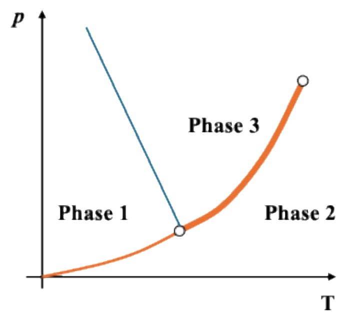
1. Suppose we have a pure substance in a liquid-vapor two-phase mixture regime with both its **temperature** and **pressure** determined. Which of the following statement is correct?
   A. We can determine its **specific volume**, but not its **specific entropy**
   B. We can determine its **specific entropy**, but not its **specific volume**
   C. We can determine **both** its **specific volume** and its **specific entropy**.
   D. We can determine **neither** its **specific volume nor** its **specific entropy**.
2. Which of the following statements related to the second law of thermodynamics is **NOT** correct?
   A. The entropy of a closed system can only go up or stay the same.
   B. A system's entropy production term can only be non-negative.
   C. With a single temperature reservoir, one **cannot** create a thermodynamic cycle that outputs work.
   D. One cannot construct a system with the sole result being net heat transfer from a cooler object to a hotter object
3. Suppose we have a closed system containing a fixed amount of ideal gas, which is NOT a perfect gas. When the system goes through an isothermal compression, increasing its pressure from $\boldsymbol{P_1}$ to $\boldsymbol{P_2}$, please provide an expression for the entropy change per unit mass $\boldsymbol{\Delta s}$ in the system, given the universal gas constant $\boldsymbol{\tilde{R}}$ and the molar mass of the gas $\boldsymbol{M}$.
   A. $\Delta s = 0$
   B. $\Delta s = \tilde{R} M \ln \frac{P_2}{P_1}$
   C. $\Delta s = \tilde{R}/M \ln \frac{P_1}{P_2}$
   D. Δs cannot be calculated without more information on the gas's specific heat
4. Which of the following statements describes a supercritical fluid?
   A. A substance at a temperature and pressure **both** below its critical point, exhibiting distinct liquid and gas phases.
   B. A substance at a temperature above its critical point temperature **or** at a pressure above its critical pressure, where liquid and gas phases are indistinguishable.
   C. A substance at a temperature and pressure **both** above its critical point, where liquid and gas phases are indistinguishable.
   D. A substance at its triple point, where solid, liquid, and gas phases coexist in equilibrium.

5. Given the p-T diagram for a certain substance shown here, which of the following statements is true when this substance experience phase transition from Phase 1 to Phase 3?



A. The specific volume decreases

B. The specific volume increases

C. The specific volume stays the same

D. The specific volume first increases and then decreases

6. When performing a control-volume analysis for an open system at a steady state, which of the following terms is NOT zero:

   A. Rate of change of the total volume of the system as a function of time

   B. Rate of change of the total entropy of the system as a function of time

   C. The mass passing through the inlets per unit time

   D. Rate of change of total entropy of the system as a function of time

7. Which one of the following groups only includes intensive properties:

   A. A system's mass and volume

   B. A system's temperature and pressure

   C. A system's enthalpy and entropy

   D. A system's internal energy and specific enthalpy

8. Consider a system that goes through a quasi-equilibrium process, in which the system's entropy stays constant. Which of the following statements about the system is correct?

   A. The entropy production in the system has to be zero during this process

   B. The internal energy change of the system has to be zero if this is an isobaric process

   C. The enthalpy change of the system has to be zero during this process if this is an isobaric process

   D. None of the above is true

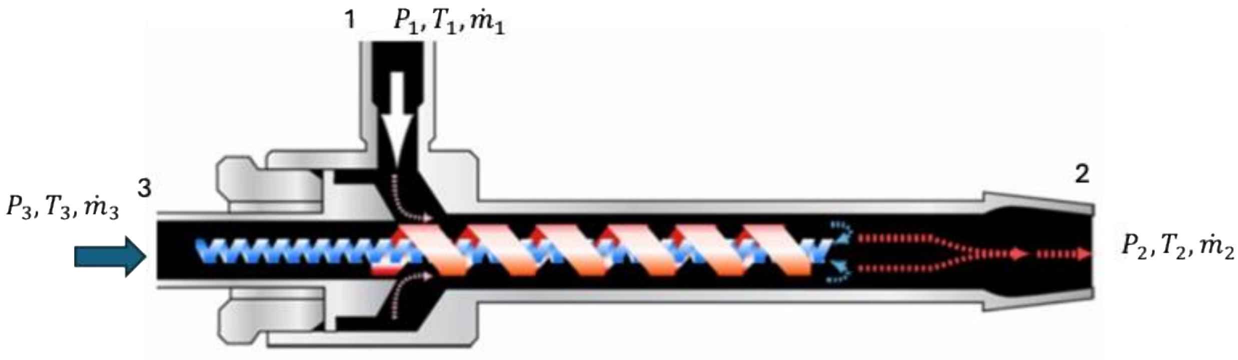
9. Consider a liquid pump with an inlet pressure of 100 kPa and outlet pressure of 300 kPa. The mass flow rate across this pump is constant at 1 g/s and we assume the liquid to be incompressible with a constant specific volume at 1 cm^3/g. Please calculate the power that you need to put into the system to operate this pump.
   A. 100 mW
   B. 200 mW
   C. 300 mW
   D. 0, because the liquid specific volume is assumed to be constant

Modeling Vortex Tube

A vortex tube requires no external work or heat input, yet able to produce hot and cold streams of air from a single stream of air at an intermediate temperature. Here, air is our working substance, modeled as a perfect gas with a constant-volume specific heat $c_{v,air} = 2.5\,R$, where R is the specific gas constant of air. Also, we know the universal gas constant $\tilde{R}$ = 8.314 kJ/(kmol·K) and the molar mass of air M_{air} = 29 kg/kmol. The vortex tube receives air at an inlet pressure of P_1 = 500 kPa and temperature T_1 = 20 °C. It separates the incoming air into two streams: a hot stream at an outlet pressure P_2 = 100 kPa and temperature T_2 = 50 °C, and a cold stream at an outlet pressure P_3 = 100 kPa and temperature T_3 = – 10 °C . The mass flow rate of the inlet air is $\dot{m}_1$ = 1 kg/s.

Assume the vortex tube operates at a steady state adiabatically and that changes in kinetic and potential energy are negligible.

a. Determine mass flow rates of the hot and the cold streams ($\dot{m}_2$ and $\dot{m}_3$) (**6 pts**)
b. Determine entropy production rate within the vortex tube, assuming an environment with temperature T_0 = 20 °C and pressure P_0 = 100 kPa (**4 pts**)
c. Replace the working substance with liquid water instead of air. Model liquid water as an incompressible fluid with constant-volume specific heat c_v = 4.18 kJ/(kg·K). If the conditions at the inlet and the outlets (P_1, T_1, P_2, T_2, P_3, T_3, and $\dot{m}_1$) are kept the same, determine whether the process within the vortex tube violates the 2$^{\text{nd}}$ law of thermodynamics with quantitative analysis. (You won't get any point by simply answering yes or no without quantitative explanation.) (**3 pts**)



Solution (with grading rubrics):

(a) Mass conservation:

$$\dot{m}_1 = \dot{m}_2 + \dot{m}_3 \qquad \text{(2 pts)}$$

Energy balance:

$$\dot{m}_1 h_1 = \dot{m}_2 h_2 + \dot{m}_3 h_3 \qquad \text{(2 pts)}$$

If one fails to recognize some negligible terms in the energy balance equation, he/she will not get the pts.

$$\Longrightarrow \dot{m}_2(h_2 - h_1) = \dot{m}_3(h_1 - h_3)$$

Perfect gas:

$$\Longrightarrow \dot{m}_2 c_p(T_2 - T_1) = \dot{m}_3 c_p(T_1 - T_3)$$

Plug in the numbers:

$$\dot{m}_2 = \dot{m}_3 = \frac{1}{2}\dot{m}_1 = 0.5 \text{ kg/s} \qquad \text{(2 pts)}$$

(b) 2nd law:

$$0 = \dot{m}_1 s_1 - \dot{m}_2 s_2 - \dot{m}_3 s_3 + \dot{\sigma} \qquad \text{(2 pts)}$$

$$\dot{\sigma} = \dot{m}_2(s_2 - s_1) + \dot{m}_3(s_3 - s_1)$$
$$= \dot{m}_2\left(c_p \ln\frac{T_2}{T_1} - R\ln\frac{P_2}{P_1}\right) + \dot{m}_3\left(c_p \ln\frac{T_3}{T_1} - R\ln\frac{P_3}{P_1}\right) \qquad \text{(1 pt)}$$

Correctly applying entropy difference for perfect gases give you one point.

Noting temperature needs to be Kelvin and $c_p = c_v + \tilde{R}/M$

$$\Longrightarrow \dot{\sigma} = 436.13\ \text{J}/(\text{K}\cdot\text{s}) \qquad \text{(1 pt)}$$

(c) Mass conservation:

$$\dot{m}_1 = \dot{m}_2 + \dot{m}_3$$

Energy balance:

$$\dot{m}_1 h_1 = \dot{m}_2 h_2 + \dot{m}_3 h_3$$

Incompressible fluid implies $c_v = c_p$

Since $v\Delta P \ll c_p \Delta T$ in this problem, we can ignore the enthalpy dependence on pressure

$$\Longrightarrow \dot{m}_2 c_v (T_2 - T_1) = \dot{m}_3 c_v (T_1 - T_3)$$

Plug in the numbers

$$\dot{m}_2 = \dot{m}_3 = \frac{1}{2}\dot{m}_1 = 0.5\ \text{kg/s} \qquad \text{(1 pt)}$$

2nd law:

$$\dot{\sigma} = \dot{m}_2 (s_2 - s_1) + \dot{m}_3 (s_3 - s_1)$$
$$= \dot{m}_2 c_v \ln\frac{T_2}{T_1} + \dot{m}_1 c_v \ln\frac{T_3}{T_1} \qquad \text{(1 pt)}$$

Plug in the numbers to recognize $\dot{\sigma} < 0$ and thus 2nd law is violated (1 pt). No point is given for directly stating $\dot{\sigma} < 0$ and the violation of 2nd law.