I. (30) **Hot Metal.** 175.0 g of a metal at 115.0°C is dropped into 24.0 g of water at 10.0°C, and the system is allowed to reach thermal equilibrium in an open, adiabatic container. The final temperature is 29.0°C. The heat capacity of water may be taken as \(c_p = 1.00 \text{ cal g}^{-1} \text{ K}^{-1}\).

A. Calculate \(q_{\text{met}}\), \(q_{\text{wat}}\), and the total \(q\) for this process. Also determine the average \(C_{p,\text{met}}\) and \(c_{p,\text{met}}\) over the relevant \(T\) range.

B. Assuming that volume changes are negligible, calculate \(\Delta H\), \(\Delta U\), \(\Delta S_{\text{met}}\), \(\Delta S_{\text{wat}}\), and the total \(\Delta S\) for this process. (Assume heat capacities are constant over the respective \(T\) ranges.)

C. Is this process a reversible one?
II. (25) **Heat Pumps, in Hot Times and Cold.** An ideal heat pump (*i.e.*, one operating on a reversible Carnot cycle) is used to maintain a home at 20°C in winter and at 24°C in summer. Calculate the pump's ideal efficiency (defined in terms of heat removed or delivered, as appropriate) if the outside temperature is 0°C in the winter and 35°C in the summer. Specifically, calculate the ideal amount of heat delivered or removed (as appropriate) in the two seasons (in kJ) per kJ of work input.
III. (25) **Taking Gas (ideally speaking).** $n$ moles of a perfect gas having $C_{V,m} = \frac{3}{2} R$ is heated from $T_1$ to $T_2$ along a path described by $V = bT^3$, where $b$ is a positive constant, independent of $T$. At all times $P_{\text{ext}} = P$. Obtain expressions for the following: $q$, $w$, $\Delta U$, $\Delta H$, and $\Delta S$. [For full credit, your answers should be expressed entirely in terms of $n$, $R$, $b$, $T_1$, and $T_2$.]
The Essentials.

A. Plus and Minus. For each of the following processes, state whether each of the given quantities is positive (+), negative (−), zero, or indeterminate (ind).

1. A perfect gas undergoes a Joule expansion.
2. A real gas undergoes a Joule-Thomson expansion.
3. One mole of liquid water is vaporized reversibly at its normal boiling point.
4. A real gas is taken completely around a Carnot (reversible) cycle in a clockwise sense on a P-V diagram.
5. A real gas undergoes a cyclical process that is in part irreversible.
6. \( \text{H}_2(g) \) and \( \text{O}_2(g) \) react explosively to form \( \text{H}_2\text{O}(g) \) in an isolated system (e.g., a bomb calorimeter).

\[
\begin{array}{cccccccc}
q & w & \Delta T & \Delta P & \Delta U & \Delta H & \Delta S & \Delta S_{\text{univ}} \\
\hline
(1) & & & & & & & \\
(2) & & & & & & & \\
(3) & & & & & & & \\
(4) & & & & & & & \\
(5) & & & & & & & \\
(6) & + & & & & & & \\
\end{array}
\]

B. Inten/Extensive. Indicate whether each of the following quantities is intensive, extensive, or neither:

\[
\begin{align*}
P : & & V : & & \frac{n}{V} : \\
T : & & S : & & \text{mass} : \\
\text{density} : & & C_P : & & (P V_m) : \\
\mu_J : & & & & \\
\end{align*}
\]

C. State functions. Indicate (yes or no) whether each of the following cyclic integrals must vanish for a closed system with P-V work only:

\[
\begin{align*}
\oint V^2dP : & \oint \frac{dq}{T} : \\
\oint (SdT + TdS) : & \oint (dq + dw) : \\
\oint \frac{dw_{\text{rev}}}{V} : & \oint C_{P, \text{id.gas}}dT :
\end{align*}
\]

Prob

\[
\begin{array}{cc}
I & \\
II & \\
III & \\
IV & \\
V & \\
\end{array}
\]
V. (15) **Derivations. Do ONLY ONE of the following TWO.**

A. Express the exact differential \( dU \) for a closed system in terms of the independent variables \( T \) and \( V \) and also in terms of \( dq \) and \( dw \). Combine these to obtain an expression for \( dq_{rev} \) in terms of \( C_V \,dT \), \( P \,dV \), and \( (\partial U/\partial V)_T \,dV \).

B. We will soon be able to show that \((\partial H/\partial P)_T = V - T (\partial V/\partial T)_P \).

1. What does this equation yield for \((\partial H/\partial P)_T \) for an ideal gas?

2. What does it yield for \((\partial H/\partial P)_T \) for a gas that obeys the equation of state, \( P (V-nb) = nRT \), where \( b \) is a constant (independent of \( T \)) specific to the gas?

3. Hence, in the latter case what does it yield for the Joule-Thompson coefficient?