

H133: 1094 Session 7

KEY

Write your name and answers on this sheet and hand it in at the end.

After the indicated time, move on to the next activity, even if you are not finished!

1. T3 Group Warm-Up Problems [10 minutes]

a. Do T3T.1, putting your answers below. This is work vs. heat, as in class. $W \rightarrow F$ $Q \rightarrow T$

a. F

b. F

c. F

d. T (temperature difference with sun) e. F (evaporation is not from temperature difference)

b. Do Exercise T3X.2 without looking at the answer first. This is about thermodynamic work (W) versus center-of-mass work ("k-work"). The distinction is explained at the top of pg. 42. The key is that thermodynamic work is any energy flowing across the boundary of your system; it doesn't have to move the center of mass, but changes the system's thermal energy. When you've agreed on answers, check them on pg. T3X.2 and discuss any you got wrong.

a. K

b. W

c. W

d. K

e. W

f. W

c. Do T3T.2. Positive work means it flows in. Your basic definition is Equation (T3.6). Explain your answers. $\Delta W = -P\Delta V$. $P = 100 \times 10^3 \text{ Pa}$, $\Delta V = (10^{-3} \text{ m}) \times (10 \times 10^{-2} \text{ m})^2 = -10^{-5} \text{ m}^3$

So $\Delta W > 0$ (work flows into the gas since you are compressing it) A

$$\Rightarrow -P\Delta V = 1 \text{ J}$$

D

2. Gas Properties PhET Simulation [15 minutes]

Start up the PhET applet "Gas Properties" from the H133 webpage (under "Heat and Thermo"). By operating the pump, you add molecules of a gas to the box, which settles down to a pressure and temperature (but fluctuates noticeably because of the small number of molecules). You can change the volume of the box (by moving the little figure), add or remove heat, and let molecules escape.

a. Pump enough times so that there are over 100 molecules. Assume that it is an ideal gas and make some measurements to calculate the volume of the box. Show your work.

Initially, $N=150$, $P=0.78 \times 101.3 \times 10^3 \text{ Pa}$, $T=300 \text{ K}$
 ideal gas $\Rightarrow V = \frac{Nk_B T}{P} = \frac{150 \times 1.38 \times 10^{-23} \text{ J/K} \cdot 300}{0.78 \times 101.3 \times 10^3 \text{ Pa}} = 7.9 \times 10^{-24} \text{ m}^3$ (or 7900 nm^3). Small box!

b. Now add heat and/or molecules and recalculate the volume. Is it really (approximately) an ideal gas?

Now $N \rightarrow 300$, $P \rightarrow 1.52 \text{ atm}$, $T \rightarrow 297 \Rightarrow V = 8.0 \times 10^{-24} \text{ m}^3 \Rightarrow$ pretty ideal.
 Add heat: $T=413$, $P=2.10 \text{ atm} \Rightarrow V = 8.0 \times 10^{-24} \text{ m}^3 \checkmark$

and decrease the volume rapidly. Discuss the difference.

Both the pressure and temperature increase. It seems that the box is isolated, so we expect this to be an adiabatic process. This would imply $T \propto V^{-\gamma}$ and $P \propto V^{-\gamma-1}$ (see T3.6). This is roughly consistent with observed numbers for a monatomic gas. A rapid change is not quasistatic, so is not in equilibrium during the compression. It follows the top of the curve.

- d. Let the top off the box for a few seconds, letting some molecules escape. What happens to the temperature? Explain in terms of the relationship between T and the average kinetic energy (as observed by the speed of the remaining molecules). So why does evaporation cause cooling?

The temperature drops significantly. It's clear that faster moving molecules are more likely to escape, so $\langle v^2 \rangle_{avg}$ decreases. Since $\frac{1}{2}m\langle v^2 \rangle_{avg} = \frac{3}{2}k_B T$, the temperature goes down \Rightarrow this evaporation force leads to cooling.

- e. Turn on gravity halfway on the scale. Is what you observe qualitatively consistent with the result of T2A.1 (from class). [The "Layer Tool" option may be helpful.]

Initially, the pressure is the same throughout the box. With gravity on, there is a pronounced preference for the lower regions, consistent with $P(z) = P_0 e^{-mgz/k_B T}$ [with $z=0$ at the bottom of the box and $P_0 = P(z=0)$].

3. T3 Two-Minute Drill [15 minutes]

Be careful about the sign of the work (see above) and about which direction the process is running. The processes are defined on pp. 45-46. Look at Example T3.1 first to see how to decide on the signs. Explain your answers *briefly*.

- a. T3T.3 C The pressure is constant, so isobaric.

- b. T3T.4 C Isothermal $\Rightarrow T$ constant so $\Delta U = 0$. $V \uparrow$ means $-PdV < 0$ so $W < 0$. Since $\Delta U = Q + W$, must have $Q > 0$.

- c. T3T.5 F (-, +, -) $PV = Nk_B T$ so $V \downarrow$ means $T \downarrow \Rightarrow \Delta U < 0$. $-PdV > 0$, so $W > 0$ (since $dV < 0$). So $Q < 0$ from $\Delta U = Q + W$.

- d. T3T.6 B adiabatic $\Rightarrow Q = 0$. $W = -PdV > 0$ (since $dV < 0$). So $\Delta U > 0$ from $\Delta U = Q + W$.

- e. T3T.7 A, D $-PdV > 0$, so positive work in, $\Delta V \sim -0.03 \text{ m}^3$, $P = 20 \times 10^3 \text{ Pa}$
 $\Rightarrow W = 600 \text{ J}$.

4. StatMech Program [10 Minutes]

Start up the StatMech program from the Start Menu under H133. The program is described in chapter T4. We are simulating a solid using the Einstein model, which is pictured in Figure T4.1: atoms connected by springs. We think of each atom as being in three one-dimensional oscillators (one for each direction), with energies given by integers times $\hbar\omega$ (measuring with respect to absolute zero; what does this do?). To find the total energy, specify the integers for each atom. Let N be the number of atoms and U the total internal energy.

- a. Do T4X.6, then look at the answer and correct if wrong.

As the systems get larger, the total number of microstates grows rapidly. The even division of energy is always most probable, and the spread about this distribution becomes narrower as the system gets larger.

- b. Do T4B.5. Use equation (T4.7) then check with StatMech. [Set A to have 5 atoms and set total $U=15$, then look for $U(A)=15$ and $U(B)=0$.]

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