroundings (the room the refrigerator is in). It requires work (typically in the form of electrical energy) to do this. Most refrigerators employ a thermodynamic cycle with refrigerant circulating around a loop. As the refrigerant circulates around the loop, its internal energy (and temperature) is alternately raised and lowered by a series of devices. First the internal energy is lowered either by passing through a small turbine or through an expansion valve. In these devices, work is done by the refrigerant so its internal energy is lowered. The internal energy is lowered to a point where the temperature of the refrigerant is lower than that of the air in the refrigerator. A heat exchanger is used to transfer energy from the air (and food) in the refrigerator to the cold refrigerant (energy transferred by virtue of a temperature difference only = heat). This lowers the internal energy of the air/food and raises the internal energy of the refrigerant. Then a pump or compressor is used to do work on the refrigerant adding additional energy to it and thus further raising its internal energy. Electrical energy is used to drive the pump or compressor. The internal energy of the refrigerant is raised to a point where its temperature is hotter than the temperature of the room. The refrigerant is then passed through a heat exchanger (the coils at the back of the refrigerator) so that energy is transferred from the refrigerant to the surroundings. As a result, the internal energy of the refrigerant is reduced and the internal energy of the surroundings is increased. It is at this point where the internal energy of the food and the energy used to drive the compressor or pump are transferred to the surroundings. The refrigerant then continues on to the turbine, repeating the cycle.
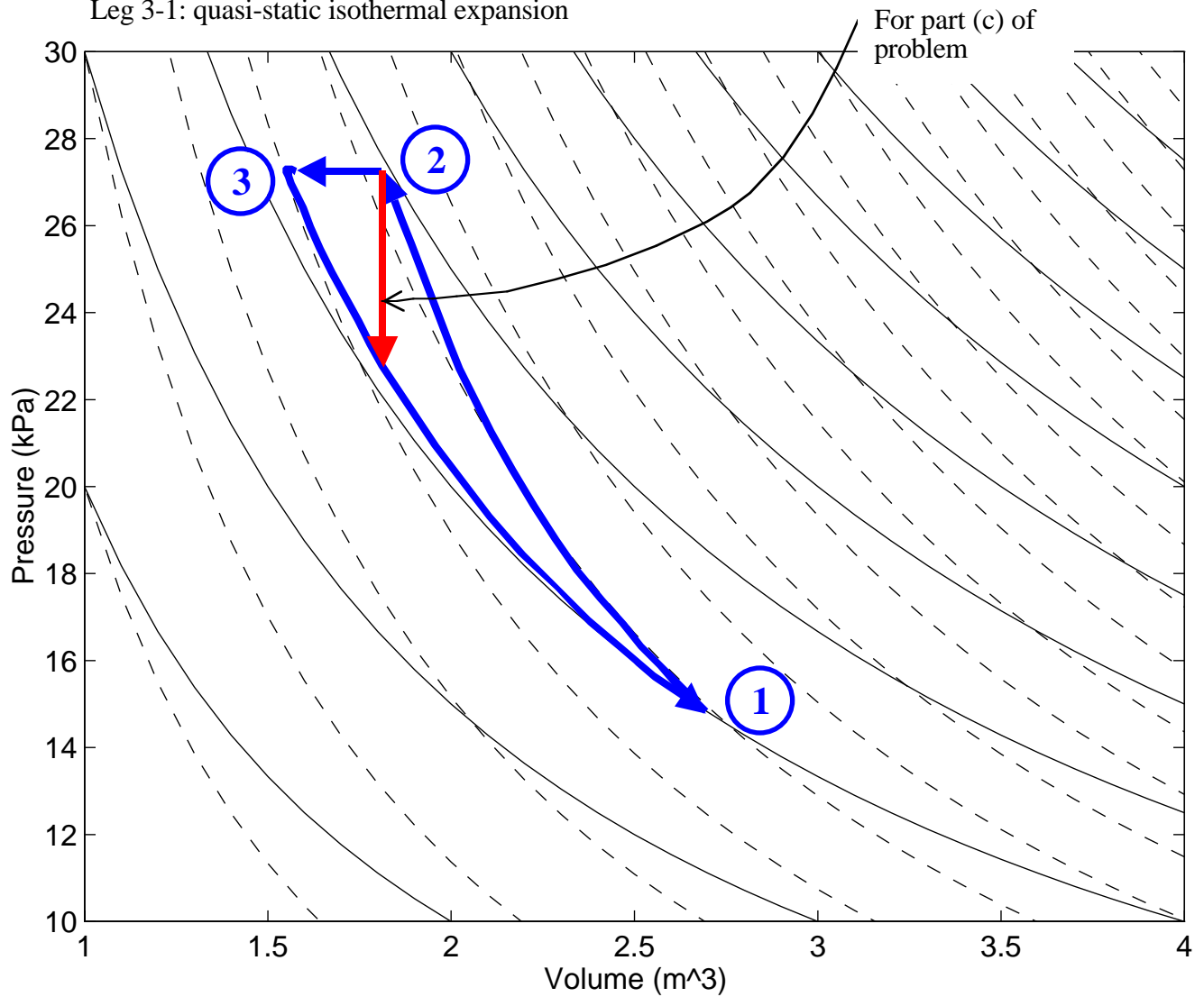
NAME___WAITZ SOLUTIONS_____

3) (24%, partial credit given)

a) **(6%, partial credit given)** Draw (and label) a thermodynamic cycle consisting of three processes involving an ideal gas: (LO# 4, 6)

Leg 1-2: quasi-static adiabatic compression
Leg 2-3: isobaric cooling
Leg 3-1: quasi-static isothermal expansion

For part (c) of problem

(dashed lines = adiabats, solid lines = isotherms)

NAME___WAITZ SOLUTIONS_____

b) **(12%, partial credit given)** Determine the sign of the heat and work transfers and change in internal energy for each leg and the cycle as a whole.

	Q (+, - or zero)	W (+, - or zero)	Δu (+, - or zero)
Leg 1-2	**0**	**-**	**+**
Leg 2-3	**-**	**-**	**-**
Leg 3-1	**+**	**+**	**0**
Sum for cycle	**-**	**-**	**0**

c) **(6%, partial credit given)** Now assume states 1 and 2 remain the same but the constant pressure cooling leg is replaced by a constant volume cooling leg. Sketch the new cycle (please do this on the diagram of part (a), but be sure to label the new leg). Is the q_{cycle} greater or less than that for the original cycle (explain your reasoning)?

For the cycle $q_{cycle} = w_{cycle}$. The magnitude of w_{cycle} is related to the area inscribed by the processes on the p-v diagram. This area is reduced, therefore the magnitude of q_{cycle} is reduced. But the sign of q_{cycle} is negative (in both cases).

So $q_{cycle\text{-part a}} < q_{cycle\text{-part c}} < 0$

4) (20%, partial credit given) A high speed aircraft is traveling at M=3 at 11km altitude where the atmospheric temperature is 217K. Assume the air flow through the engine can be treated as an ideal gas with constant specific heats (R = 287 J/kg-K, c_p = 1003.5 J/kg-K, c_v = 716.5 J/kg-K, γ = 1.4) (LO# 4)

a) (8%, partial credit given) In the inlet, the flow is moving at M=0.8 relative to the reference frame of the airplane. In the reference frame of the airplane, what is the stagnation temperature of the flow in the inlet of the engine?

$$\frac{T_T}{T} = 1 + \frac{\gamma - 1}{2}M^2 = 1 + \frac{1.4 - 1}{2}3^2 = 2.8$$

$$\therefore T = 217K \Rightarrow T_T = 607.6K$$

(Note that the fact that the flow is moving at M=0.8 does not matter for calculating the stagnation temperature.)

b) (12%, partial credit given) Downstream of the inlet, 16 MW of shaft power is used to drive a compressor in the engine which operates at a pressure ratio (P_{Te}/P_{Ti}) of 8. During the compression process 2 MW of heat are lost from the 30 kg/s engine airflow. The air leaves the compressor at M=0.5 in the reference frame of the aircraft. What is the static temperature at the exit of the compressor?

Note that although the pressure ratio is given, the process is not adiabatic (nor is it necessarily quasi-static), therefore the relationship pv^g=constant does NOT apply for the compression process.

Start by writing the steady flow energy equation:

$$\dot{Q} - \dot{W}_s = \dot{m}[\Delta h_T] = \dot{m}c_p[\Delta T_T] = \dot{m}c_p[T_{Texit} - T_{Tinlet}]$$

$$\dot{Q} = -2e10^6 J/s \qquad \dot{W}_s = 16e10^6 J/s \qquad \dot{m} = 30kg/s \qquad T_{Tinlet} = 607.6K$$

$$-2e10^6 - -16e10^6 = 30(1003.5)[T_{Texit} - 607.6] \Rightarrow T_{Texit} = 1073K$$

This is the total temperature in the airplane reference frame leaving the compressor. It is moving at M=0.5, so the static temperature is then:

$$\frac{T_T}{T} = 1 + \frac{\gamma - 1}{2}M^2 \qquad T = \frac{1073}{1 + \frac{1.4 - 1}{2}(0.5)^2} \qquad \therefore T_{exit} = 1021.6K$$