Physics 4C Practice Test Questions from Ch21-22

Name: _____

May 15, 2020

Please show your work! Answers are not complete without clear reasoning. When asked for an expression, you must give your answer in terms of the variables given in the question and/or fundamental constants.

Answer as many questions as you can, in any order. Books and notes are not allowed. Use any blank space to answer questions, but please make sure it is clear which question your answer refers to.

$g = 9.8\ \text{ms}^{-2}$

$P_0 = 1.013 \times 10^5\ \text{Pa} = 1\ \text{atm}$

$R = 8.314\ \text{J mol}^{-1}\ \text{K}^{-1}$

$k_B = 1.38 \times 10^{-23}\ \text{J/K}$

$N_A = 6.022 \times 10^{23}$

$m_p = 1.67 \times 10^{-27}\ \text{kg}$

$\sigma = 5.6696 \times 10^{-8}\ \text{W m}^{-2}\ \text{K}^{-4}$

$1\ \text{cal} = 4.186\ \text{J}$

$1\ \text{eV} = 1.60 \times 10^{-19}\ \text{J}$

Fahrenheit to Celsius:
$([^\circ\text{F}] - 32) \div 1.8 = [^\circ\text{C}]$

Celsius to Fahrenheit:
$([^\circ\text{C}] \times 1.8) + 32 = [^\circ\text{F}]$

$e = 1 - \frac{1}{(V_1/V_2)^{(\gamma-1)}}$

$\int_v^{v+\text{dv}} N_v\,\text{dv} = \int_v^{v+\text{dv}} 4\pi N \left(\frac{m_0}{2\pi k_B T}\right)^{3/2} v^2 e^{-m_0 v^2/2k_B T}\,\text{dv}$

1. **[15pts]** Initially, a container of volume V contains n moles of helium gas at a pressure P. Suppose the pressure is of the gas is increased to $4P$ while the volume is unchanged.

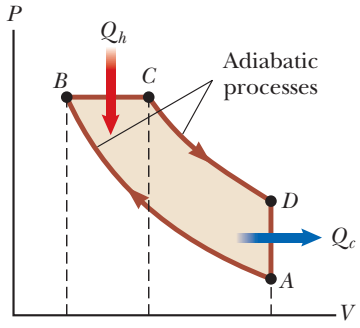
   (a) By what factor does the average kinetic energy of the helium atoms change? [4 pts]

   (b) By what factor does the root-mean-square (rms) speed of the atoms change? [2 pts]

   (c) By what factor does the most probable speed of the atoms change? [2 pts]

   (d) On the same (labeled) axes, sketch the distribution of molecular speeds for each pressure. Label the most probable speed and the rms speed on each distribution. [7 pts]

2. **[23pts]** An idealized diesel engine operates in the cycle shown. Fuel is sprayed into the cylinder at the point of maximum compression, B. Combustion occurs during the expansion $B \to C$, which is modeled as an isobaric process. The gas in the cycle has n moles, a molar heat capacity at constant pressure of C_p, and a molar heat capacity at constant volume of C_v, and ratio γ. T_A, T_B, T_C, and T_D are the temperatures at points A, B, C, and D, respectively.



(a) What is the heat transferred to the gas in processes C $\to$ D and A $\to$ B? [2 pts]

(b) Show that the efficiency of an engine operating in this cycle is [5 pts]

$$e = 1 - \frac{1}{\gamma}\left(\frac{T_D - T_A}{T_C - T_B}\right)$$

(c) What is the entropy change in the process B $\to$ C? [3 pts]

(d) What is the entropy change in the process D $\to$ A? [3 pts]

(e) Show that [5 pts]

$$\frac{T_D}{T_A} = \left(\frac{T_C}{T_B}\right)^{\gamma}$$

(f) Using your results from (c), (d), and (e), find/confirm the net change in entropy of the working fluid going clockwise around the cycle from A $\to$ A. [5 pts]

3. Consider a gas of identical molecules, each with mass m_0, in thermal equilibrium at temperature, T.

   (a) Sketch the distribution of molecular speeds and label the most probable speed for a gas molecule on it. [4 pts]

   (b) Starting from the Maxwell-Boltzmann speed distribution, find an expression for the most probable speed of a gas molecule. [5 pts]

   (c) What is the the root-mean-square (rms) speed for the gas and how does the rms speed relate to the most probable speed? [2 pts]

4. A sample of a diatomic ideal gas with specific heat ratio 1.40, confined to a cylinder, is carried through a closed cycle. The gas is initially at pressure P_0 and volume V_0. First, in step 1, its pressure is tripled under constant volume. Then, in step 2, it expands adiabatically to its original pressure. Finally, in step 3, the gas is compressed isobarically to its original volume.

   (a) Draw a PV diagram of this cycle, labeling the steps. [4 pts]

   (b) Find an expression for the volume of the gas at the end of the adiabatic expansion in terms of V_0. [3 pts]

   (c) Assuming that there are n moles of gas in the sample, find expressions for the temperatures of the gas at the start of the adiabatic expansion, at the end of the expansion, and at the end of the cycle. [4 pts]

   (d) During which of the three steps does heat enter the gas? During which of the three steps does heat leave the gas? [2 pts]

   (e) If the cycle is used as a heat engine, what is the engine's efficiency? (Find a numerical value.) [7 pts]

   (f) How does that compare to the efficiency of a Carnot engine operating between the same temperature extremes? (Find the Carnot engine's efficiency.) [3 pts]