**Portland State University**
**General Physics Workshop**
**Problem Set 9** **Laws of thermodynamics**

**Equations and Relations:**

Universal gas law: $pV = nN_A kT = nRT$

Boltzmann's constant: $k = 1.381 * 10^{-23} \frac{J}{K}$

Avogadro's number: $N_A = 6.022 * 10^{23} \frac{1}{mol}$

Universal gas constant: $R = 8.314 \frac{J}{molK}$

1st law of thermodynamics: $\Delta U = Q - W$

Isobaric process: $W = nR\Delta T$

$\Delta U = Q - p\Delta V$

Isochoric process: $W = 0$

$\Delta U = Q$

Isothermal process: $W = nRT \ln\left(\frac{V_f}{V_i}\right)$

$\Delta U = 0 \qquad Q = W$

Adiabatic process: $Q = 0$

$\Delta U = -W$

$TV^{\gamma - 1} = const$

$pV^{\gamma} = const$

$\gamma = \frac{c_p}{c_v}$

$c_p - c_v = R$

monatomic gases: $W = \frac{3}{2} nR(T_i - T_f)$

$c_v = \frac{3}{2} R$

$\gamma = \frac{5}{3}$

diatomic gases: $W = \frac{5}{2} nR(T_i - T_f)$

$c_v = \frac{5}{2} R$

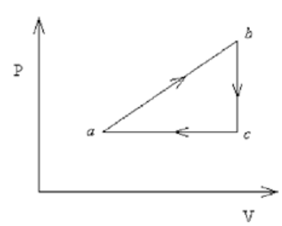
$\gamma = \frac{7}{5}$

Carnot efficiency: $e_c = 1 - \frac{T_C}{T_H}$

Entropy: $\Delta S = \frac{Q_{rev}}{T}$

Loss of available energy: $\Delta W = T_C \Delta S_{univ}$

1. An ideal gas undergoes the process *a* -> *b* -> *c* -> *a* shown in the Figure. $p_a = p_c = 240.0$ kPa, $V_b = V_c = 40.00$ L, $V_a = 15.00$ L, and $p_b = 400.0$ kPa. How much work is done by the system in this process?



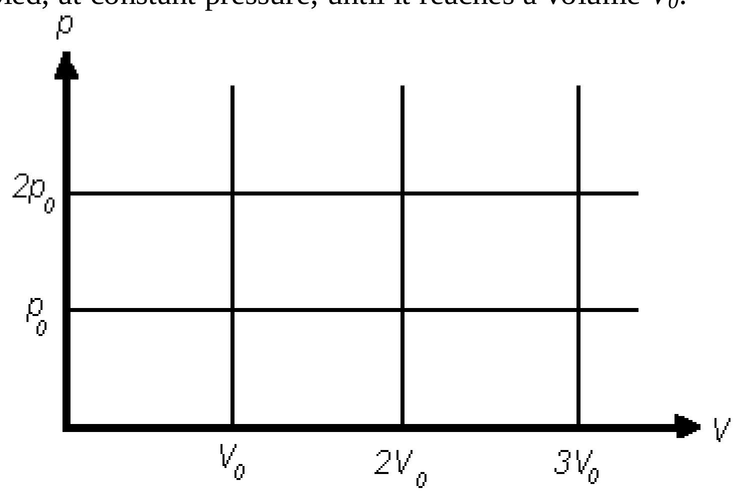
2. A system gains a certain amount of energy in the form of heat at constant pressure, and the internal energy of the system increases by an even greater amount.
(a) Is any work done? If so, is it done *on* or *by* the system?
(b) If there is work, is it positive or negative?
(c) Does the volume of the system increase, decrease, or remain the same?
(d) A system gains 2780 J of heat at a constant pressure of $120 \times 10^5$ Pa, and its internal energy increases by 3990 J. What is the change in volume of the system, and is it an increase or a decrease?

3. A monatomic ideal gas expands adiabatically from an initial volume of 72 L and an initial temperature of 350 K until its temperature falls to 290 K. What is the final volume of the gas?

4. Carnot engine has an efficiency of 83.0% and performs 4500 J of work every cycle. How much energy is discharged to the lower temperature reservoir every cycle?

5. An ideal gas initially has pressure $p_0$, volume $V_0$, and absolute temperature $T_0$. It then undergoes the following series of processes.

I. It is heated, at constant volume, until it reaches a pressure $2p_0$.
II. It is heated, at constant pressure, until it reaches a volume $3V_0$.
III. It is cooled, at constant volume, until it reaches a pressure $p_0$.
IV. It is cooled, at constant pressure, until it reaches a volume $V_0$.




(a) On the axes below, draw the *pV* diagram representing the series of processes, and label each end point with the appropriate value of absolute temperature in terms of $T_0$.

(b) For this series of processes, in terms of $p_0$ and $V_0$ determine the net work done by the gas, the net change in internal energy, and the net heat absorbed.

(c) Given that $C_p = \frac{5}{2}R$ and $C_V = \frac{3}{2}R$, determine the heat transferred during process 2 in terms of $p_0$ and $V_0$.

6. After initially at rest, a mountain climber does work in climbing upward before resting again when reaching the top of Chavez Butte. In the process, the climber's body generates $4.6 \times 10^6$ J of energy via metabolic processes. In fact, the climber's body acts like a heat engine with efficiency $e = W/Q_H$, where $W$ is the work and $Q_H$ is the input heat.
   (a) Is the $4.6 \times 10^6$ J of energy equal to $W$ or $Q_H$?
   (b) How is the work done in climbing upward related to the vertical height of the climb?

7. A large block of copper initially at 20°C is placed in a vat of hot water (80°C). For the first 1.0 J of heat that flows from the water into the block, find:
   (a) the entropy change of the block,
   (b) the entropy change of the water, and
   (c) the entropy change of the universe.
   Note: The temperatures of the block and water are essentially unchanged by the flow of only 1.0 J of heat.

8. A proposed ocean power plant will utilize the temperature difference between surface seawater and seawater at a depth of 100 meters. Assume the surface temperature is 25ºC and the temperature at the 100-meter depth is 3ºC.
   (a) What is the ideal (Carnot) efficiency of the plant?
   (b) If the plant generates useful energy at the rate of 100 MW while operating with efficiency found in part (a), at what rate is heat given off to the surroundings?

<u>Additional Questions</u>

1. If you leave the refrigerator door open and the refrigerator runs continuously, qualitatively how much colder will the kitchen get?

2. An electric baseboard heater can convert 100% of the electrical energy used into heat that flows into the house. Since a gas furnace might be located in a basement and sends exhaust gases up the chimney, the heat flow into the living space is less than 100% of the chemical energy released by burning.
   (a) Does this mean that electric heating is better? I.e. consider other factors that might affect heating efficiency (cost per heat output).
   (b) Which heating method consumes less fuel? (Note electricity heaters' energy→heat conversion efficiency compared with gas's.)