Physics 123 Thermodynamics Review

I. Definitions & Facts

thermal equilibrium	ideal gas	thermal energy
internal energy	heat flow	heat capacity
specific heat	heat of fusion	heat of vaporization
phase change	expansion coefficient	thermal conduction
convection	radiation	pascal (unit)
state variables	reversible process	irreversible process
adiabatic process	free expansion	degrees of freedom
equipartition theorem	efficiency of an engine	engines and refrigerators
mole	Avagadro's number	

II. Mathematics & Tools

Calorimetry is just bookkeeping with heat flow. If you're not sure if a phase change has occurred, try the bookkeeping without a phase change (because its simpler) and see if the results make sense.

Thermodynamical processes can be represented on p-V diagrams. Work is the area under a curve on a p-V diagram.

Entropy is only calculable from a reversible cycle, but since it is a state variable, we can choose any reversible path and get the same result.

The probability of a given outcome is the number of ways that outcome can occur out of all possible outcomes.

III. Basic Concepts

Thermal energy is the translational kinetic energy of random motion (as opposed to bulk motion). Temperature is a measurement of the average thermal energy of a system. Internal energy is the sum of the random translational and rotational kinetic energy and potential energy associated with the molecules in a system. Heat flow is the transfer of thermal energy.

When a phase change occurs, heat flowing into or out of the system rearranges the fundamental structure of the material without changing its temperature.

The First Law of Thermodynamics results from energy conservation.

Internal energy, temperature, pressure, volume are state variables..

The Second Law of Thermodynamics results from probability considerations. The universe moves toward its most probable configuration. The entropy of the universe cannot decrease in a process.

Internal energy, temperature, pressure, volume, entropy are state variables.

There is no such thing as a perfect engine or a perfect refrigerator. The Carnot engine is the most efficient.

By using a molecular model, we can express macroscopic variables (T,U,C_v) in terms of microscopic variables ($\langle v_x^2 \rangle$, $\langle K \rangle$).

IV. Equations to Memorize

Ideal Gas Law: $pV = nRT = NkT$

heat flow: $Q = C\,\Delta T = mc\,\Delta T, \quad Q = mL_f, \quad Q = mL_v$

Thermal expansion: $\Delta L = \alpha L_0\,\Delta T$

Thermal conduction: $H = -kA\,\dfrac{dT}{dx}$

Work $W = -\int p\,dV$

1st Law: $\Delta E_{int} = Q + W$

Adiabatic process: pV^{γ} = constant

Heat: $Q = n\,C_V\,\Delta T, \quad Q = n\,C_P\,\Delta T$

Internal energy: $E_{int} = n\,C_v\,T$

2nd Law: $dS \equiv \dfrac{dQ}{T}$ (reversible), $\quad \Delta S \geq 0$

Carnot efficiency: $e = \dfrac{W}{Q_h} = 1 - \dfrac{T_c}{T_h}$

Physics 123
Sample Exam #2

● Possibly useful information:

$$R = 8.3145 \text{ J / mole} \cdot \text{K}$$
$$Q = nC_V \Delta T, \text{ constant volume}$$
$$C_P = C_V + R, \quad \gamma = C_P / C_V, \quad C_V = Rf / 2$$

Conceptual Applications

1. 37.2 J of thermal energy is put into each of two objects made of the same material but having different masses. The object which has the greatest temperature rise is the object with:

A. greater heat capacity.
B. smaller heat capacity.
C. greater specific heat.
D. smaller specific heat.
E. None of the above.

2. Which of the following statements is **not** true regarding the freezing of water:

A. The water molecules slow down as the water begins to freeze.
B. During the freezing process the temperature remains constant.
C. Heat leaves the water as the water freezes.
D. $Q = -m L_f$.

3. A metal sphere is filled with helium gas at low pressure and sealed. A pressure gauge reads the pressure of the helium inside the sphere. The device is then used as a thermometer. Which of the following statements about the thermometer is **not** true?

A. Ignoring small corrections, pressure is directly proportional to temperature.
B. As the temperature increases, the thermal expansion of the metal causes the pressure to be slightly larger than if the metal did not expand.
C. The thermometer ceases to function normally at temperatures below the boiling point of helium.
D. The thermometer must be in thermal equilibrium with its surroundings in order to read properly.

Problems

4. In a constant pressure process, 1.00 mole of an ideal gas is heated from 100 K to 300 K. The initial volume of the gas is 0.010 m^3. The molar specific heat at constant volume, C_V, is 12.5 J/mole•K and the molar specific heat at constant pressure, C_P, is 20.8 J/mole•K

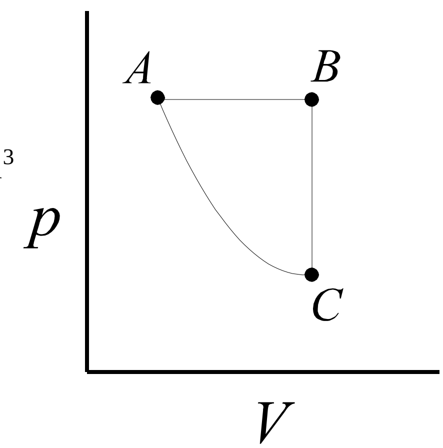
(a) What is the pressure of the gas?
(b) What is the final volume of the gas?
(c) How much heat flows into the gas in this process?
(d) How much heat would flow would there be if the gas goes from the same initial state to the same final temperature, but via a constant volume process?

5. A bimetallic strip of metal is often used as a thermometer. The thin strip is composed of two layers, each made of a different metal. The linear coefficients of expansion are :

upper material: 11×10^{-6} $(°C)^{-1}$
lower material: 19×10^{-6} $(°C)^{-1}$

(a) Describe how the bimetallic strip can be used as a thermometer.
(b) What is the ratio of the lengths of the upper and lower surfaces if the strip is at 100°C and was made (with equal length strips) at 20°C?

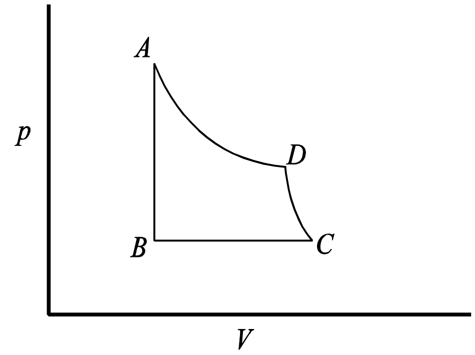
6. An engine runs through the cycle shown at the right. A → B is constant pressure, B → C is constant volume, and C→ A is adiabatic. The following information is given:



$$n = \frac{1}{8.31}\text{ moles},\quad C_P = \frac{7}{2}R,\quad T_A = 200K,\quad T_B = 400K,\quad V_A = 0.001\text{m}^3$$

(a) What is the heat that flows **into** the engine?
(b) Show that V_B = 0.002 m^3.
(c) Show that the ratio of specific heats is $\gamma = 1.4$
(d) Show that $p_C = p_A \frac{1}{2^\gamma}$

7. A refrigerator runs through the cycle A⇒B⇒C⇒D⇒A as shown. One side is constant volume, one is constant pressure, one is isothermal, and one is adiabatic. n = 2.000 moles. C_P = 29.10 J/ mole·K. C_V = 20.79 J/ mole·K. R = 8.3145 J/ mole·K. The following are known:



	A	B	C	D
p	300,000 Pa	200,000 Pa	200,000 Pa	225,000 Pa
V	0.01109 m^3	—	—	—

(a) Identify the type of process for each side of the cycle.
(b) Find the temperatures at each vertex. (Assume all numbers are accurate to four significant digits.)
(c) What is the net work put into the refrigerator during each cycle?

Answers

Conceptual Applications
1.*B* 2.*A* 3.*B*

Problems
4. (a) $$p = \frac{nRT}{V} = \frac{1.0\,\text{mole} \times 8.31\,\text{J/mole}\cdot\text{K} \times (100\,\text{K})}{0.010\,\text{m}^3} = 83.1\text{ kPa}$$

(b) $$p = \frac{nRT}{V} \quad \Rightarrow \quad \frac{p}{nR} = \frac{T_1}{V_1} = \frac{T_2}{V_2} \quad \Rightarrow V_2 = \frac{V_1 T_2}{T_1} = \frac{0.010\,\text{m}^3 \times 300\,\text{K}}{100\,\text{K}} = 0.030\,\text{m}^3$$

(c) $$Q = n\, C_P\, \Delta T = 1 \text{ mole} \times 20.8 \text{ J / mole K} \times 200 \text{ K} = 4160 \text{ J}$$

(d) $$Q = n\, C_V\, \Delta T = 1 \text{ mole} \times 12.5 \text{ J / mole K} \times 200 \text{ K} = 2500 \text{ J}$$

5. (a) *Since the two metals expand differently, the strip cannot remain flat as the temperature changes. The curvature of the strip will be an indicator of temperature.*

(b) $$\frac{\ell'_{up}}{\ell'_{down}} = \frac{\ell_{up} + \Delta\ell_{up}}{\ell_{down} + \Delta\ell_{down}} = \frac{\ell_0 + \ell_0 \alpha_{up} \Delta T}{\ell_0 + \ell_0 \alpha_{down} \Delta T} = \frac{1 + \alpha_{up}\Delta T}{1 + \alpha_{down}\Delta T} = \frac{1 + 11 \times 10^{-6} \times 80}{1 + 19 \times 10^{-6} \times 80} = 0.99936$$

6. (a) *For constant temperature and constant volume processes, the heat flow is given by the specific heat equations. It is readily seen from these equations that heat flows into the system when the temperature rises, so heat flows in during the constant pressure leg:*

$$Q = nC_P \Delta T = \frac{7nR}{2}\Delta T = \frac{7}{2}\,\text{J/K} \times 200\text{ K} = 700\,\text{J}$$

(b) *By the Ideal Gas Law:*

$$\frac{P}{nR} = \frac{T_A}{V_A} = \frac{T_B}{V_B} \quad \Rightarrow \quad V_B = \frac{T_B V_A}{T_A} = \frac{400\,\text{K} \times 0.001\,\text{m}^3}{200\,\text{K}} = 0.002\,\text{m}^3$$

(c) $$\gamma = \frac{C_P}{C_V} = \frac{7/2R}{7/2R - R} = \frac{7}{5} = 1.4$$

(d) $$PV^\gamma = \text{constant}$$
$$P_A V_A^\gamma = P_C V_C^\gamma$$
$$P_C = P_A \left(\frac{V_A}{V_C}\right)^\gamma = P_A \left(\frac{V_A}{V_B}\right)^\gamma = P_A \frac{1}{2^\gamma}$$

7. (a) *A→B is constant volume, B→C is constant pressure, C→D is adiabatic, and D→A is isothermal.*

(b) *At A we need the Ideal Gas Law:*

$$T_A = \frac{p_A V_A}{nR} = 200.1\ \text{K}$$

The temperature at D must be the same as the temperature at A:

$$T_D = T_A = 200.1\,\text{K}$$

This implies the volume at D is:

$$V_D = \frac{P_A V_A}{P_D} = \frac{300000\,\text{Pa} \times 0.01109\,\text{m}^3}{225000\,\text{Pa}} = 0.01479\,\text{m}^3$$

For the adiabatic process,

$$\gamma = \frac{C_P}{C_V} = \frac{29.10}{20.79} = 1.400$$

The volume at C is then given by:

$$P_C V_C^{\gamma} = P_D V_D^{\gamma} \quad \Rightarrow \quad V_C = V_D \left(\frac{P_D}{P_C} \right)^{\frac{1}{\gamma}} = 0.01479\,\text{m}^3 \times \left(\frac{225000\,\text{Pa}}{200000\,\text{Pa}} \right)^{\frac{1}{1.400}} = 0.01609\ \text{m}^3$$

The temperature at C is then:

$$T_C = \frac{P_C V_C}{nR} = \frac{200000\,\text{Pa} \times 0.01609\,\text{m}^3}{2.000\,\text{mole} \times 8.3145\,\text{J}/\text{mole}\,\text{K}} = 193.5\,\text{K}$$

We know the volumes at A and B are the same:

$$T_B = \frac{P_B V_B}{nR} = \frac{200000\,\text{Pa} \times 0.01109\,\text{m}^3}{2.000\,\text{mole} \times 8.3145\,\text{J}/\text{mole}\,\text{K}} = 133.4\,\text{K}$$

(c) *Since Q = −W, we can either calculate work or heat. We'll use the latter:*

$$Q = nC_V \Delta T_{BA} + nC_P \Delta T_{CB} + 0 + nRT_D \ln(V_A/V_D) = -234.1\,\text{J}$$