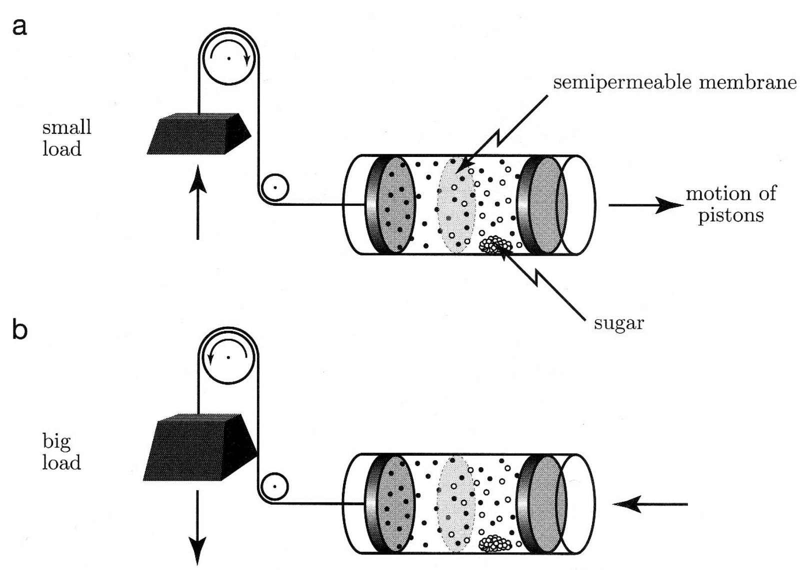
HW 1 (due September 5, 2019)

(1) Thermodynamics of *free energy* conversion **(20 pts)**

The thermodynamical machine depicted below is a transducer of *free energy*. As discussed in class (and described in more deteil in ch. 1.2 of the *Nelson* text), the device consists of a cylinder filled with an incompressible solution, separated into two chambers by a semipermeable membrane that is fixed at the cylinder walls. Osmosis may occur, as the membrane is permeable to water (solid dots) but not the solute (open circles). Two pistons slide freely, allowing the volumes of both chambers to adjust by exchanging water across the membrane. Total volume, and hence the distance between the two pistons, remains constant during the exchange. The cylinder is in thermal contact with its environment, which fixes its temperature at T to that of the surrounding reservoir. The initial energy of the system (load at a certain height, h) is E_0. The entropy S is mainly determined by the state of the solute molecules in solution (high concentration – low entropy, and vice versa), and is particularly low in a crystal at the bottom of the cylinder.



a) Define the free energy F in terms of E, T and S.
b) In situation **a**, sugar is introduced in crystalline form on the bottom of one chamber. Its dissolution into the water increases S and consumes heat, Q. As a result, the load is lifted and potential energy is gained.
– Describe in your own words the thermodynamic changes that occur in the system.
– Where does the energy come from that is converted into mechanical work, W?
– Write down an energy balance that compares the initial and final states of the process.
c) If we put a heavy load on the hoist (situation **b**), the process reverses direction. – Describe what happens now in terms of thermodynamics. Why is this process (a.k.a. *reverse osmosis*, and used on the industrial scale for, among others, water purification) a paradigm for the creation of order in biology?

(2) Energy units in biology **(10 pts)**

In molecular biophysics, energy is often expressed in units of $k_B T$, which is – for example – the energy per molecule in an ideal gas. k_B is Boltzmann's constant, 1.38×10^{-23} J/K. At room temperature ($T_r = 298$ K), this energy is therefore,

$$\boxed{k_B T_r \approx 4.1 \cdot 10^{-21}\ \text{J} = 4.1\ \text{pN nm.}}$$

a) Discuss briefly whether a process such as the excitation of a vibrational state, which requires energy input of smaller than or comparable to $k_B T_r$, is likely or unlikely in the context of a biological system.
b) Verify the above identity by putting in numbers and explain why the latter units might be preferable to SI units (joules) in the description of biophysical processes.
c) Express $k_B T_r$ in units of eV (electron-volts) and of kcal/mol (remember: the electron charge is $e = 1.6 \cdot 10^{-19}$ C).