PROBLEM 1 35 PTS TOTAL

5.0 moles of an ideal gas, initially at a temperature of 350°K and pressure 1.5 x 10^5 N/m^2 are expanded isobarically. During the expansion the volume of the gas increases to double its initial volume.

(a) Determine the initial volume of this ideal gas.

\[ V_i = \frac{nRT}{P} = \frac{(5.0 \text{ moles})(8.31 \text{ J/mol.K})(350 \text{ K})}{(1.5 \times 10^5 \text{ N/m}^2)} \]

\[ V_i = 0.09 \text{ m}^3 \]

**Note**

\[ V_i = 2 \times V_i = 0.19 \text{ m}^3 \]

(b) Determine the work done by the gas during the expansion.

\[ W = P \Delta V = (1.5 \times 10^5 \text{ N/m}^2)(0.09 \text{ m}^3) = 1.45 \times 10^4 \text{ J} \]

(c) By how much did the initial energy of the gas change during the expansion?

\[ \Delta U = \frac{3}{2} n R \Delta T \]

\[ \frac{1}{2} \frac{d}{d \ln P} \left( \frac{V}{T} \right) \]

\[ T = \frac{(1.5 \times 10^5 \text{ N/m}^2)(0.15 \text{ m}^3)}{(8.31 \text{ J/mol.K})} \]

\[ T = 700 \text{ K} \]

\[ \Delta U = 2.18 \times 10^4 \text{ J} \]

(d) How much heat, Q, was added to (or removed from) the gas?

\[ Q = \Delta U + W \]

\[ = 2.18 \times 10^4 \text{ J} + 1.45 \times 10^4 \text{ J} \]

\[ Q = 3.63 \times 10^4 \text{ J} \]

(e) If the same process were carried out isothermally instead of isobarically, would the answers to (b), (c) and (d) above be more, less, equal to the original answers, or you can't tell what the direction of the change will be. Respond by filling in the table with the correct symbol pictured to the right of the table.

<table>
<thead>
<tr>
<th>W</th>
<th>(\Delta U)</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>(\downarrow)</td>
<td>(\downarrow)</td>
<td>(\downarrow)</td>
</tr>
</tbody>
</table>

\[ \uparrow = \text{ increase} \]
\[ \downarrow = \text{ decrease} \]
\[ 0 = \text{ no change} \]
\[ X = \text{ can't tell} \]
PROBLEM 2  

33 pts TOTAL

The figure shown is a PV diagram that consists of a pair of constant volume processes (DA and BC) and a pair of adiabatic processes (AB and CD).

(a) The following table is filled partially with thermal data about the cycle. Complete the table.

\[ \Delta U = Q - W \]

\begin{align*}
& \text{DA} & 0 & 18,000 \text{ J} & 18,000 \text{ J} \\
& \text{AB} & 0 & -10,000 \text{ J} & -10,000 \text{ J} \\
& \text{BC} & 0 & -12,000 \text{ J} & -12,000 \text{ J} \\
& \text{CD} & -4000 \text{ J} & 0 & 4000 \text{ J} \\
\end{align*}

(b) What is the thermal efficiency of this cycle?

\[ \varepsilon = 1 - \frac{Q_{\text{in}}}{Q_{\text{out}}} = \frac{W_{\text{out}}}{Q_{\text{in}}} = \frac{1000 \text{ J}}{18,000 \text{ J}} = 0.05555 \approx 0.06 \]

(c) Determine the sum of all the internal energy changes for all the steps in the cycle.

\[ \Delta U (\text{cycle}) = 0 \]

(d) If this system were redesigned to operate so that \( Q_h \) were absorbed at 1000 K and the heat removed, \( Q_c \), was removed at 1500 K, what would be the ideal (Carnot) efficiency of this redesigned system?

\[ \varepsilon_c = 1 - \frac{Q_c}{Q_{\text{in}}} = 1 - \frac{4230 \text{ K}}{12730 \text{ K}} = 0.67 \]

\[ \]
A heat engine operates at an actual efficiency of 42.2% with a high temperature reservoir of 473 K. In each cycle the engine does 250 J of work. Operating as a reversible (ideal engine) this particular engine is capable of doing 444 J of work with the same input heat \( Q_H \).

A. What is the ideal (Carnot) efficiency of this engine?

\[
\eta_{\text{ideal}} = \frac{W_{\text{ideal}}}{Q_H} = \frac{444 \text{ J}}{592 \text{ J}} = 0.75
\]

\( Q_H = 592 \text{ J} \)

B. What is the Kelvin temperature of the low temperature reservoir assuming the engine is operating ideally?

\[
\eta_{\text{ideal}} = 1 - \frac{T_c}{T_H}
\]

\[
T_c = 118 \text{ K}
\]

C. Suppose the heat engine described above is already operating ideally, i.e., 44.2% is the ideal efficiency. To what temperature would the high temperature reservoir have to be raised to get the same efficiency as you calculated in part A, without changing \( T_c \)?

\[
\eta_{\text{ideal}} = 0.442 = 1 - \frac{T_c}{T_H}
\]

\[
\frac{T_c}{T_H} = 1 - 0.442 = 0.558
\]

\[
\frac{T_H}{T_c} = \frac{1}{0.558} = 1.79
\]

\[
T_H = (T_c)(1.79)
\]

\[
T_H = 211 \text{ K}
\]
Starting at point A, 2.00 moles of an ideal monatomic gas are taken through a 3-step cycle, A-B-C-A shown on the PV diagram. The process B-C is an isothermal expansion. \( \dot{W}_{BC} = 6280 \text{ J} \).

**A. 12 pts**

Determine \( \dot{W}_{cycle} \), \( Q_{cycle} \), and \( \Delta U_{cycle} \).

\[
\Delta U_{cycle} = 0
\]

\[
\dot{W}_{cycle} = \dot{W}_{AB} + \dot{W}_{BC} - \dot{W}_{CA} = 0 + 6280 + (2.02 \times 10^5 \text{ N m}^{-2})(-0.0224 \text{ m}^3) = 1760 \text{ J}
\]

\[
\Delta U_{cycle} = Q_{cycle} - \dot{W}_{cycle} \quad \text{or} \quad Q_{cycle} = \Delta U_{cycle} + \dot{W}_{cycle} = 1760 + 1760 = 3520 \text{ J}
\]

**B. 21 pts**

Fill in the missing information in the table below. SHOW WORK BELOW.

<table>
<thead>
<tr>
<th></th>
<th>W</th>
<th>Q</th>
<th>( \Delta U )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-B</td>
<td>0</td>
<td>9140 J</td>
<td>9140 J</td>
</tr>
<tr>
<td>B-C</td>
<td>6280 J</td>
<td>6280 J</td>
<td>0</td>
</tr>
<tr>
<td>C-A</td>
<td>-4520 J</td>
<td>-13,660 J</td>
<td>-9140 J</td>
</tr>
</tbody>
</table>
A certain amount of an ideal gas is taken around the cycle shown in the PV plot below. Point A on the plot is the starting and finishing point of the cycle. The following data are also known: \( \Delta U_{BC} = -9.0 \times 10^5 \text{ J} \) and \( Q_{AB} = 4.0 \times 10^5 \text{ J} \).

(a) Determine the work done during each step of the cycle, i.e., \( W_{AB} \), \( W_{BC} \), and \( W_{CA} \):

\[ W_{AB} = 0 \]

\[ W_{BC} = \text{Area of } \triangle ABC \times \frac{3}{2} \]

\[ W_{CA} = -4.0 \times 10^5 \text{ J} - 4.0 \times 10^5 \text{ J} = -8.0 \times 10^5 \text{ J} \]

(b) Determine the net work done during the cycle.

\[ W_{NET} = \text{Area in } \triangle ABC = 8.0 \times 10^5 \text{ J} \]

(c) Determine the net change in internal energy and the net heat added (or lost) for the cycle.

\[ \Delta U_{NET} = 0 \quad (\text{ALWAYS!}) \]

\[ Q_{NET} = \Delta U_{NET} + W_{NET} = 8.0 \times 10^5 \text{ J} \]

Finally, from the data and the results of parts (a), (b) and (c) fill in the blanks below.

\[ \Delta U_{AB} = 4.0 \times 10^5 \text{ J} \]

\[ \Delta U_{CA} = 5.0 \times 10^5 \text{ J} \]

\[ Q_{BC} = 7.0 \times 10^5 \text{ J} \]

\[ Q_{CA} = -3.0 \times 10^5 \text{ J} \]

\[ Q_{NET} = 8.0 \times 10^5 \text{ J} = Q_{AB} + Q_{BC} + Q_{CA} = 4.0 \times 10^5 \text{ J} + 7.0 \times 10^5 \text{ J} + Q_{CA} \]

\[ Q_{CA} = -3.0 \times 10^5 \text{ J} \]

\[ \Delta U_{NET} = 0 = \Delta U_{AB} + \Delta U_{BC} + \Delta U_{CA} = 4.0 \times 10^5 \text{ J} + 7.0 \times 10^5 \text{ J} - 3.0 \times 10^5 \text{ J} \]
The previous problem describes an ideal gas taken through a cyclic process. Let's now assume that cycle is the basis of an operating heat engine. From the work on the previous page copy down in the space provided the net work done during the cycle.

\[ W_{\text{net}} = 18 \times 10^5 J \]
\[ Q_{AB} = -10 \times 10^5 J \]
\[ Q_{BC} = -12 \times 10^5 J \]
\[ Q_{CA} = 16 \times 10^5 J \]

(a) Determine \( Q_{\text{input}} \), the total amount of heat added to the gas.

\[ Q_{\text{input}} = Q_{BC} + Q_{CA} = 28 \times 10^5 J \]

(b) What is the actual efficiency of this cycle acting as a heat engine?

\[ \eta = 1 - \frac{Q_e}{Q_H} = \frac{W}{Q_H} = \frac{W}{Q_{\text{input}}} = \frac{18 \times 10^5 J}{28 \times 10^5 J} \]
\[ \eta = 0.643 \ (64.3\%) \]

(c) Suppose this heat engine is operating between a pair of high and low temperature heat reservoirs at \(-223^\circ C\) and \(475^\circ C\), respectively. What is the ideal efficiency of this engine?

\[ T_H = 475^\circ C + 273 = 748 K \]
\[ T_C = -223^\circ C + 273 = 50 K \]

\[ \eta_{\text{Ideal}} = 1 - \frac{T_C}{T_H} = 1 - \frac{50}{748} = 0.933 (93.3\%) \]
2.48 moles of Ar, Argon, are placed in a cylindrical vessel whose initial volume is fixed at 0.0440 m$^3$. The pressure the gas exerts is $1.88 \times 10^5$ N/m$^2$. $M_{Ar} = 40.0$.

A. **8 pts** Calculate how many atoms of Ar and what total mass of Ar are present in the container.

\[ N = nN_A = (2.48 \text{ moles})(6.023 \times 10^{23} \text{ atoms/mole}) = 1.49 \times 10^{24} \text{ atoms} \]

\[ m_{\text{tot}} = (2.48 \text{ moles})(40 \text{ g/mole}) = 99.2 \text{ g} \]

B. **4 pts** What is the Kelvin temperature of the gas in the container?

\[ T = \frac{PV}{nR} = \frac{PV}{N/k} = \frac{1.88 \times 10^5 \text{ N/m}^2 \times 0.0440 \text{ m}^3}{6.023 \times 10^{23} \text{ mols} \times 1.38 \times 10^{-23} \text{ J/K}} \]

\[ T = 403 \text{ K} \]

C. **8 pts** What is the total internal energy of the Ar gas and what is the average kinetic energy of the Ar atoms?

\[ U = \frac{3}{2} N k T = \frac{3}{2} \times 6.023 \times 10^{24} \times 1.38 \times 10^{-23} \text{ J/K} \times 403 \text{ K} \]

\[ U = 1.24 \times 10^4 \text{ J} \]

\[ \frac{k_B \bar{v}}{2} = \frac{3}{2} \frac{1}{2} k T = \frac{3}{2} \times 1.38 \times 10^{-23} \text{ J/K} \times 403 \text{ K} \]

\[ \frac{k_B \bar{v}}{2} = 8.32 \times 10^{-21} \text{ J} \]

D. **5 pts** Suppose an additional mole of Ar is added to the container while keeping the volume and temperature the same. By what factor does the average particle speed of the Ar atoms change? Be sure to indicate whether that average speed has increased, decreased or did not change.

\[ \bar{v}_{\text{Ar}} \text{ does not change since } T \text{ is kept the same} \]

E. **8 pts** Suppose the Ar gas is replaced by an identical number of moles of N$_2$ gas ($M_{N_2} = 28.0$) keeping the pressure and volume the same as it was for the Ar gas. Next to each item below place the word, increase, decrease or unchanged to indicate the difference with N$_2$ present than Ar.

1. total mass: **smaller**
2. number of particles: **unchanged**
3. temperature of the gas: **unchanged**
4. average kinetic energy per particle: **unchanged**
In a 10.0 l vessel is an amount of an ideal gas at a temperature of 27.0°C and a pressure of 1.65 x 10^5 N/m^2.

11 pts

(a) How many particles of ideal gas occupy the container?

\[ N = \frac{PV}{kT} = \frac{(1.65 \times 10^5 \text{ N/m}^2)(1.00 \times 10^{-2} \text{ m}^3)}{(1.38 \times 10^{-23} \text{ m}^3/\text{K})(300 \text{ K})} \]

\[ N = 3.99 \times 10^{23} \text{ particles} \]

11 pts

(b) If the gas is helium, He, what mass of He is in the vessel? \((M_{He} = 4.00 \text{ gm/mole})\)

\[ \text{MASS} = N \cdot m_{\text{PARTICLE}} = \left(3.99 \times 10^{23} \text{ particles}\right) \left(6.64 \times 10^{-24} \text{ gm/particle}\right) \]

\[ m_{\text{PARTICLE}} = 6.64 \times 10^{-24} \text{ gm} \]

\[ \text{MASS} = 2.65 \text{ gm} = 0.00265 \text{ kg} \]

11 pts

(c) If the vessel were now heated to 127°C, what would be the new pressure exerted by the gas? Assume the volume the gas occupies does not change, nor does any gas escape from the vessel.

\[ P_1 = 1.65 \times 10^5 \text{ N/m}^2 \]
\[ T_1 = 300 \text{ K} \]
\[ V_1 = 1.00 \times 10^{-2} \text{ m}^3 = V_2 \]

\[ \frac{P_1 V_1}{T_1} = \frac{P_2 V_2}{T_2} \]

\[ P_2 = P_1 \left(\frac{T_2}{T_1}\right) = (1.65 \times 10^5 \text{ N/m}^2) \left(\frac{400 \text{ K}}{300 \text{ K}}\right) \]

\[ P_2 = 2.20 \times 10^5 \text{ N/m}^2 \]
Determine the speed of an average (RMS value) He atom in the container. From the previous problem $M_{He} = 4.00 \text{ gm/mole}$.

\[
P V = \frac{1}{3} N m v_{rms}^2
\]

\[
u_{rms} = \sqrt{\frac{3 P V}{N m}}
\]

\[
u_{rms} = \sqrt{\frac{3 \text{ m}^2}{\text{N}}} = \sqrt{\frac{3 \text{ m}}{2}} = \sqrt{\frac{3 \text{ m}}{2}}
\]

With the temperature of the gas in the vessel increased to 127°C, would the average particle speed increase or decrease? By what factor? That is, compute the ratio of the average speed at the initial $T$ to be the average speed of the final $T$.

\[
\frac{\nu_{rms}(\text{New})}{\nu_{rms}(\text{Old})} = \left(\frac{T_{\text{New}}}{T_{\text{Old}}}\right)^{1/2}
\]

\[
= \left(\frac{400\text{K}}{300\text{K}}\right)^{1/2} = 1.15 : 1
\]

\[
u_{rms} \text{ INCREASES BY A FACTOR OF } 1.15 \text{ AS A RESULT OF THE } T \text{ INCREASE.}
\]

The gas in the vessel is now removed and replaced with an equal number of $N_2$ particles. By what factor (a ratio calculation) would the average speed (i.e., the RMS velocity) change with the new gas relative to the average speed of the original gas. Be sure to indicate which gas particles travel faster. Note: $M_{N_2} = 28.0 \text{ gm/mole}$.

Assume the conditions are arranged so that the pressure of the new gas is maintained at the same $1.65 \times 10^4 \text{ N/m}^2$ as the original gas, and the vessel's volume does not change from $P V = \frac{1}{3} N m v_{rms}^2$. $\nu_{rms} \propto \left(\frac{1}{m}\right)^{1/2}$ if $P, V$ and $N$ are held the same.

Thus,

\[
\frac{\nu_{rms}(\text{New})}{\nu_{rms}(\text{Old})} = \left(\frac{M_{He}}{M_{N_2}}\right)^{1/2} = \left(\frac{4}{28}\right)^{1/2} = 0.378
\]
A car moves with speed $17 \text{ m/s}$ toward a stationary wall. Its horn emits 200 Hz sound waves, which move at 340 m/s.

(a) Find the wavelength of the sound in front of the car and the frequency with which the waves strike the wall.

\[
\frac{f'}{f} = \frac{1 - \frac{v_s}{v}}{1 - \frac{17 \text{ m/s}}{340 \text{ m/s}}} = (200 \text{ Hz}) \left(1 - \frac{17 \text{ m/s}}{340 \text{ m/s}}\right)
\]

\[f' = 211 \text{ Hz}\]

(b) Since the waves reflect off the wall, the wall acts as a source of sound waves at the frequency found in the previous question. What frequency does the driver of the car hear reflected from the wall?

\[
\frac{f''}{f'} = \frac{1 + \frac{v_s}{v}}{1 + \frac{17 \text{ m/s}}{340 \text{ m/s}}} = (211 \text{ Hz}) \left(1 + \frac{17 \text{ m/s}}{340 \text{ m/s}}\right)
\]

\[f'' = 222 \text{ Hz}\]

(c) The horn emits sound uniformly in all directions with power 4.0 $\text{W}$. Find the sound intensity at a distance of 10 meters from the car.

\[I = \frac{P}{A} = \frac{4.00 \text{ W}}{(4\pi)(10.0 \text{ m})^2} = 3.18 \times 10^{-3} \text{ W/m}^2\]

\[I = 3.18 \text{ mW/m}^2\]

(d) Find the intensity level in decibels at that distance.

\[IL = 10 \log_{10} \frac{I}{I_0} = 10 \log_{10} \frac{3.18 \times 10^{-3}}{1 \times 10^{-12}}\]

\[IL = 95.0\]
A. **20 pts**

The plot shows the displacement vs. position of a longitudinal repetitive wave traveling in the positive x direction. The speed of the wave is 1000 m/s. Points A, B, C, etc., mark different points in space through which the wave is traveling.

1. The wavelength of this wave is **4.0 m**.
2. The amplitude of this wave is **0.1 m**.
3. The frequency of the wave is **250 Hz**.
4. The period of the wave is **0.0040 s**.

On the empty graph below plot the displacement vs. time of the medium at the spatial point B from above. You may assume at time \( t = 0 \) the particle of the medium is at its equilibrium position moving with maximum positive velocity. Be sure to write in numbers for scale values.

**Displacement**

5. **1.0 m/s** An instant at which the particle's velocity is zero.

6. **4.0 m/s** An instant, other than \( t = 0 \), at which the particle's velocity is a positive maximum.

B. **10 pts**

Waves are caused to move to the right along a very long cable under the influence of a fixed frequency vibrator as shown in the figure. Answer the following with increase, decrease, remains the same, or cannot tell.

1. **INCREASE** The wavelength of the waves on the cable if the tension on the cable is increased.

2. **REMAINS THE SAME** The frequency of the waves on the cable if a more dense cable is used (same tension).

3. **DECREASE** The speed of the waves on the cable if the tension is reduced.

4. **REMAINS THE SAME** The wavelength of the waves on the cable if the length of the cable is increased.

5. **REMAINS THE SAME** The period of the waves on the cable if both the tension in the cable and the cable density are doubled.

6. **DECREASE** The speed of the waves on the cable if a new cable made of the same material as the old cable is used with the cross-sectional area doubled.
A pneumatic jackhammer (a device for breaking up concrete) has an intensity level of 110 dB at 2.00 m from the device.

A. Determine the power output assuming the jackhammer behaves as a point source.

\[ I' = 10 \log_{10} \frac{I}{I_0} \]
\[ 110 = 10 \log_{10} \frac{I}{I_0} \]
\[ 10'' = I' (I_0) \]
\[ P = IA = \frac{I}{(4\pi R^2)} \]
\[ P = (0.100 \text{ W/m}^2)(4\pi)(2.00 \text{ m})^2 \]
\[ P = 5.03 \text{ W} \]

B. How far away would an observer have to be for the intensity level to be 80.0 dB?

\[ I_{L2} = 80 \text{ dB} = 10 \log_{10} \frac{I_2}{I_0} \]
\[ I_2 = (10^{-2} \text{ W/m}^2)(10^8) \]
\[ I_2 = 1.00 \times 10^{-4} \text{ W/m}^2 \]

\[ P_2 = (2.00 \text{ m}) \sqrt{\frac{100 \text{ W/m}^2}{1.00 \times 10^{-4} \text{ W/m}^2}} \]

\[ 1/R_2 = 63.2 \text{ m} \]

C. Assume 2 additional and identical jackhammers start working on the same section of concrete, at pretty much all at the same spot, how far away from this group would an observer have to be to hear the same intensity level of a single jackhammer produced at 2.00 m? Assume the jackhammer intensities add.

\[ I_{L2\text{NEW}} = 80 \text{ dB} \text{ CORRESPONDS } I = 0.100 \text{ W/m}^2 \text{ AT SOME UNKNOWN } R. \text{ AT } 200 \text{ m } I = 3 (0.100 \text{ W/m}^2) = 0.300 \text{ W/m}^2 \]

Thus

\[ R_{\text{NEW}} = R_{\text{OLD}} \sqrt{\frac{I_2}{I_2}} = (2.00 \text{ m}) \sqrt{\frac{0.300 \text{ W/m}^2}{0.100 \text{ W/m}^2}} \]

\[ R_{\text{NEW}} = 3.46 \text{ m} \]
A. A siren is producing sound uniformly in all directions at \( f = 900 \text{ Hz} \). At 100 m from the siren the intensity level is 80 dB. A detector is moved to a new position where the intensity level is 60 dB.

1. What is the intensity of the siren at the new position?

\[
\beta = 10 \log_{10} \frac{I}{I_0}
\]

\[
60 = 10 \log_{10} \frac{I}{10^{-12} \text{ W/m}^2}
\]

\[
\frac{I}{10^{-12} \text{ W/m}^2} = 10^6
\]

\[
I = 10^{-6} \text{ W/m}^2
\]

2. How far away from the siren is the new position?

\[
P_1 = I_1 \left(4\pi R_1^2\right)
\]

\[
P_2 = I_2 \left(4\pi R_2^2\right)
\]

\[
P_2 = P_2 \cdot \frac{R_2}{R_1}
\]

\[
I_2 = 10^{-6} \text{ W/m}^2
\]

\[
I_1 = 10^{-4} \text{ W/m}^2
\]

\[
P_2 = 1000 \text{ m}
\]

B. A pedestrian standing at an intersection hears a fire engine siren vary in frequency from 476 Hz when the engine is coming towards her and 404 Hz when it is moving away from her. Take the speed of sound in air to be \( v = 343 \text{ m/s} \). What is the speed of the fire engine?

\[
\frac{f}{f'} = \frac{v + v_s}{v - v_s}
\]

\[
\frac{476 \text{ Hz}}{404 \text{ Hz}} = \frac{1}{1 - \frac{v_s}{v}} = \frac{v + v_s}{v - v_s}
\]

\[
\frac{404 \text{ Hz}}{476 \text{ Hz}} = \frac{1}{1 + \frac{v_s}{v}} = \frac{v + v_s}{v - v_s}
\]

\[
f' = 476 \text{ Hz}
\]

\[
f = 404 \text{ Hz}
\]

\[
\frac{476 \text{ Hz}}{404 \text{ Hz}} = \frac{1}{1 - \frac{v_s}{v}} = \frac{v + v_s}{v - v_s}
\]

\[
\frac{404 \text{ m/s}}{476 \text{ m/s}} = \frac{1}{1 + \frac{v_s}{v}} = \frac{v + v_s}{v - v_s}
\]

\[
\frac{v_s}{v} = 0.178
\]

\[
v_s = 68.1 \text{ m/s}
\]
A Boeing 757 is beginning to take-off from the Salt Lake Airport. A construction worker standing next to the runway observes that when the jet is 1000 m away, the intensity of the sound is $4.0 \times 10^2$ W/m². Assume the sound from the jet radiates isotropically (same in all directions).

A. [8 pts.] What is the average power output of the 757 as a sound producer?

\[
P_{AV} = I_{AV} \cdot (4\pi r^2) = (4.0 \times 10^{-2} \text{ W/m}^2) \cdot (4\pi) (10^3 \text{ m})^2
\]

\[
P_{AV} = 5.0 \times 10^3 \text{ W}
\]

B. [8 pts.] By what factor has the intensity increased when the jet is 100 m from the construction worker.

\[
\frac{I_{\text{new}}}{I_{\text{old}}} = \left( \frac{r_{\text{old}}}{r_{\text{new}}} \right)^2 = 10^2 = \frac{100}{1}
\]

The $I$ at 100m is 100 TIMES LARGER THAN AT 1000m.

C. [8 pts.] What are the decibel (dB) readings at the 1000 m mark and at the 100 m?

At 1000 m
\[
\text{dB} = 10 \log_{10} \left( \frac{4 \times 10^{-2} \text{ W/m}^2}{1 \times 10^{-12} \text{ W/m}^2} \right) = 10 \log_{10} \left( 4 \times 10^6 \right) = 10 \left( \log_{10} 4 + 10 \right) = 106 \text{dB}
\]

Since $I$ at 100m is 100 TIMES LARGER THAN AT 1000m, the dB value at 100m MUST BE 106dB LARGER THAN AT 1000m.

At 100m
\[
\text{dB} = 126 \text{dB}
\]

D. [8 pts.] Assume that when the plane is at the 1000 m distance from the worker it is traveling at 60 m/s and the predominant frequency the jet engine produces is 250 Hz (as heard by the pilot). What is the predominant frequency the worker hears? Use $v_{\text{sound}} = 340$ m/s.

\[
f_0 = f_0 \left( \frac{v + v_0}{v + v_s} \right) = f_S \left( \frac{v}{v - v_s} \right) = (250 \text{ Hz}) \left( \frac{340 \text{ m/s}}{780 \text{ m/s}} \right)
\]

\[
f_0 = 304 \text{ Hz}
\]
A reversible 3-step cycle is carried out on one mole of an ideal gas. The steps of the cycle are:
A. an isochoric pressure increase at volume \( V_1 \) from pressure \( P_1 \) to \( P_2 \)
B. an isothermal compression from \( P_2 \) and \( V_1 \) to pressure \( P_3 \) and volume \( V_2 \)
C. an adiabatic expansion back to the starting point at pressure \( P_1 \) and volume \( V_1 \)

A. [6 pts.] Draw the P-V diagrams for this cycle on the graph below.

B. [16 pts.] In the table below, enter "+", "-" or "0" to indicate the value of the requested quantity or the change in the value of the requested quantity.

<table>
<thead>
<tr>
<th>Quantity/Process</th>
<th>( W )</th>
<th>( Q )</th>
<th>( \Delta U )</th>
<th>( \Delta S )</th>
</tr>
</thead>
<tbody>
<tr>
<td>A</td>
<td>-</td>
<td>+</td>
<td>-</td>
<td>+</td>
</tr>
<tr>
<td>B</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>C</td>
<td>+</td>
<td>0</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Whole Cycle</td>
<td>-</td>
<td>-</td>
<td>0</td>
<td>0</td>
</tr>
</tbody>
</table>

C. [6 pts.] In the questions below write start, end of A, and/or end of B to best answer the query.

2. [8 pts] 1. START. The state at lowest temperature.

4/17. 2. END OF B. The state at which the average \( X E \) per particle is greatest.

D. [2 pts.] Is this thermodynamic cycle acting like a heat engine or a refrigerator?

\( \Omega \in \mathbb{P}_1 \in \mathbb{E} \in \mathbb{A} \in \mathbb{D} \in \mathbb{R} \)
A. On top of the police station in a small Kansas town sits a siren that emits a 1.00 kHz tone as a spherical isocpic emitter with an average power $P_0 = 1.257 \times 10^3$ W. The police chief, Dorothy Overlook, is initially at a direct line of sight distance from the siren such that she just hears the siren at the threshold of human hearing, i.e., $I_{hearing} = 1.00 \times 10^{-6}$ W/m$^2$. 

1. How far is Dorothy from the siren? 

$R = \frac{(1.257 \times 10^3 \text{ W})(3 \times 10^8 \text{ m/s})}{(2 \pi)(200 \text{ Hz})} = 1.00 \times 10^4 \text{ m} = 10.0 \text{ km}$ 

2. What is the intensity level, $\beta$, for the sound from the siren at Dorothy’s initial position? 

$\beta = 0$ at $10.0 \text{ km}$ since $I = I_0 \text{ at the threshold}$ 

3. Dorothy jumps in her cruiser and takes off toward the police station heading directly towards it at 10.0 m/s. While traveling with that velocity, what frequency of the sound coming from the siren does Dorothy hear? Use $v(\text{sound}) = 340$ m/s. 

$\nu_{obs} = \frac{c}{v} \frac{(340 \text{ m/s})}{(300 \text{ m/s})^2} = 1.10 \text{ kHz}$ 

4. When Dorothy reaches a point halfway to the police station from where she started, what would be the intensity level, $\beta$, of the sound coming from the siren? AT $\frac{1}{2}$ ORIGIN $\text{ she will go 100 m to 100 m}$ from origin. 

$\beta = 10 \log \frac{I_0}{I} = 10 \log \frac{10.0 \text{ W/m}^2}{I_0} = 10 \log 10 = 10 \text{ dB}$ 

B. Two speakers, separated by 10.0 m and each emitting sound at the same wavelength $\lambda = 3.40$ m, are facing each other. The speakers emit $\frac{1}{2}$ cycle out of the phase, i.e., when a crest of the sound disturbance is emitted by one of the speakers, at that instant the other speaker is emitting a trough in the sound wave. 

1. Is the midpoint between the two speakers a location for constructive, destructive interference, or something in-between? 

Destructive interference is between B and C. 

2. If sound travels at 340 m/s, what is the frequency of the sound wave from each speaker? 

$f = \frac{v}{\lambda} = \frac{340 \text{ m/s}}{3.40 \text{ m}} = 100 \text{ Hz}$
A. [12 pts.] Examine the plots showing either displacement vs. time or displacement vs. positions of waves moving along the +x direction in the same medium.

To fill in the blanks below you will have to do some quick calculations of the targeted quantities based upon graphical data.

1. is the wave with the smallest frequency.
2. is the wave with the largest frequency.
3. is the wave with the smallest wavelength.
4. is the wave with the largest wavelength.
5. is the wave with the smallest period.
6. is the slowest moving wave whose amplitude is 2.0 cm.

B. [24 pts.] The following diagram is a P-V plot of a three step thermodynamic cycle in which an ideal gas, starting at point A is taken through the cycle ABCA. In the table below, enter "+", "-", or "0" to indicate whether the requested quantity is positive, negative, or zero.

<table>
<thead>
<tr>
<th></th>
<th>W</th>
<th>ΔU</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>A → B</td>
<td>-</td>
<td>+</td>
<td>0</td>
</tr>
<tr>
<td>B → C</td>
<td>+</td>
<td>0</td>
<td>+</td>
</tr>
<tr>
<td>C → A</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Entire Cycle</td>
<td>+</td>
<td>0</td>
<td>+</td>
</tr>
</tbody>
</table>
EXAM 1

Name: ___________________________ Student ID #: ___________________________

TA (circle one): Mangum Schrank Shepherd Soemori Stoker

A. [16 pts.] Imagine you are in your car waiting for a left turn light to go from red to green when an oncoming car passes through the intersection without turning, its horn blowing continuously and traveling with a constant speed \( v \). As the oncoming car approaches, the frequency of the horn is 653 Hz and after the car passes you and is receding away down the street, its frequency is 547 Hz. What is the constant speed of the passing car? Take the speed of sound to be 343 m/s.

\[
\text{OBS: } 653 \quad \text{SCH: } f_0 = \frac{f_0}{1 + \frac{v}{u_v v/334}}
\]

\[
\text{NCH: } f_0 = \frac{f_0}{1 - \frac{v}{u_v v/334}}
\]

Divide and solve for \( v \).

\[
\frac{653}{547} = \frac{343 + v_5}{343 - v_5}
\]

\[
(1.194)(343 - v_5) = 343 + v_5
\]

\[
0.194v_5 = (1.194)(343)
\]

\[
v_5 = 30.3 \text{ m/s}
\]

B. [12 pts.] In an audition for a role in an opera the soprano produces a sound that registers 110 dB on a sound level meter. How many identical soprano singing the same note together would it take to produce a sound that would register 120 dB on the sound level meter? You must show work.

\[
\text{Soprano: } 110 \text{ dB} = 10 \log \left( \frac{I_{\text{soprano}}}{I_0} \right) \quad \Rightarrow \quad \sum N_{\text{soprano}} = N_{\text{soprano}}
\]

\[
\text{Soprano: } 120 \text{ dB} = 10 \log \left( \frac{I_{\text{soprano}}}{I_0} \right) \quad \Rightarrow \quad \sum N_{\text{soprano}} = 10 \log N
\]

\[
\text{Tune Diff: } 10 \text{ dB} = 10 \left( \log \left( \frac{I_{\text{soprano}}}{I_0} \right) - \log \left( \frac{I_{\text{soprano}}}{I_0} \right) \right) = 10 \log \left( \frac{N_{\text{soprano}}}{10} \right)
\]

or

\[
1 \Rightarrow N = 10
\]
4.00 moles of an ideal monatomic gas is taken through an unusual 3-step cycle shown in the accompanying figure. Pertinent data for the cycle is to the right of the PV diagram.

A. [30 pts.] Fill in all the blank entries in the table below. Be very careful with signs. There will be large point deductions for incorrect signs. Use back of page if you need additional space.

<table>
<thead>
<tr>
<th></th>
<th>A-B</th>
<th>B-C</th>
<th>C-A</th>
<th>Whole Cycle</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \Delta U )</td>
<td>(-9.55 \times 10^5 ) J</td>
<td>(-8.18 \times 10^3 ) J</td>
<td>(-1.37 \times 10^4 ) J</td>
<td>(0) J</td>
</tr>
<tr>
<td>( W )</td>
<td>(-2.48 \times 10^5 ) J</td>
<td>(0) J</td>
<td>(-9.0 \times 10^3 ) J</td>
<td>(1.5 \times 10^5 ) J</td>
</tr>
<tr>
<td>Q (_{A-B} )</td>
<td>(1.20 \times 10^5 ) J</td>
<td>(-8.18 \times 10^3 ) J</td>
<td>(-2.03 \times 10^4 ) J</td>
<td>(1.5 \times 10^5 ) J</td>
</tr>
</tbody>
</table>

\[ Q_{A-B} = Q_{A}\text{, work done by gas from A to B} \]
\[ Q_{C-A} = Q_{C}\text{, work done by gas from C to A} \]
\[ Q_{WAT} = Q_{W}\text{, total work done by gas} \]

B. [3 pts.] Is the device based on the cycle described in this problem behaving as a heat engine or refrigerator?

\[ \text{Heat Engine}\text{ or Refrigerator?} \]
A. A tsunami warning siren behaving as an isotropic spherical sound source, has an intensity level of 100.0 dB at 6.00 m. Note: \( I = 1.00 \times 10^4 \text{ W/m}^2 \)

1. [5 pts.] What is the average intensity of the siren at 6.00 m?

\[
\bar{I}_{\text{siren}} = 10 \log \left( \frac{I}{I_{\text{ref}}} \right) = 10 \log \left( \frac{10^2}{10^{-10}} \right) = 10 \log (10^{12}) = 120 \text{ dB} \\
\bar{I}_{\text{siren}} = \frac{1}{4 \pi R^2} I_{\text{source}} = \frac{1}{4 \pi (6.00)^2} (10^2) = \frac{1}{24 \pi} \times 10^2 = 1.06 \times 10^{-1} \text{ W/m}^2
\]

2. [10 pts.] What is the intensity level in dB of the siren at a distance of 120 m?

\[
P_{\text{siren}}(R) = \frac{P_{\text{siren}}}{R^2} = \frac{10 \log \left( \frac{R_{\text{ref}}}{R} \right)}{R^2} = 10 \log \left( \frac{10^2}{120} \right) = 10 \log \left( \frac{1}{120} \right) = -54.77 \text{ dB}
\]

3. [3 pts.] Suppose a second identical siren is located right next to the original siren. What would now be the intensity level in dB of the 2-siren system at the original 6.00 m?

\[
I_{\text{2-siren}} = 10 \log \left( \frac{I_{\text{siren}}}{I_{\text{ref}}} \right) = 10 \log \left( \frac{10^2}{10^{-10}} \right) = 10 \log (10^{12}) = 120 \text{ dB}
\]

B. A police cruiser is proceeding south on I-15 at 52.0 m/s in a high speed chase of a stolen car which is traveling south on I-15 at 40.0 m/s. The siren on the cruiser produces sound at a single 1500 Hz frequency, as heard by the driver of the cruiser. Take \( v_{\text{sound}} = 340 \text{ m/s} \).

1. [16 pts.] What is the frequency of the siren heard by the driver of the stolen car?

\[
f_0 = f_s \left( \frac{v_{\text{sound}} + v_{\text{car}}}{v_{\text{sound}} - v_{\text{car}}} \right) = (1500 \text{ Hz}) \left( \frac{340 \text{ m/s} + 40 \text{ m/s}}{340 \text{ m/s} - 52 \text{ m/s}} \right) = 1560 \text{ Hz}
\]

2. [4 pts.] At what speed would the driver of the stolen car have to travel in order to hear the siren at 1500 Hz?

\[
v_{\text{car}} = 0 \text{ m/s}
\]

3. [3 pts.] If the driver of the stolen car starts slowing down while the police cruiser maintains its 52.0 m/s speed, will the frequency of the siren tone, as heard by the driver of the stolen car, increase, decrease, or stay the same?

\[
\text{INCREASE}
\]
A. \[26\text{ pts.}\] The following is a PV plot of a 3-step thermodynamic cycle in which an ideal gas starting at point A is taken through the cycle ABCA. On the table enter "+", "−", or "0" to indicate whether the requested quantity is positive, negative, or zero.

<table>
<thead>
<tr>
<th></th>
<th>W</th>
<th>ΔU</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>A − B</td>
<td>−</td>
<td>−</td>
<td>−</td>
</tr>
<tr>
<td>B − C</td>
<td>+</td>
<td>−</td>
<td>+</td>
</tr>
<tr>
<td>C − A</td>
<td>+</td>
<td>+</td>
<td>+</td>
</tr>
<tr>
<td>Entire cycle</td>
<td>−</td>
<td>+</td>
<td>−</td>
</tr>
</tbody>
</table>

1. **Removal** Is net heat added or removed from the gas?

2. **Fr16** Could this cycle be used in refrigeration? (Enter either yes or no.)

B. \[12\text{ pts.}\] Two different ropes are separately tied to a wall, held taut, and yanked continuously up and down. Waves, as shown, are sent traveling to the right along each rope with speeds \(v_A\) and \(v_B\) \((v_A > v_B)\). See drawing. Select the statements below that could account for \(v_A > v_B\) by placing a check mark in the blank space of those that could and leaving blank those that could not.

1. \(\checkmark\) The linear density of rope A is less than that of rope B.

2. \(\_\_)\) The yanking frequency for rope A is greater than that for B.

3. \(\_\_)\) The wavelength of the wave on rope A is greater than that on B.

4. \(\checkmark\) The tension in rope A is greater than the tension in B.

5. \(\_\_)\) The linear density of rope A is greater than that of rope B.

6. \(\_\_)\) The tension in rope A is less than the tension in B.
2.40 moles of a monatomic ideal gas, initially at STP, i.e., $T = 273\, \text{K}$ and $P = 1.01 \times 10^5\, \text{N/m}^2$, are taken through a 3-step thermodynamic cycle. The steps are:

1. An isobaric expansion of the gas to 3 times the original volume.
2. An isochoric drop in pressure to a new pressure that is $\frac{1}{2}$ the original pressure.
3. A compression returning the gas to its starting point. The PV plot of this compression is a straight line.

A. [6 pts.] Draw the cycle on the empty PV plot.

B. [4 pts.] What is the initial volume of the gas?

$$V_0 = \frac{\sqrt[3]{RT_0}}{P_0} = \frac{(2.4\, \text{mole})(8.315\, \text{J/molK})(273\, \text{K})}{1.01 \times 10^5\, \text{N/m}^2}$$

$$V_0 = \text{0.0539 m}^3$$

C. [24 pts.] Fill in the missing items on the table below.

<table>
<thead>
<tr>
<th></th>
<th>W</th>
<th>$\Delta U$</th>
<th>Q</th>
</tr>
</thead>
<tbody>
<tr>
<td>Process 1</td>
<td>$1.09 \times 10^4, \text{J}$</td>
<td>$1.63 \times 10^4, \text{J}$</td>
<td>$2.73 \times 10^4, \text{J}$</td>
</tr>
<tr>
<td>Process 2</td>
<td>$0$</td>
<td>$-1.32 \times 10^4, \text{J}$</td>
<td>$-1.32 \times 10^4, \text{J}$</td>
</tr>
<tr>
<td>Process 3</td>
<td>$-8.17 \times 10^3, \text{J}$</td>
<td>$-4.07 \times 10^3, \text{J}$</td>
<td>$-1.33 \times 10^4, \text{J}$</td>
</tr>
<tr>
<td>Entire cycle</td>
<td>$2.73 \times 10^4, \text{J}$</td>
<td>$0$</td>
<td>$2.73 \times 10^4, \text{J}$</td>
</tr>
</tbody>
</table>

Note: The temperature of the gas at the end of the isobaric expansion is $819\, \text{K}$.

$$W_1 = PV = (1.01 \times 10^5\, \text{N/m}^2)(2.4\, \text{mole})(0.0539\, \text{m}^3) = 1.09 \times 10^4\, \text{J}$$

$$W_2 = -1.32 \times 10^4\, \text{J}$$

$$W_3 = -(8.17 \times 10^3\, \text{J})$$

$$\Delta U_2 = \frac{3}{2} \frac{R}{M} \Delta T = (1.5)(8.315\, \text{J/molK})(546\, \text{K}) = 1.63 \times 10^4\, \text{J}$$

D. [4 pts.] What is the actual efficiency of this cycle?

$$\eta = \frac{W_{\text{NET}}}{Q_{\text{ADDED}}} = \frac{2.73 \times 10^4\, \text{J}}{2.72 \times 10^4\, \text{J}} = 0.10\, (10\%$$)
At the top of the police department building in a small Missouri town sits a tornado warning siren. The siren produces a 1.20 kHz (khz = kilohertz) tone as an isotropic, spherical sound source at a 1800 W power level. The siren is on top of a tower.

A. \( [8 \text{ pts.}] \) What is the minimum height of the tower such that at the level of the roof of the building the intensity of the sound from the siren is no more than the threshold of pain, i.e., \( I_{\text{pain}} = 1.0 \text{ W/m}^2 \)? (Note: \( A_{\text{sphere}} = 4\pi r^2 \))

\[
I_p = 1.0 \text{ W/m}^2 = \frac{P}{A} = \frac{1800\text{ W}}{4\pi r^2}
\]

\[
r = \sqrt{\frac{1800\text{ W}}{4\pi}} = 12 \text{ m}
\]

B. \( [8 \text{ pts.}] \) Suppose the town policeman is driving toward the police department. At a distance of 2.82 km, what is the intensity level, in decibels, of the sound from the siren as detected in the police car.

\[
I(\text{at } 2.82 \text{ km}) = \frac{P}{A} = \frac{1800\text{ W}}{4\pi (2.82 \times 10^3 \text{ m})^2} = 1.80 \times 10^{-5} \text{ W/m}^2
\]

\[
\Delta \beta = 10 \log \frac{I}{I_0} = 10 \log_{10} \frac{1.80 \times 10^{-5}}{1.0 \times 10^{-12}} = 10 \log_{10} 1.8 \times 10^7
\]

\[
\Delta \beta = 72.6 \text{ dB} = 73 \text{ DECIBELS}
\]

C. \( [8 \text{ pts.}] \) Now suppose the policeman is racing toward the police department at 26.0 m/s. Assuming the 26.0 m/s is the same speed the police car is traveling toward the siren, determine the frequency of the siren sound detected by the police car. Take the speed of sound in air to be 340 m/s.

\[
f_{\text{obs}} = f_s \left( \frac{v + v_0}{v + v_0} \right) = (120 \text{ kHz}) \left( \frac{340 \text{ m/s} + 26 \text{ m/s}}{340 \text{ m/s}} \right)
\]

\[
f_{\text{obs}} = 1.39 \text{ kHz}
\]