Name: _____________________________  Section: __________

**Guidelines:**
- Assume 3 significant figures for all given numbers.
- Show all of your work – no work, no credit.
- Write your final answer in the box provided - include units for all answers.
- If you finish with less than 5 minutes remaining, remain seated until the end of the exam and all exams are collected.

### Thermal Expansion

**Linear**

\[ \Delta V = \alpha V_0 \Delta T \]

**Linear, Stresses**

\[ \sigma = \alpha E \Delta T \]

**Volumetric**

\[ \Delta V = \beta V_0 \Delta T \]

### Ideal Gas Law

\[ pV = nRT \]

\[ R = 8.314 \text{ J/(mol-K)} \]

Avogadro’s Number: 6.02x10^{23}

### 1st Law of Thermodynamics

- \( U \) – internal energy
- \( W \) – work done by thermal system
- \( Q \) – heat flow into thermal system

\[ \Delta U = -W_{A\rightarrow B} + Q_{A\rightarrow B} \]

### Molecular Thermal Physics

- \( m \) – mass of a molecule
- \( M \) – molecular mass
- \( n \) – number of moles
- \( N \) – number of molecules
- \( k \) – Boltzmann constant = 1.38065 × 10^{-23} J/ K

\[ U = N \left( \frac{1}{2} m \langle v^2 \rangle \right) \]

\[ U = \frac{3}{2} nRT \]

\[ v_{rms} = \sqrt{\frac{3RT}{M}} = \sqrt{\frac{3kT}{m}} \]

### Conversions

- 1 cal = 4.186 J
- 1 L = 1000 cm^3
- 1 m^3 = 1000 L

\[ T_{sc} = \frac{5}{9} (T_{sf} - 32) \]

\[ T_{sf} = \frac{9}{5} T_{sc} + 32 \]

### Work of Thermal Systems

**Volumetric**

\[ W = \int p dV \]

- Isobaric (constant pressure)

\[ W = p \left( V_f - V_i \right) \]

\[ \Delta Q = n c_p' \Delta T \]

- Isochoric (constant volume)

\[ W = 0 \]

\[ \Delta Q = n c_v' \Delta T \]

- Isothermal (constant temp)

\[ W = nRT \ln \left( \frac{V_2}{V_1} \right) \]

\[ \Delta Q = W \]

**Adiabatic** ($\Delta Q = 0$)

\[ W = \frac{1}{\gamma - 1} \left( c_A V_A - p_B V_B \right) \]

### Efficiency

**General**

\[ \eta = \frac{W}{Q_h} = 1 - \frac{|Q_c|}{|Q_h|} \]

**Otto Cycle**

\[ r \) – compression ratio

\[ \eta = 1 - \frac{1}{r^{\gamma - 1}} \]

**Carnot Cycle**

\[ \eta = 1 - \frac{T_c}{T_h} \]

\[ \frac{|Q_h|}{|Q_c|} = \frac{T_c}{T_h} \]

### Entropy

**Ideal Gas**

\[ \Delta S = \frac{n}{\gamma} \frac{dQ}{T} \]

### Heat

- \( Q \) – heat
- \( c \) – specific heat
- \( \kappa \) – thermal conductivity
- \( R \) – thermal resistance

### Heat Capacity

\[ Q = mc \Delta T \]

### Thermal Conductivity

\[ \frac{\Delta Q}{\Delta t} = -kA \frac{T_2 - T_1}{L} = \frac{-A}{R} \frac{T_2 - T_1}{L} \]

### Thermal Resistance

\[ R = \frac{L}{k} \]

**Thermal Resistance, Series**

\[ R_{eff} = R_1 + R_2 \]

**Thermal Resistance, Parallel**

\[ \frac{1}{R_{eff}} = \frac{1}{A_1} + \frac{1}{A_2} \left( \frac{A_1}{R_1} + \frac{A_2}{R_2} \right) \]

### Refrigerators

**General**

- \( K \) – coefficient of performance
- \( H \) – heat current
- \( P \) – power input

\[ \left| Q_h \right| = W + \left| Q_c \right| \]

\[ K = \frac{\left| Q_c \right|}{W} = \frac{H}{P} \]

**Carnot**

\[ K_{Carnot} = \frac{T_c}{T_h - T_c} \]

### Water Properties

- \( c \) = 1 cal/(g\cdot°C) = 4.186J/(g\cdot°C)
- \( L_f \) = 79.6 cal/g
- \( L_v \) = 540 cal/g
- \( \rho \) = 1 g/cm^3 = 1 kg/L
  \[ = 1000 \text{ kg/m}^3 = 62.4 \text{ lb/ft}^3 \]

### Ideal Gas

\[ nRT = V_B \]

\[ \frac{V}{V} \]

\[ Q = nr \]
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1. (8 pts) What is the magnitude of the internal stress in a constrained copper beam as it cools from 60°F to 22°F? \( \alpha_{\text{copper}} = 17 \times 10^{-6} \text{ C}^{-1}, \ E_{\text{copper}} = 110 \text{ GPa} \)

2. (8 pts) What is the kinetic energy of 4 moles of gas at 45°F and pressure of 1.2 ATM?
3. (14 pts) When a 20 gallon gas tank was completely filled with gas the temperature was 60°F. Determine the volume of the gas that will overflow the tank if the temperature increases to 80°F. 
\( \beta_{\text{gasoline}} = 950 \times 10^{-6} \degree \text{C}^{-1}, \quad \beta_{\text{tank}} = 35 \times 10^{-6} \degree \text{C}^{-1} \)

4. (14 pts) Determine the equilibrium temperature if you pour 300g of coffee at 85°C into a 400g coffee mug at 20°C. There are 3.1 KJ of heat lost to the surroundings.

Coffee: \( c = 1.0 \text{ cal/(g-°C)} \quad L_f = 79.6 \text{ cal/g} \quad L_v = 540 \text{ cal/g} \)

Mug: \( c = 0.255 \text{ cal/(g-°C)} \quad L_f = 210 \text{ cal/g} \)
5. (14 pts). Determine the mass density of air at 35°C if the absolute pressure is 120 kPa and the molecular mass of air is 29 g/mole.

6. (14 pts) How much work do 0.3 moles of helium gas (γ = 1.7) do in this adiabatic expansion process?
7. (14 pts). A gas in a cylinder expands from a volume of 0.11 m$^3$ to 0.32 m$^3$. Heat flows into the system just rapidly enough to keep the pressure constant at 180 kPa during the expansion. The total heat added is 115 kJ. Determine the change in internal energy of the gas.

8. (14 pt) Determine the change in entropy as you mix 1 kg of water at 100°C with 1 kg of water at 20°C. Assume no heat flow to the surroundings.

water: $c = 1.0$ cal/(g·°C)  $L_f = 79.6$ cal/g  $L_v = 540$ cal/g