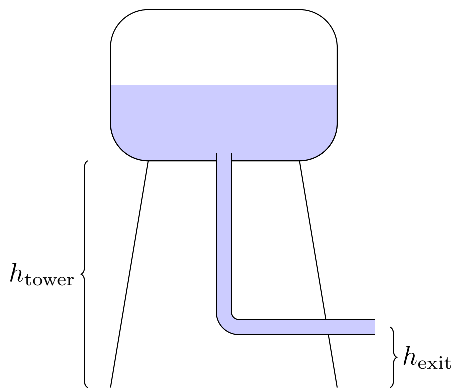
Model water tower

Jackson constructs a model of a water tower, connecting the bottom of the reservoir to a pipe that expels the water elsewhere. The water exits at a height (h_{exit}) that is smaller than the height of the tower (h_{tower}). The pressure at the bottom of the reservoir is fixed ($P_{\text{reservoir}}$), and is at least as large as atmospheric pressure. The pressure at the exit is atmospheric. The pipe has a constant area (A), and some resistance (R). Jackson can modify the model by changing the heights, the reservoir pressure, the area, and the resistance.



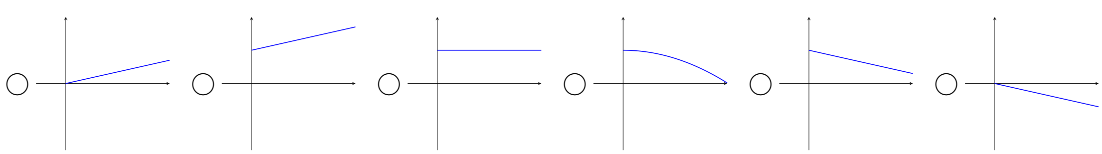
(a) Which of the following modifications would double the flow rate within the pipe?

○ doubling h_{tower} ○ halving h_{exit} ○ doubling $P_{\text{reservoir}}$ ○ halving A ○ halving R

(b) Which of the following modifications would increase the speed at which water exits the pipe?

☐ increasing h_{tower} ☐ increasing h_{exit} ☐ increasing $P_{\text{reservoir}}$ ☐ increasing A ☐ increasing R

(c) Suppose $P_{\text{reservoir}} = P_{\text{atm}}$. Which of the following is plots could depict the flow rate on the vertical axis plotted against the exit height on the horizontal axis, with all other parameters held fixed?



(d) With $P_{\text{reservoir}} = 2P_{\text{atm}}$, $h_{\text{tower}} = 2h_{\text{exit}} = 20$ m, $A = 1$ m^2, and $R = 10^6$ J$\cdot$s/m^6, determine the speed of the water.

$v =$ ☐ m/s

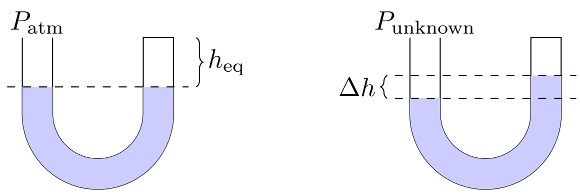
Energy Density Equation	Continuity Equation	Constants
$\Delta P + \frac{\Delta PE}{\text{vol.}} + \frac{\Delta KE}{\text{vol.}} = \frac{E_{\text{pump}}}{\text{vol.}} - \frac{\Delta E_{\text{th}}}{\text{vol.}}$ $\Delta P + \rho g \Delta h + \frac{1}{2}\rho\Delta(v^2) = E_{\text{pump}}/\text{vol.} - IR$	$I = Av$ $I_{\text{in}} = I_{\text{out}}$	$\rho_{\text{water}} = 1000$ kg/m^3 $g = 10$ m/s^2 $P_{\text{atm}} = 1$ atm $= 10^5$ Pa OR J/m^3 OR kg/(m$\cdot$s^2)

Unusual Barometer

An unusual barometer (i.e. device for measuring pressure) is constructed by having a U-shaped pipe that is open on the left end, and closed on the right end. On the open end, water is exposed to the pressure of the room it is in. On the closed end, some fixed amount of an ideal gas is stored at a constant temperature. Recall that the volume of an ideal gas is inversely proportional to pressure, e.g. doubling the pressure requires the volume to be halved.

The pipe has a constant area. The amount of water, and the amount of air in the closed side, is the same in the following scenarios:

- Scenario A: When the room is at atmospheric pressure, the water levels are equal, with h_{eq} being the height of the air column on the closed side.
- Scenario B: When the room is at some unknown pressure ($P_{unknown}$), a difference in the height of the water levels (Δh) is observed.



(a) What relationship does $P_{unknown}$ have with P_{atm}?

○ $P_{unknown} < P_{atm}$ ○ $P_{unknown} = P_{atm}$ ○ $P_{unknown} > P_{atm}$ ○ cannot be determined

(b) Suppose, starting with Scenario A, extra water is poured into the left side. Which of the following would be true when equilibrium is reached:

☐ The left water level is higher than before.

☐ The right water level is higher than before.

☐ The water level on the left still matches the water level on the right.

☐ The pressure of the air in the closed side is still atmospheric.

(c) With $h_{eq} = \Delta h = 1$ m, one may deduce that the volume of the air in the closed side of the pipe is twice as large in Scenario A as it is in Scenario B.
Use this information to determine $P_{unknown}$.

$P_{unknown} =$ ☐ $\times 10^5$ Pa

Energy Density Equation	Continuity Equation	Constants
$\Delta P + \frac{\Delta PE}{\text{vol.}} + \frac{\Delta KE}{\text{vol.}} = \frac{E_{pump}}{\text{vol.}} - \frac{\Delta E_{th}}{\text{vol.}}$	$I = Av$	$\rho_{water} = 1000$ kg/m^3
$\Delta P + \rho g \Delta h + \frac{1}{2}\rho\Delta(v^2) = E_{pump}/\text{vol.} - IR$	$I_{in} = I_{out}$	$g = 10$ m/s^2
		$P_{atm} = 1$ atm $= 10^5$ Pa OR J/m^3 OR kg/(m $\cdot$ s^2)