Problem 1. (10 pts) Water flows steadily upward through a long, straight vertical pipe with inner diameter $d = 4.09 \text{ cm}$. The volumetric flow rate is 200 liters per minute. You can assume that the pressure and internal energy of the water are uniform on cross-sections of the pipe. We are interested in two locations on the pipe: location 1, where the water pressure and temperature are $p_1$ and $T_1$, respectively, and location 2, which is 1 meter downstream of location 1, where the pressure and temperature are $p_2$ and $T_2$. Treat water as incompressible, with density $\rho = 999 \text{ kg/m}^3$ and specific heat $4.186 \text{ J/(g·°C)}$.

a) Suppose that there is no work done by or on the water, and no heat transfer to or from the water, between locations 1 and 2. If the pressure difference is $\Delta P = p_1 - p_2 = 1.25 \cdot 10^4 \text{ N/m}^2$, what’s $\Delta T = T_1 - T_2$?

b) Now, suppose again that there is no heat transfer between locations 1 and 2. However, there is a pump in the water flow that does work on the flow between locations 1 and 2. If $\Delta P = 9790 \text{ N/m}^2$ and $\Delta T = -0.0008 \degree \text{ C}$, what power is being supplied to the pump if the pump efficiency (defined in §8.7 in the text) is 30%?

Problem 2. (15 pts) The pipe flow system shown (it’s a top view, and all of the pipes are at the same elevation) is constructed of pipe with uniform composition and uniform inner diameter $d = 1.049 \text{ inches}$. Water at $70\degree \text{ F}$ flows into the system at section 1, flows through a length $L = 5 \text{ ft}$ of pipe, then splits into two paths at section 2. Water in the ‘upper’ path flows through $L_t = 30 \text{ ft}$ of pipe, and water in the ‘lower’ path flows through $L_l = 15 \text{ ft}$ of pipe, before the two paths rejoin at section 3. After that, the water flows through another $5 \text{ ft}$ section of pipe before it enters the atmosphere.

a) Suppose that the flow rate of the water is 0.5 gallons per minute, and that the upper path is blocked off, forcing the entire flow to go through the lower path. Verify that the flow is laminar under these conditions, by computing the Reynolds number based on the average flow velocity and the pipe diameter.

b) Ignoring minor head losses, the head loss for a laminar pipe flow through a pipe with length $L$ is given by

$$h_l = \frac{64 L \bar{V}^2}{Re D}$$

What upstream gage pressure, $p_1$, is necessary to drive the flow under these conditions?
c) Now suppose that the flow rate through the pipe system is still 0.5 gallons per minute, but that both the upper and lower paths are open. What’s the flow rate through the upper path, still ignoring minor head losses? (The text discusses the analysis of flow systems with multiple paths.)

**Problem 3.** (15 pts) Water flows from left to right through a pipe with diameter \( d = 1.3 \text{ cm} \). A mercury manometer measures the pressure difference between points on the pipe separated by \( L = 0.80 \text{ m} \).

![Manometer Diagram]

a) If the height of the mercury on the two sides of the manometer differs by \( h = 14 \text{ cm} \), and \( H = 40 \text{ cm} \), what’s the pressure difference in the pipe across the length \( L \)? Include the water in the manometer in your calculation.

b) Repeat a), but now assume that pressure doesn’t vary in the water in the manometer.

c) Using the result from b), what’s the volume flow rate, \( Q \) through the pipe if the pipe is made of galvanized iron?

d) Using the result from b) again, what’s \( Q \) if the pipe is made of drawn tubing?