Exam Overview:
a) The exam consists of 8 questions worth 12 points each (you get 4 points for correctly identifying your section number A1, A2, B1, B2, C1, C2, D1 & D2)
b) Show all of your work
c) Include units for all answers which require units
d) Include the correct number of significant digits
e) Write your final answer in the space provided

Hints:
a) Stay calm
b) Glance over all problems, tackle the “easy” ones first
c) Use reasonableness to guide you
d) Allow yourself an average of 6 minutes per problem (12 minutes per page)

R Units

<table>
<thead>
<tr>
<th>Value</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.987</td>
<td>Btu/(lb mole · R)</td>
</tr>
<tr>
<td>1.987</td>
<td>cal/mole · K</td>
</tr>
<tr>
<td>0.730</td>
<td>atm · ft³/(lb mole · R)</td>
</tr>
<tr>
<td>10.73</td>
<td>psia · ft³/(lb mole · R)</td>
</tr>
<tr>
<td>1545.0</td>
<td>(lb/ft²) · ft³/(lb mole · R)</td>
</tr>
<tr>
<td>1.314</td>
<td>atm · ft³/(lb mole · K)</td>
</tr>
<tr>
<td>82.06</td>
<td>atm · cm³/(mole · K)</td>
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<tr>
<td>0.082</td>
<td>L · atm/(mole · K)</td>
</tr>
<tr>
<td>0.083</td>
<td>L · bar/(mole · K)</td>
</tr>
<tr>
<td>8.31</td>
<td>J/(g mole · K)</td>
</tr>
</tbody>
</table>

Q is positive for heat flowing into a system
W is positive for work done by a system
Differential work done by a thermal system, dW = p dV

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1) Describe the First Law of Thermodynamics physically and mathematically. What does it mean and why is it so important for engineering calculations? Be complete and give at least one example.

See review lecture, slides 3-4

2) Describe the Second law physically and mathematically. What does it mean and why is it so important for engineering calculations? Be complete and give at least one example.

See review lecture, slides 5-6
3. Calculate the entropy change when 1 kg of water is cooled from 100°C to 0°C. Calculate the entropy change when the water turns to ice at 0°C (Fig. 20–25). The latent heat of fusion is 80 cal/g.

We use a reversible process in which the water is in contact with a series of reservoirs of decreasing temperature:
\[
\Delta S_{\text{water}} = \int \frac{dQ}{T} = mc \int \frac{dT}{T} = mc \ln(T/T_0) \\
= (1 \times 10^3 \text{ g})(1 \text{ cal/g} \cdot \text{K})(4.185 \text{ J/cal}) \ln(273/373) = -1 \times 10^3 \text{ J/K}.
\]

Because the freezing occurs at constant temperature, we have
\[
\Delta S_{\text{ice}} = \frac{\Delta Q}{T} = \frac{mL}{T} \\
= - (1 \times 10^3 \text{ g})(80 \text{ cal/g})(4.185 \text{ J/cal})/273 \text{ K} = -1 \times 10^3 \text{ J/K}.
\]

4. A heat pump is used to heat a home in winter when the temperature in the ground is 0°C and the temperature of the radiator in the house is 35°C. When a Carnot cycle is run backwards for this purpose, the objective is to obtain as much heat in the radiator as possible for a given amount of electrical work. The coefficient of performance \(\text{COP}'\) for a heat pump is defined by:
\[
\text{COP}' = \frac{|Q_H|}{|w|} = \frac{|Q_H|}{|Q_H| - |Q_G|} = \frac{T_H}{T_H - T_G}
\]

What is the minimum amount of electrical work needed to produce a kilowatt-hour of heat?
\[
\text{COP}' = \frac{|Q_H|}{|w|} = \frac{|Q_H|}{|Q_H| - |Q_C|} = \frac{T_H}{T_H - T_C}
\]
\[
\text{COP}' = \frac{308}{308 - 273} = 8.8
\]
\[
8.8 = \frac{1.0}{w} \\
w = 0.1136 \text{ kwh}
\]

**Answer:**
5. The purest acetic acid is often called glacial acetic acid because it is purified by fractional freezing at its melting point of 16.6°C. A flask containing several moles of acetic acid at its melting point of 16.6°C is lowered into an ice-water bath briefly. When it is removed it is found that exactly 1 mol of acetic acid has frozen. Given: ΔH_f^\circ (acetic acid) = 11.45 kJ/mol and ΔH_f^\circ (water) = 5.98 kJ/mol
   a) What is the change in entropy of the acetic acid?
   b) What is the change in entropy of the water bath?

\[ \Delta S_{ac} = \frac{Q}{T} = \frac{11.45 \text{ J}}{289.8 \text{ K}} = -39.51 \text{ J/K} \]
\[ \Delta S_{wb} = \frac{11.45 \text{ J}}{273.2 \text{ K}} = 41.91 \text{ J/K} \]

\text{Answer:} \quad \Delta S_{ac} = -39.51 \text{ J/K}, \quad \Delta S_{wb} = 41.91 \text{ J/K}

\text{Note: sum of } 2 \Delta S' \text{'s is +, indicating process is possible}

6. The heat capacity at constant volume of a sample of gas is determined to be 22 J/K. If this amount of gas is heated in a constant-volume container from 273K to 840K, what is the change in entropy?

\[ \Delta S = S \frac{Q}{T} = \sum S \frac{dT}{T} = \sum c \ln \frac{T_f}{T_i} = 22 \ln \frac{840}{273} \]
\[ = 24.7 \text{ J/K} \]

\text{Answer:} \quad \Delta S = 24.7 \text{ J/K} \]
7. Half a mole of an ideal gas is compressed isothermally at 293 K so that the pressure is increased from 1.0 atm to 3.6 atm. What are the initial and final volumes of the gas, and how much work is done by the gas during the compression?

For the ideal gas, we have
\[ pV = nRT, \text{ or } V = nRT/p; \]
\[ V_i = (0.5 \text{ mol})(8.314 \text{ J/mol} \cdot \text{K})(293 \text{ K})/(1.0 \text{ atm})(1.01 \times 10^5 \text{ Pa/atm}) = 0.012 \text{ m}^3; \]
\[ V_f = (0.5 \text{ mol})(8.314 \text{ J/mol} \cdot \text{K})(293 \text{ K})/(3.6 \text{ atm})(1.01 \times 10^5 \text{ Pa/atm}) = 0.0034 \text{ m}^3. \]

From Eq. (18-35), we have
\[ W = nRT \ln(p_f/p_i) = (0.5 \text{ mol})(8.314 \text{ J/mol} \cdot \text{K})(293 \text{ K}) \ln[(1.0 \text{ atm})/(3.6 \text{ atm})] = 1.6 \times 10^3 \text{ J}. \]

The negative value means that work is done on the gas to compress it.

ANSWER

8. A gasoline engine of volume 25 cm³ intakes air at 25°C and 1.0 atm. The engine compresses the air adiabatically to 30% of the original volume. Find the final pressure and temperature and how much work is performed on the gas. You can assume that the air is ideal and \( \gamma = 1.4 \).

\[ P_0V_0^{\gamma} = P_fV_f^{\gamma}. \text{ For air (which is primarily diatomic) } \gamma = 1.40. \text{ Thus } \]
\[ P_f = P_0(V_0/V_f)^{\gamma} = (1.0 \text{ atm}) [(0.30)(V_0)/V_0]^{1.40} = 5.4 \text{ atm}. \]

From \( P_0V_0/T_0 = P_fV_f/T_f \),
\[ T_f = T_0(P_f/P_0)(V_f/V_0) = (25 + 273.15) \text{ K } (5.4 \text{ atm/1.0 atm})(0.30V_0/V_0) = 483 \text{ K} \]

\( \text{(210°C).} \)

Work on gas - either
a) From 1st law \( \Delta U = Q + W \)
\[ W = -\Delta U = c_v(T_f - T_i) \text{ - need } c_v \text{ for air} \]

b) \( W = \int P dV = nRT(T_f - T_i) \text{ for } \rho V = c \]

\( \text{need expression} \)

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