UNIVERSITY OF OTTAWA
Principles of Physics
PHY1321/1331 FALL 2011
Dr. A. Czajkowski

CLASS: PHY_____

STUDENT #: ________________

NAME: ____________________

Assignment 9: Ideal Gas Equation
First Law of Thermodynamics

Assigned: Monday Nov 14 Due: Monday Nov 21 19:00

1 An automobile tire is inflated with air originally at 10.0°C and normal atmospheric pressure. During the process, the air is compressed to 28.0% of its original volume and the temperature is increased to 40.0°C. (a) What is the tire pressure? (b) After the car is driven at high speed, the tire air temperature rises to 85.0°C and the interior volume of the tire increases by 2.00%. What is the new tire pressure (absolute) in pascals?

(a) Initially, $P_iV_i = n_iRT_i$ $(1.00\text{ atm})V_i = n_iR(10.0+273.15)\text{ K}$

Finally, $P_fV_f = n_fRT_f$ $P_f(0.280V_i) = n_iR(40.0+273.15)\text{ K}$

Dividing these equations, $\dfrac{0.280P_f}{1.00\text{ atm}} = \dfrac{313.15\text{ K}}{283.15\text{ K}}$

giving $P_f = 3.95\text{ atm}$

or $P_f = \boxed{4.00\times10^5\text{ Pa(abs)}}$.

(b) After being driven $P_d(1.02)(0.280V_i) = n_iR(85.0+273.15)\text{ K}$

$P_d = 1.121P_f = \boxed{4.49\times10^5\text{ Pa}}$

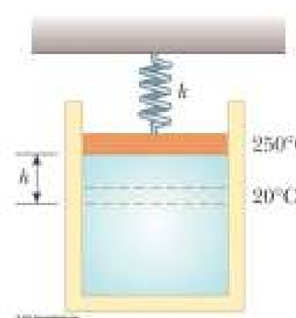
2 Just 9.00 g of water is placed in a 2.00-L pressure cooker and heated to 500°C. What is the pressure inside the container?

water contributes $P = \dfrac{nRT}{V} = \left(\dfrac{9.00\text{ g}}{18.0\text{ g/mol}}\right)\left(\dfrac{8.314\text{ J}}{\text{molK}}\right)\left(\dfrac{773\text{ K}}{2.00\times10^{-3}\text{ m}^3}\right) = \boxed{1.61\text{ MPa}} = 15.9\text{ atm}$

air contributes $p_{air} = \dfrac{nRT}{V} = \left(\dfrac{2l}{22.4l}\right)mol\,\dfrac{8.31J}{molK}\left(\dfrac{773K}{2\times10^{-3}m^3}\right) = 286769.2Pa = 2.83atm$

SUM IS THE CORRECT ANSWER 18.73atm.

A cylinder is closed by a piston connected to a spring of constant 2.00×10^3 N/m (see Fig. P19.50). With the spring relaxed, the cylinder is filled with 5.00 L of gas at a pressure of 1.00 atm and a temperature of 20.0°C. (a) If the piston has a cross-sectional area of 0.010 0 m² and negligible mass, how high will it rise when the temperature is raised to 250°C? (b) What is the pressure of the gas at 250°C?



(a) $\dfrac{P_0V}{T} = \dfrac{P'V'}{T'}$

$V' = V + Ah$

$P' = P_0 + \dfrac{kh}{A}$

$\left(P_0 + \dfrac{kh}{A}\right)(V + Ah) = P_0V\left(\dfrac{T'}{T}\right)$

$\left(1.013\times10^5\text{ N/m}^2 + 2.00\times10^5\text{ N/m}^3\,h\right)$

$\left(5.00\times10^{-3}\text{ m}^3 + \left(0.010\,0\text{ m}^2\right)h\right)$

$= \left(1.013\times10^5\text{ N/m}^2\right)\left(5.00\times10^{-3}\text{ m}^3\right)\left(\dfrac{523\text{ K}}{293\text{ K}}\right)$

$2\,000h^2 + 2\,013h - 397 = 0$

$h = \dfrac{-2\,013 \pm 2\,689}{4\,000} = \boxed{0.169\text{ m}}$

(b) $P' = P + \dfrac{kh}{A} = 1.013\times10^5\text{ Pa} + \dfrac{\left(2.00\times10^3\text{ N/m}\right)(0.169)}{0.010\,0\text{ m}^2}$ $P' = \boxed{1.35\times10^5\text{ Pa}}$

4. An aluminum calorimeter with a mass of 100 g contains 250 g of water. The calorimeter and water are in thermal equilibrium at 10.0°C. Two metallic blocks are placed into the water. One is a 50.0-g piece of copper at 80.0°C. The other block has a mass of 70.0 g and is originally at a temperature of 100°C. The entire system stabilizes at a final temperature of 20.0°C. (a) Determine the specific heat of the unknown sample. (b) Guess the material of the unknown, using the data in Table 20.1.

(a) $Q_{cold} = -Q_{hot}$

$\left(m_wc_w + m_cc_c\right)\left(T_f - T_c\right) = -m_{Cu}c_{Cu}\left(T_f - T_{Cu}\right) - m_{unk}c_{unk}\left(T_f - T_{unk}\right)$

where w is for water, c the calorimeter, Cu the copper sample, and *unk* the unknown.

$\left[250\text{ g}\left(1.00\text{ cal/g}\cdot°\text{C}\right) + 100\text{ g}\left(0.215\text{ cal/g}\cdot°\text{C}\right)\right](20.0-10.0)°\text{C}$

$= -(50.0\text{ g})\left(0.092\,4\text{ cal/g}\cdot°\text{C}\right)(20.0-80.0)°\text{C} - (70.0\text{ g})\,c_{unk}(20.0-100)°\text{C}$

$2.44\times10^3\text{ cal} = \left(5.60\times10^3\text{ g}\cdot°\text{C}\right)c_{unk}$

or $c_{unk} = \boxed{0.435\text{ cal/g}\cdot°\text{C}}$.

(b) The material of the sample is $\boxed{\text{beryllium}}$.

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Assignment 9: CONT

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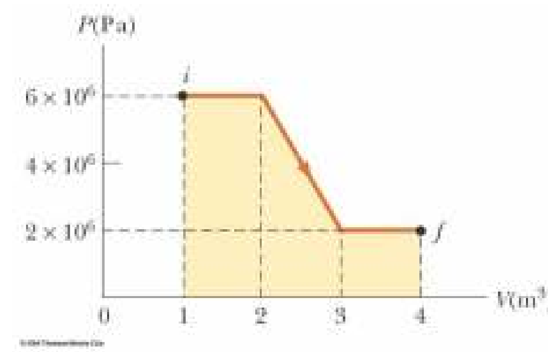
5. A 1.00-kg block of copper at 20.0°C is dropped into a large vessel of liquid nitrogen at 77.3 K. How many kilograms of nitrogen boil away by the time the copper reaches 77.3 K? (The specific heat of copper is 0.092 0 cal/g·°C. The latent heat of vaporization of nitrogen is 48.0 cal/g.)

$$Q = m_{Cu} c_{Cu} \Delta T = m_{N_2} \left(L_{vap}\right)_{N_2}$$

$$1.00 \text{ kg}\left(0.092\,0 \text{ cal/g}\cdot°\text{C}\right)\left(293-77.3\right)°\text{C} = m\left(48.0 \text{ cal/g}\right)$$

$$m = \boxed{0.414 \text{ kg}}$$

6. (a) Determine the work done on a fluid that expands from *i* to *f* as indicated in Figure (b) How much work is performed on the fluid if it is compressed from *f* to *i* along the same path?



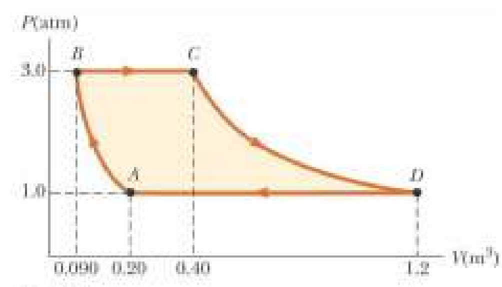
(a) $W = -\int P dV$

$$W = -\left(6.00\times10^6 \text{ Pa}\right)\left(2.00-1.00\right) \text{ m}^3 +$$
$$-\left(4.00\times10^6 \text{ Pa}\right)\left(3.00-2.00\right) \text{ m}^3 +$$
$$-\left(2.00\times10^6 \text{ Pa}\right)\left(4.00-3.00\right) \text{ m}^3$$

$$W_{i\to f} = \boxed{-12.0 \text{ MJ}}$$

(b) $$W_{f\to i} = \boxed{+12.0 \text{ MJ}}$$

7. A sample of an ideal gas goes through the process shown in Figure P20.32. From *A* to *B*, the process is adiabatic; from *B* to *C*, it is isobaric with 100 kJ of energy entering the system by heat. From *C* to *D*, the process is isothermal; from *D* to *A*, it is isobaric with 150 kJ of energy leaving the system by heat. Determine the difference in internal energy $E_{int,B} - E_{int,A}$.



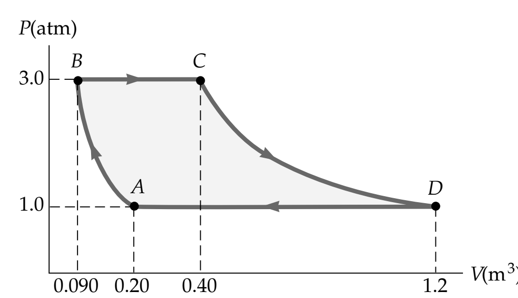
$$W_{BC} = -P_B\left(V_C - V_B\right) = -3.00 \text{ atm}\left(0.400-0.090\,0\right) \text{ m}^3$$
$$= -94.2 \text{ kJ}$$

$$\Delta E_{int} = Q + W$$

$$E_{int,C} - E_{int,B} = \left(100 - 94.2\right) \text{ kJ}$$

$$E_{int,C} - E_{int,B} = 5.79 \text{ kJ}$$

Since *T* is constant,



$$E_{int,D} - E_{int,C} = 0$$

$$W_{DA} = -P_D\left(V_A - V_D\right) = -1.00 \text{ atm}\left(0.200-1.20\right) \text{ m}^3$$
$$= +101 \text{ kJ}$$

$$E_{int,A} - E_{int,D} = -150 \text{ kJ} + \left(+101 \text{ kJ}\right) = -48.7 \text{ kJ}$$ Now,

$$E_{int,B} - E_{int,A} = -\left[\left(E_{int,C} - E_{int,B}\right) + \left(E_{int,D} - E_{int,C}\right) + \left(E_{int,A} - E_{int,D}\right)\right]$$

8. Assume that the Earth's atmosphere has a uniform temperature of 20°C and uniform composition, with an effective molar mass of 28.9 g/mol. (a) Show that the number density of molecules depends on height according to

$$n_V(y) = n_0 e^{-mgy/k_B T}$$

where n_0 is the number density at sea level, where $y = 0$. This result is called the *law of atmospheres*. (b) Commercial jetliners typically cruise at an altitude of 11.0 km. Find the ratio of the atmospheric density there to the density at sea level.

SOLUTION:

(a) Consult the lecture notes from Nov 22/Nov21

(b) $$\frac{n(y)}{n_0} = e^{-mgy/k_B T} = e^{-Mgy/N_A k_B T} = e^{-Mgy/RT}$$

$$= e^{-\left(28.9\times10^{-3} \text{ kg/mol}\right)\left(9.8 \text{ m/s}^2\right)\left(11\times10^3 \text{ m}\right)/\left(8.314 \text{ J/mol K}\right)\left(293 \text{ K}\right)}$$

$$= e^{-1.279} = \boxed{0.278}$$