Exam 3; Phys 185 Name ________________

Note: As I walk around, you can ask me for help; for example, to supply an equation or a number you have forgotten down, or to give you algebra aid. If you do, however, I will write down what help I provided on your exam, and grade your answer accordingly. It costs nothing to have me check and tell you if your answer on a question is correct or not.

1. (40 points) You have a hook fixed to the wall by a suction cup, on which you hang a towel of mass m. The radius of the suction cup is r. When you attach it to the wall, you push out the air between the wall and cup, and when it slightly expands again, the pressure inside the cup is $0.1p_{\text{atm}}$, and the outside pressure is p_{atm}. The coefficient of kinetic friction between the wall and the suction cup is μ_k, and and the coefficient of static friction is μ_s.

(a) Find an equation for the *maximum* mass m_{max} that can be hung on your hook.

(b) Choose reasonable values for any variables you need and calculate m_{max}.

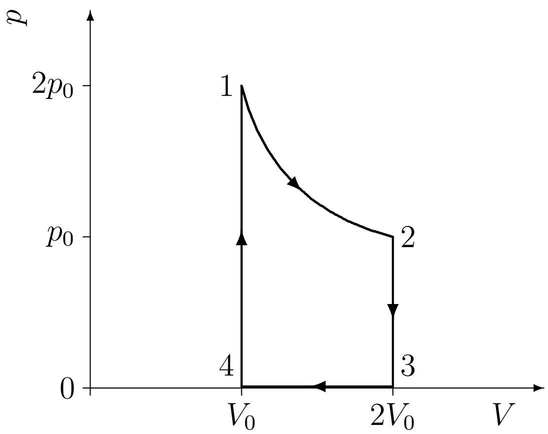
2. (40 points) The most general equation for gravitational potential energy for two masses with separation r between their centers of mass is $U = -Gm_1m_2/r$. Note that U is negative, and that as r becomes very large, U approaches zero.

(a) If the total energy, $E = K + U$, of two gravitationally interacting objects is negative, they are *bound*: they will be in orbit around a common center of mass. But if $E \geq 0$, they are *unbound*: the separation between them can become arbitrarily large. Explain why this is so. *Hint 1:* Can K be negative? *Hint 2:* Look at very large r.

(b) Using the astronomical data in your book, calculate the total energy for the Sun-Earth system and the Sun-Jupiter system. (Add the planets' kinetic energies due to their rotation around the Sun and their potential energies due to their distance from the Sun.) Do your results make sense in light of part (a)?

3. (40 points) It's physically impossible to have a cold reservoir at absolute zero, but let's see what would happen if such a thing were available.

You have a monatomic ideal gas that goes through the cycle $1 \to 2 \to 3 \to 4 \to 1$ shown in the diagram. No gas molecules are added or removed during the cycle.



Find everything (W, ΔE, Q) in terms of p_0 and V_0.

(a) The $1 \to 2$ part of the cycle takes place at *constant temperature*, so $T_1 = T_2$. The area under a constant temperature curve with temperature T on the p-V diagram, going from from an initial V_i to a final V_f, is

$$nRT \ln\left(\frac{V_f}{V_i}\right)$$

Find the work done by the gas for each step of this cycle: $W_{1\to2}$, $W_{2\to3}$, $W_{3\to4}$, $W_{4\to1}$.

(b) Find the change in thermal energy for each step: $\Delta E_{1\to2}$, $\Delta E_{2\to3}$, $\Delta E_{3\to4}$, $\Delta E_{4\to1}$.

(c) Find the heat added to the gas for each step of this cycle: $Q_{1\to2}$, $Q_{2\to3}$, $Q_{3\to4}$, $Q_{4\to1}$.

(d) Find the total heat input to this gas in one cycle, Q_{in}. Also find the total heat removed from the gas, Q_{out}, and the total work done, W.

(e) What is the efficiency of this heat engine? (Your result should be a number.)

4. (40 points) If you look up how convection works, you will find $Q/\Delta t = hA\Delta T$, where A is the surface area of an object, and h is a convection coefficient that depends on the material and its geometric shape. You know how conduction and radiation works.

(a) You have two cubes made of identical materials, in identical environments, at identical starting temperatures. Cube 1 has a side of length a, cube 2 has $2a$. Find the ratio of the rates at which each cube cools:

$$\frac{\left(\frac{\Delta T_1}{\Delta t}\right)}{\left(\frac{\Delta T_2}{\Delta t}\right)}$$

Note: ΔT refers to the temperature difference with the environment. ΔT_1 and ΔT_2 are *different*—they refer to the change in temperature over time of cubes 1 and 2.

Hint: Your final result should be a number, with no symbols. Cancel things!

(b) Use this to predict whether in cold climates, small or large animals will have proportionally thicker coats, and area-reducing adaptations such as smaller external ears. Explain.

5. (40 points) A plastic tub has a square base with sides a and thickness $0.100a$. Its four walls have a height of $0.900a$ and thickness $0.100a$. The plastic has density $\rho_p = 2.00\rho_w$, where ρ_w is the density of water. You set the tub to float in water. h, the distance from the bottom of the tub to the waterline, will be related to a like $h = ca$, where c is a number. Find c.

Hint: You have to be careful calculating the volume of the tub. Be sure to ask me to check whether you have that right.