Physics 9, Fall 2018, Homework #9.

Due at start of class on Friday, November 16, 2018

Problems marked with (*) must include your own drawing or graph representing the problem and at least one complete sentence describing your reasoning.

Heat/atoms problems

1. $\boxed{\text{(a)}}$ How much energy is needed to raise 1.00 kg of liquid water from 22.0°C to 99.9°C? $\boxed{\text{(b)}}$ How much energy is needed to evaporate 1.00 kg of liquid water (at 100°C) into steam (at 100°C)? Be careful not to confuse J with kJ. $\boxed{\text{(c)}}$ Is the relative size of these two numbers consistent with everyday experience that it takes much longer (e.g. maybe an hour or so) to boil away an entire pot of water than it does (e.g. maybe 10 minutes) to heat the water up from room temperature to boiling temperature?

2. If a scuba diver fills her lungs to full capacity (4.5 L) when she is 12.0 m below the surface, to what volume would her lungs expand if she quickly rose to the surface without exhaling? Is this a good idea? (To keep things simple, use the density of ordinary water, not of salt water.)

3. Four particles have the following velocities, written in the form $\vec{v} = (v_x, v_y, v_z)$:

$$\vec{v}_1 = (-6.0, 5.0, 1.0)\,\text{m/s}, \qquad \vec{v}_2 = (4.0, 5.0, -2.0)\,\text{m/s},$$

$$\vec{v}_3 = (7.0, 0.0, 8.0)\,\text{m/s}, \qquad \vec{v}_4 = (-4.0, 9.0, -6.0)\,\text{m/s}.$$

$\boxed{\text{(a)}}$ What is the average velocity of the four particles? (The answer is a 3-dimensional vector.) $\boxed{\text{(b)}}$ What is the speed v of each of the four particles? (Remember that speed, a scalar, is the magnitude of the velocity vector.) $\boxed{\text{(c)}}$ What is the average speed of the four particles? $\boxed{\text{(d)}}$ What is the squared speed v^2 of each of the four particles? $\boxed{\text{(e)}}$ What is the average v^2 for the four particles? $\boxed{\text{(f)}}$ What is the root-mean-squared speed of the four particles?

4. I stop at my favorite bagel shop for a bagel with cream cheese (yum!), whose energy content is 350 food Calories. If my body converts chemical energy into mechanical energy with 20% efficiency, how many flights of stairs do I need to climb in order to burn off these 350 Cal? (Take one storey to be 3 m tall.) Remember that 1 Cal = 1000 cal. Assume that my mass is 65 kg.

5. A basement sometimes contains a dehumidifier to prevent mold from growing. If an 8.0 m × 8.0 m × 2.5 m basement is kept at 20°C, what volume of liquid water must

be removed from it to drop the relative humidity from 90% to 40%? (From table 13-3, the saturated vapor pressure of water at 20°C is $2.33 \times 10^3\,\mathrm{N/m^2}$. You can figure out the mass of the removed water vapor, and then convert that to volume of liquid water that shows up in the output of the dehumidifier.)

6. You drop a 25 gram ice cube ($T = -15°\mathrm{C}$) into a 300 mL cup of hot ($T = 85°\mathrm{C}$) tea. Once the ice cube has melted and mixed with the tea, what is the final temperature of the tea? (Assume that the cup is well insulated and that the cup itself has negligible heat capacity.) Remember to consider the heat capacity of the unmelted ice cube, the latent heat of the melting ice, and the heat capacity of the liquid water.

7. How long does it take the sun to melt a sheet of ice at 0°C with a flat horizontal area of $1.0\,\mathrm{m^2}$ and thickness 0.2 cm? Assume that the sun's rays make an angle of 35° with the vertical and that the emissivity of ice is 0.40. Also assume that the intensity reaching Earth's surface for "direct rays" from the sun is $1000\,\mathrm{W/m^2}$; you multiply this intensity by area $\times \cos\theta$ to get the solar power incident on a surface whose surface normal makes an angle θ w.r.t. the direct rays, and then you multiply that by the emissivity to get the absorbed solar power.

8. An ideal Carnot heat pump must deliver thermal energy to your house at a rate of 12.0 kW to keep it at 20°C. This pump uses the outside air at −5°C as its low-temperature reservoir and runs off of electricity that costs 14.0 cents per kilowatt-hour. $\boxed{\text{(a)}}$ What is the COP of an ideal Carnot heat pump operating with $T_{\mathrm{cold}} = -5°\mathrm{C}$ and $T_{\mathrm{hot}} = +20°\mathrm{C}$? (An ideal Carnot heat pump doesn't exist, but it sets an upper bound on what is theoretically possible.) $\boxed{\text{(b)}}$ How much electrical power does the heat pump consume to supply the necessary 12.0 kW of thermal power? $\boxed{\text{(c)}}$ How much does it cost to keep your house at 20°C from 8 pm to 8 am?

Note: Remember that the definition of COP(heating) for any heat pump is $\mathrm{COP}_{\mathrm{heating}} = Q_{\mathrm{output}}/W_{\mathrm{input}}$, where Q_{output} is the heat transferred **to** the (warm) living space, while W_{input} is the work done **on** the heat pump (e.g. to run its electric motor). In the ideal Carnot case, $\mathrm{COP}_{\mathrm{heating}} = T_{\mathrm{hot}}/(T_{\mathrm{hot}} - T_{\mathrm{cold}})$, with all temperatures measured in kelvin.

9. A certain walk-in freezer requires an average of 2300 W of thermal power to be removed from it to maintain a temperature of −5°C on a hot day in July, when the ambient temperature is 31°C. $\boxed{\text{(a)}}$ What is the *coefficient of performance of cooling,* for the freezer, assuming an ideal (Carnot) heat pump? $\boxed{\text{(b)}}$ What would be the new COP if the freezer were installed in the basement, where the air temperature is 19°C? $\boxed{\text{(c)}}$ How much electrical power does the freezer use (for 2300 W of cooling) when installed in each of the two locations? In the U.S., one often quotes the Energy Efficiency Ratio (EER) instead of the Coefficient of Performance (COP). Whereas a

COP measures both Q and W in joules (or power in watts, equivalently), an EER measures Q in British Thermal Units (BTU) and W in watt-hours. Thus, a COP of 1.0 equals an EER of 3.412. $\boxed{\text{(d)}}$ What are the EER values corresponding to the COP values you wrote in parts a and b?

Note: Remember that COP(cooling) for any refrigerator or air conditioner is defined as $\mathrm{COP}_{\mathrm{cooling}} = Q_{\mathrm{input}}/W_{\mathrm{input}}$, where Q_{input} is the heat removed from the (cold) refrigerated space, while W_{input} is the work done ON the refrigerator (e.g. to run its electric motor). In the ideal Carnot case (which sets an upper limit on what can be achieved in real life), $\mathrm{COP}_{\mathrm{cooling}} = T_{\mathrm{cold}}/(T_{\mathrm{hot}} - T_{\mathrm{cold}})$, with all temperatures measured in kelvin.

10. Suppose that a heat pump used to heat a home operates on an ideal Carnot cycle and runs off of electricity. The low-temperature reservoir consists of a pipe driven 10 m into the ground, where the temperature remains a constant 12°C all year round. The high-temperature reservoir is the interior of the house, kept at 22°C.
$\boxed{\text{(a)}}$ For every 1.0 J of electrical energy used to run the heat pump, how many joules of thermal energy are delivered to the house?
$\boxed{\text{(b)}}$ Suppose you did not want to spend the extra money to drive the pipe into the ground, but instead decided just to use the outside air at −10°C (you live in a cold climate) as your low-temperature reservoir. Now how many joules of interior energy would 1.0 J of electrical energy provide? Does it seem to be worth the added expense of putting the pipe in the ground?
$\boxed{\text{(c)}}$ What is the coefficient of performance of the heat pump for each case above?
$\boxed{\text{(d)}}$ If you just use an electric heater (works on the same principle as a toaster: $Q_{\mathrm{output}} = W_{\mathrm{input}}$) instead of a heat pump, how many joules of thermal energy are delivered to the house for every 1.0 J of electrical energy used to run the heater? When you compare part (a) with part (d), do you see why so-called "ground-source" heat pumps have been called "the most energy-efficient, environmentally clean, and cost-effective space conditioning systems available?" The main drawback is the large expense of digging up the back yard to install the underground heat-exchanger loop.

`http://en.wikipedia.org/wiki/Geothermal_heat_pump`
`http://energy.gov/energysaver/articles/geothermal-heat-pumps`

Remember **online response** at `positron.hep.upenn.edu/wja/jitt/?date=2018-11-16`