Physics 201, Exam 4 **Name (printed)** ______________________________

On my honor as a Texas A&M University student, I will neither give nor receive unauthorized help on this exam.

Name (signed) ______________________

The multiple-choice problems carry no partial credit.
Circle the correct answer or answers. **An answer is approximately correct if it is correct to 2 significant figures.**
In the work-out problems, you are graded on your work, with partial credit.
(The answer by itself is not enough, and you receive credit only for your work.)
Be sure to include the correct units in the answers, and give your work in the space provided.

---

1. (5) From http://www.dangerousdecibels.org/:

A typical conversation occurs at 60 dB - not loud enough to cause damage.
A bulldozer that is idling (note that this is idling, not actively bulldozing) is loud enough at 85 dB that it can cause permanent damage after only 1 work day (8 hours).
When listening to music on earphones at a standard volume level 5, the sound generated reaches a level of 100 dB, loud enough to cause permanent damage after just 15 minutes per day!
A clap of thunder from a nearby storm (120 dB) or a gunshot (140-190 dB, depending on weapon), can both cause immediate damage.

You are listening to your iPod, and your ears are receiving a sound intensity of 0.0003 W/m^2. What is your level of risk for hearing loss?

$$\boxed{\beta =} (10\ dB) \log\left(\frac{0.0003\ W/m^2}{10^{-12}\ W/m^2}\right) = (10\ dB)(8.5) = \boxed{85\ dB}$$

(a) not loud enough to cause damage
(b) loud enough to cause damage if continued for about a year
(c) loud enough to cause damage if continued for about a day
(d) loud enough to cause damage if continued for about 15 minutes
(e) loud enough to cause immediate damage

2. (5) A string of length 0.300 m is vibrating at 100 Hz in its second harmonic and producing sound that moves at 340 m/s. What is true about the frequency and wavelength of these sound waves? (There may be more than one correct answer.)

$$\boxed{\lambda =} \frac{v}{f} = \frac{340\ m/s}{100\ Hz} = \boxed{3.4\ m}$$

(a) The wavelength of the sound is 0.300 m.
(b) The wavelength of the sound is 3.40 m.
(c) The frequency of the sound is 100 Hz.
(d) The frequency of the sound is 1133 Hz.
(e) none of the above

3. (5) An open pipe has a length of 0.10 m. The speed of sound is 340 m/s for the air inside it. What is the fundamental frequency?

$$\frac{1}{2}\lambda = L \Rightarrow \lambda = 2 \cdot L = 0.20\ m$$

$$\boxed{f =} \frac{v}{\lambda} = \frac{340\ m/s}{0.20\ m} = \boxed{1700\ Hz}$$

antinodes at both ends $\Rightarrow \frac{1}{2}\lambda = L$

(a) 850 Hz
(b) 1700 Hz
(c) 3400 Hz
(d) 6400 Hz
(e) 12800 Hz
(f) none of the above

4. (5) A siren on a police car emits a sound wave with frequency $f_s = 600$ Hz. The speed of sound is 340 m/s. Find the frequency heard by you if your car is moving in the $+x$ direction with a speed of 15 m/s (relative to the air) and the police car is moving in the same direction with a speed of 30 m/s (relative to the air).

L $\rightarrow$ S $\longrightarrow$

(a) 687 Hz
(b) 629 Hz
(c) 576 Hz
(d) 527 Hz
(e) none of the above

$$f_L = \frac{340+15}{340+30} = 576 \text{ Hz}$$

[But S $\longrightarrow$ L $\rightarrow$ gives $f_L = \frac{340-15}{340-30} = 629$ Hz]

5. (5) If you mix 100 g of ice at 0°C with 100 g of boiling water at 100°C in a perfectly insulating container, the final temperature in thermal equilibrium will be

(a) 0°C
(b) between 0°C and 50°C
(c) 50°C
(d) between 50°C and 100°C
(e) none of the above

[The heat of fusion for water is 334 J/g and the heat capacity is 4.2 J/(K·g).]

Heat from boiling water has to both raise temperature of water at 0°C and melt ice.
But melting ice requires 33,400 J and cooling boiling water to 0°C would require (4.2)(100)(100) = 42,000 J.
So boiling water has not been lowered to 0°C when ice is melted.

6. (5) Which of the following must be true about an ideal gas that undergoes an isothermal expansion? (There may be more than one correct answer.)

(a) No heat enters the gas.
(b) The pressure of the gas decreases.
(c) The internal energy of the gas does not change.
(d) The gas does positive work.

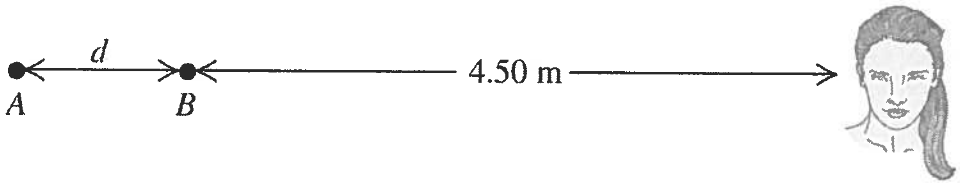
$PV = nRT \Rightarrow P \propto \frac{1}{V}$ for T const.

$U = U(T)$ does not change

work = + area under curve

7. Two small speakers A and B are driven in step at 200 Hz by the same audio oscillator. These speakers start out 4.50 m from the listener, as shown in the figure. Then speaker A is slowly moved away.

Take the speed of sound to be 340 m/s.



(a) (4) At what distance d_{dest} will the sound from the speakers first produce destructive interference at the location of the listener? (Show your work, as always.)

d_{dest} = 0.85 m

$$\lambda = \frac{v}{f} = \frac{340 \text{ m/s}}{200 \text{ Hz}} = 1.7 \text{ m}$$

$$\frac{1}{2}\lambda = 0.85 \text{ m}$$

(b) (4) As A is moved still further away, what is the next distance d'_{dest} for which the sound from the speakers will again produce destructive interference at the location of the listener?

d'_{dest} = 2.55 m

$$\frac{3}{2}\lambda = 2.55 \text{ m}$$

(c) (4) At what (nonzero) distance d_{const} will the sound from the speakers first produce constructive interference at the location of the listener?

d_{const} = 1.7 m

$$\lambda = 1.7 \text{ m}$$

8. One end of an insulated metal rod is maintained at 100°C and the other end at 0°C. The rod is 50 cm long and has a cross-sectional area of 2.0 cm^2. The heat conducted by the rod melts 12 g of ice in 10 minutes.

The latent heat of fusion for water is 334×10^3 J/kg.

(a) (8) Calculate the heat current through the rod.

heat current = $6.68\ \frac{J}{s}$

$$\boxed{H =} \frac{Q}{t} = \frac{(334\times10^{3}\ \frac{J}{kg})(12\times10^{-3}\ kg)}{(10\ min)(60\ \frac{s}{min})} = \boxed{6.68\ \frac{J}{s}}$$

[or 6.68 W]

(b) (10) Calculate the thermal conductivity of the rod.

thermal conductivity = $167\ \frac{W}{m\ K}$

$$H = kA\,\frac{T_H - T_c}{L} \Rightarrow \boxed{k =} H\,\frac{L}{(A)(T_H - T_c)}$$

$$= \left(6.68\ \frac{J}{s}\right)\frac{0.50\ m}{(2.0\times10^{-4}\ m^2)(100\ K)}$$

$$= \boxed{167\ \frac{W}{m\ K}}$$

We used $1\ cm^2 = (10^{-2}\ m)^2 = 10^{-4}\ m^2$

and $100^\circ C - 0^\circ C = 100\ C^\circ = 100\ K$ for a temperature difference

and $1\ \frac{J}{s} = 1\ W$.

9. Oxygen has a molar mass of 32.0 g/mol. (Note that 1 atomic mass unit = $1\ u = 1.66 \times 10^{-27}$ kg.)

(a) (4) Calculate the root-mean-square velocity of an oxygen molecule at a temperature of 20°C.

root-mean-square velocity of oxygen molecule = $478\ \frac{m}{s}$

$T = 273.15 + 20 = 293.15\ K$

$$\boxed{v_{rms} =} \sqrt{\frac{3RT}{M}} = \sqrt{\frac{(3)(8.314\ J/(mol \cdot K))(293.15\ K)}{32.0 \times 10^{-3}\ kg/mol}}$$

$$= \boxed{478\ \frac{m}{s}}$$

[other version: 532 m/s]

(b) (4) Calculate the average translational kinetic energy of an oxygen molecule at this temperature.

average kinetic energy = 6.07×10^{-21} J

$$\boxed{K =} \frac{1}{2} m v_{rms}^2$$

$$= \frac{1}{2}(32.0)(1.66 \times 10^{-27}\ kg)(478\ \frac{m}{s})^2$$

$$= \boxed{6.07 \times 10^{-21}\ J}$$

[other version: 7.52×10^{-21} J]

(c) (4) Calculate the root-mean-square velocity of a hydrogen molecule at this temperature, given that the molar mass of hydrogen is 2.016 g/mol.

root-mean-square velocity of hydrogen molecule = $1904\ \frac{m}{s}$

$$\boxed{v_{rms} =} \sqrt{\frac{(3)(8.314)(293.14)}{2.016}}$$

$$= \boxed{1904\ \frac{m}{s}}$$

or 1.90 km/s

[other version: 2120 m/s]

(d) (2) Compare your answer to (c) with the escape velocity of 11 km/s for Earth, and explain **clearly** why nearly all hydrogen has escaped from Earth.

v_{rms} < escape velocity, but there are some much faster molecules in the distribution of velocities.

10. A heat engine takes 0.70 mole of an ideal gas through the following cycle.

The gas starts at a temperature of 300 K and a pressure of 1 atm $= 1.01\times10^5$ Pa.

$1\rightarrow2$: The gas then is heated at constant volume to a temperature of 900 K.

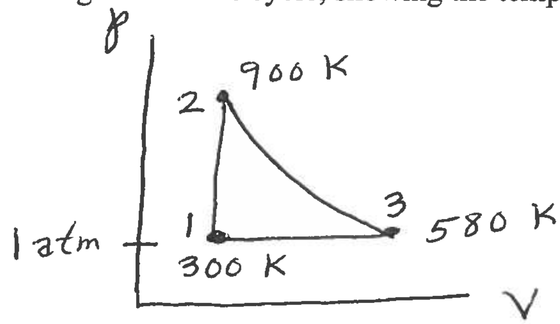
$2\rightarrow3$: It undergoes an adiabatic expansion which leaves it at a temperature of 580 K.

$3\rightarrow1$: Finally, it is cooled at constant pressure to the initial temperature.

The magnitudes of the changes in internal energy are:

$|(\Delta U)_{1\rightarrow2}| = 8730$ J , $|(\Delta U)_{2\rightarrow3}| = 4656$ J , $|(\Delta U)_{3\rightarrow1}| = 4074$ J

(a) (2) Draw the pV diagram for this cycle, showing the temperatures in K and the pressure in atm.



(b) (2) Determine the true values (with signs) of the three changes in internal energies.

$U = U(T)$

$\Rightarrow \Delta U > 0$ if $\Delta T > 0$,

$\Delta U < 0$ if $\Delta T < 0$

$(\Delta U)_{1\rightarrow2} =$ $+8730$ J , $(\Delta U)_{2\rightarrow3} =$ -4656 J , $(\Delta U)_{3\rightarrow1} =$ -4074 J

(c) (3) Calculate the volumes.

$V_1 =$ $0.0173\ m^3$, $V_2 =$ $0.0173\ m^3$, $V_3 =$ $0.0334\ m^3$

$pV = nRT \Rightarrow V = \dfrac{nRT}{p}$

$\boxed{V_1 =} \dfrac{(0.70)(8.314)(300)}{1.01\times10^5} = \boxed{0.0173\ m^3}$

$\boxed{V_2 = V_1}$

$\boxed{V_3 =} \dfrac{(0.70)(8.314)(580)}{1.01\times10^5} = \boxed{0.0334\ m^3}$

(d) (2) Calculate the pressure in state 2.

$p_2 =$ $303{,}000$ Pa

$\boxed{p_2 =} \dfrac{nRT_2}{V_2} = \boxed{303{,}000\ Pa}$

or just $p_2 = \dfrac{T_2}{T_1} p_1 = 3p_1$

since $V_2 = V_1$

(e) (9) Calculate the heat Q and work W for each process.
(Show all your work clearly and in a well-organized way to get credit.)

$$\Delta U = Q - W$$

$Q_{1\to2}$ = 8730 J , $W_{1\to2}$ = 0

$Q_{2\to3}$ = 0 , $W_{2\to3}$ = 4656 J

$Q_{3\to1}$ = − 5700 J , $W_{3\to1}$ = − 1626 J

$\boxed{W_{1\to2} = 0}$ since $\Delta V = 0$, $\boxed{Q_{1\to2} =} (\Delta U)_{1\to2} = \boxed{8730\ \text{J}}$

$\boxed{Q_{2\to3} = 0}$ since adiabatic, $\boxed{W_{2\to3} =} -(\Delta U)_{2\to3} = \boxed{+4656\ \text{J}}$

$$\boxed{W_{3\to1} =} p(\Delta V)_{3\to1} = (1.01\times10^5\ \text{Pa})\underbrace{(0.0173\ \text{m}^3 - 0.0334\ \text{m}^3)}_{V_1 - V_3}$$
$$= \boxed{-1626\ \text{J}}$$

$$\boxed{Q_{3\to1} =} (\Delta U)_{3\to1} + W_{3\to1}$$
$$= -4074\ \text{J} + (-1626\ \text{J}) = \boxed{-5700\ \text{J}}$$

(f) (2) What is the net work done?

net work = 3030 J

$$\boxed{W =} 0 + 4656 - 1626$$
$$= \boxed{3030\ \text{J}}$$

(g) (2) What is the net heat flow into the engine in one cycle?

net heat flow into engine = 3030 J

$$\boxed{Q =} 8730 + 0 - 5700$$
$$= \boxed{3030\ \text{J}}$$

so $(\Delta U)_{total} = 0$, which is a nice check

(h) (2) Calculate the thermal efficiency.

efficiency = 35%

Use $Q_{1\to2}$, not Q, as emphasized in class.

$$\boxed{e =} \frac{W}{Q_{1\to2}} = \frac{3030\ \text{J}}{8730\ \text{J}} = 0.347$$
$$= \boxed{35\%}$$

(i) (2) Calculate the efficiency that a Carnot engine would have operating between the same minimum and maximum temperatures. How does this compare with the answer to (h)?

Carnot efficiency = 67%

$$\boxed{e_{Carnot} =} 1 - \frac{T_C}{T_H}$$
$$= 1 - \frac{300\ \text{K}}{900\ \text{K}}$$
$$= \boxed{67\%}$$

11. (5 points extra credit) List and clearly explain 5 independent applications of the Doppler effect, **or** clearly list the 3 laws of thermodynamics with an example of the implications of each one (using just (i), (ii), (iii) below if you make this choice). Skeleton solution, you should do better.

(i) police radar gun to detect speeding

or 1st law, which implies work from engine cannot exceed input energy

(ii) sports radar gun to measure speed of ball

or 2nd law, which implies engine cannot convert all of input energy into useful work

(iii) Doppler radar gun to measure speed of wind (or water droplets) in hurricane

or 3rd law, which ⇒ entropy → 0 as T → 0

(iv) measurement of blood flow

(v) discovery that universe is expanding