Practice problems for feedback, due to homework box by Sunday December 15 at 8 PM
Turning in your solutions by Thursday 10:30 AM will get you feedback by Friday afternoon!
Worth 1% of course credit for completeness and effort

These problems bring together multiple ideas from the course, particularly the material since the second midterm (fluids and thermodynamics). They are provided for you to practice solving problems in a test-like situation and receive feedback before the final exam. Please solve these problems by yourself (no books or talking to fellow students; feel free to use your page of notes if you have it prepared).

Take as much time as you like; the problems are designed so that you should be able to complete them in up to 45 minutes if you are well prepared. If you give these problems your best effort, it will give you the most useful feedback!

The last page gives equations and values of useful parameters such as the density and viscosity of water.

Problem 1.

(a) Adult male giraffes can reach a height of roughly 6 m. The minimum pressure of the blood[1] leaving the giraffe's heart is 1.24 atmospheres (124 kPa). Find an approximate value for the minimum blood pressure in the giraffe's brain when its neck is extended to its full height. You may infer information from the picture of a giraffe provided.

Please briefly explain the reasoning you used to find your answer, including how you decided which equations to use, as well any approximations you made. Also please show your work.

(b) In trees, water is carried from the roots to the leaves by the flow of sap (water with other kinds of molecules dissolved in it) through stiff tube-like structures, called xylem. Although sizes vary, a typical diameter would be 100 μm. In the main trunk of the tree, they extend close to the full height of the tree, which is commonly as great as 30 meters tall or taller (5 species of tree are known to reach 90 -110 m in height). These extremely narrow, long tubes, called xylem, contain a continuous column of water which can then flow into the leaves. The evaporation of water from the leaves (called transpiration) causes water to be steadily drawn into the leaves from the xylem. The structure of the leaves allows the pressure of water in the xylem to not necessarily be the same as the surrounding atmospheric pressure.

Consider a tree in which sap flows through each 100 μm-diameter xylem at a volume flow rate of 1.1×10^{-10} m^3/s (equal to 1.1×10^{-4} mL/s or 0.40 mL/hr), corresponding to an average flow speed of 0.014 m/s. (Given the huge number of xylem, the total flow for the entire tree is substantial!) If the pressure in the roots is equal to atmospheric pressure, what is the pressure at the top of a 30 m tall xylem in the trunk?

Please briefly explain the reasoning you used to find your answer, including how you decided which equations to use, as well any approximations you made. Also please show your work.

[1] Although blood is a mixture of water and various types of blood cells, the density of blood is very close to the density of water because the cells also consist mostly of water.

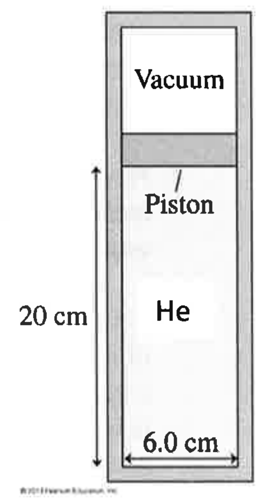
(c) You should have found different signs for your answers to (a) and (b). In this course, we have not discussed the possibility of negative values of pressure. A more in-depth study of pressure reveals that negative pressures can exist in cohesive substances such as liquids. Just as for positive pressures, a pressure difference across a surface corresponds to a force.

A critical difference between the fluid transport systems of trees and animals like giraffes is that blood vessels through which blood flows are made of a stretchy material, while the xylem through which sap flows are made of a very rigid material.

How do your results for (a) and (b) illustrate part of the reason why trees can grow much taller than land animals? ***Explain your answer using the ideas from this course and your physical intuition. Be as specific as you can be in your explanation.***

Problem 2.

A 6.0-cm-diameter cylinder of helium (He) gas has a 1 kg movable copper piston. The cylinder is oriented vertically, as shown, and the air above the piston is evacuated. When the gas temperature is 20^0C, the piston floats 20 cm above the bottom of the cylinder.



In answering the following questions, be sure to ***explain your reasoning***, and ***explain why you choose to use the equations that you use.***

a) What is the gas pressure?
b) How many moles of gas are in the cylinder?

Then 2.0 J of heat energy are transferred to the gas.

c) What is the new equilibrium temperature of the gas?

Properties of water (at 20°C)

Density: $\rho_{water} = 997\ \text{kg/m}^3$

Viscosity: $\mu_{water} = 1.005 \times 10^{-3}\ \text{Pa} \bullet \text{s}$

Units and constants:

$1\ \text{N} = 1\ \text{kg/m} \bullet \text{s}^2$

$1\ \text{Pa} = 1\ \text{N/m}^2$

$1\ \text{L} = 1 \times 10^{-3}\ \text{m}^3$

$T_K = T_C + 273$

Atomic mass unit: $1\ \text{u} = 1.66 \times 10^{-27}\ \text{kg}$

$g = 9.80\ \text{m/s}^2$

$p_{atmos} = 1.00\ \text{atm} = 1.013 \times 10^5\ \text{Pa} = 101.3\ \text{kPa}$

$R = 8.31\ \text{J/mol K}$

$k_B = 1.38 \times 10^{-23}\ \text{J/K}$

$N_A = 6.023 \times 10^{23}$ per mole

Force of gravity near Earth's surface: $F = mg$

Density, pressure, and hydrostatics:

$$\rho = \frac{m}{V} \qquad F = pA \qquad p_2 = p_1 + \rho g \Delta d$$

Fluid dynamics:

Continuity: $$Q_{volume} = \frac{d(\text{volume})}{dt} = vA$$

Bernoulli: $$p_1 + \rho g y_1 + \frac{1}{2}\rho v_1^2 = p_2 + \rho g y_2 + \frac{1}{2}\rho v_2^2$$

Hagen-Poiseuille: $$Q = \frac{\Delta p}{\ell}\frac{\pi R^4}{8\mu}; \quad v_{avg} = \frac{\Delta p}{\ell}\frac{R^2}{8\mu}$$

First law of thermodynamics: $\Delta E_{th} = W + Q$

Specific heat and calorimetry: $Q = Mc\Delta T = nC\Delta T$

Ideal gas properties:

$$pV = Nk_BT \text{ and } pV = nRT$$

$$\varepsilon_{avg} = \frac{1}{2}m_{atom}v_{rms}^2 = \frac{3}{2}k_BT$$

$$K_{micro} = \frac{3}{2}pV = \frac{3}{2}Nk_BT$$

$$C_P = C_V + R$$

For a monatomic ideal gas, $E_{th} = K_{micro}$ and $C_V = \frac{3}{2}R$

Work done in ideal gas process $$W = \int_{V_i}^{V_f} p\,dV$$