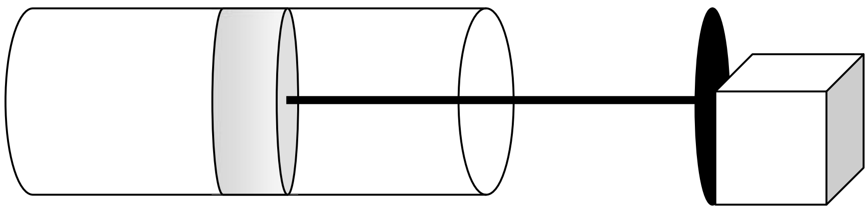
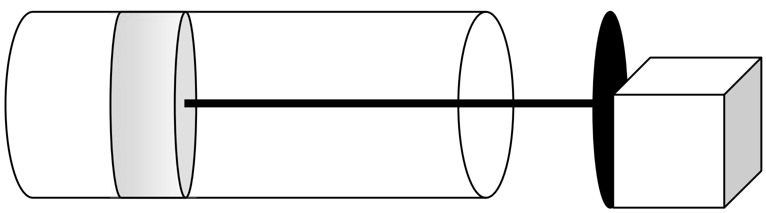
What is "Free" about Free Energy?

Part 1.

Consider two pistons each containing an *equal amount of ideal gas* and each in *thermal equilibrium with the same environment*. The gas in Piston A is compressed to a volume $V/2$, and the gas in Piston B is compressed to a volume $V/4$. The pistons are *held in place until the moment of release*, at which point each is allowed to push on two identical blocks positioned next to it as shown:



Piston A Block A



Piston B Block B

1. After the pistons are released, describe the motion of Block A and Block B. Which moves further?

2. If the Figure above represents the "before" state, draw a similar picture showing the state "after" the pistons have been released and the blocks have finished traveling.

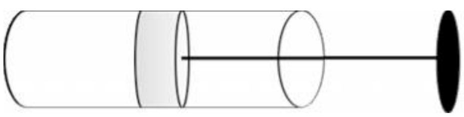
3. Before the pistons are released, how does the energy of the gas in Piston A compare to the energy of the gas in Piston B? How do you know? (*Hint: recall that* $U = C_V kT$ *for an ideal gas, where* C_V *is the heat capacity at constant volume and k is Boltzmann's constant.*) What type of energy is it?

4. Compare your answers to Questions 1 and 3 above. Are they consistent or not? Discuss with your group!

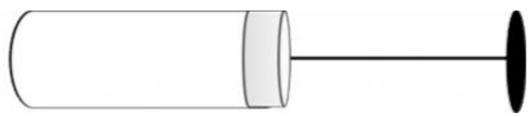
Part 2.

Now let's think about what happens to the entropy and free energy of the gas during the expansion process described in Part 1. For clarity, let's focus in on just the gas in the piston and ignore the block for now. Assume that the expansion happens very quickly upon release of the piston, as would be the case with a lightweight, frictionless piston (this scenario may remind you of the clicker questions from class in which a partition was removed between the two sides of a container of gas). The piston in both the before and after states is in thermal equilibrium with the same environment.

Piston A (before)



Piston A (after)



1. How does the **energy *U*** of the gas after the expansion compare to the energy of the gas before the piston is released? How do you know?

2. How does the **entropy *S*** of the gas after the expansion compare to the entropy of the gas before the piston is released? Explain your answer in terms of:
    a) Microstates
    b) Energy spreading

3. How does the **free energy *G*** of the gas after the expansion compare to the free energy of the gas before the piston is released? How do you know? (Hint: recall that $H = U + PV$ and $G = H - TS$)

Part 3.

Now let's put together the pieces of the story.

1. In Question 3 of Part 1, you related the energy of the gas in Piston A to the energy of the gas in Piston B before the release of the piston. Now use your result from Question 3 of Part 2 to relate the <u>*free*</u> energy of the gas in Piston A to the <u>*free*</u> energy of the gas in Piston B before the release of the piston.

2. Considering the effects that the Pistons had on their respective blocks, which of the following is true?
    a) "Energy is the capacity of a system to perform mechanical work"
    b) "Free energy is the capacity of a system to perform mechanical work"

3. Describe the role that entropy plays in relating energy to free energy.

4. What might be an appropriate term for energy that is not free energy?

5. What role does *pressure* or *pressure gradient* play in the scenario described in Part 1? For this example, could you come up with an operational definition of free energy in terms of pressure gradients? (Hint: An operational definition is one that states specifically what steps to take in order to obtain a numerical value for the quantity.)