Physics 123 section 2 CID ___________

Homework 3

Score ________ / 30

1. (3 pts) (a) What does it mean for two objects to be in thermal equilibrium? (b) Explain how two objects at the opposite side of the galaxy could be in thermal equilibrium.

2. (4 pts) Imagine that I invent a new temperature scale using a constant-volume gas thermometer. Let's call it the Durfee scale. On my scale I define 0°D to be the melting point of lead and 100°D to be the boiling point of lead. Now imagine that I put a container filled with gas in thermal contact with lead at its melting point and measure a gas pressure of 5.73×10^5 Pa. Then I put it in contact with lead at its boiling point and measure a pressure of 1.93×10^6 Pa. How many degrees Durfee is absolute zero?

3. (3 pts) Your best friend read somewhere that the temperature at the core of the sun is thought to be about 1.5×10^7 Kelvin. He wants to know what that would be in Celsius. What would you tell him? Why?

4. (5 pts) I cut a round hole with a diameter of 10 cm in a piece of aluminum (at 300 K). I then cut out a circle of copper which is 10.0001 cm in diameter (also at 300K). (a) By how many degrees C would I need to heat up the aluminum in order to get the copper piece to fit into the hole? (b) How many degrees C would I need to cool down the copper in order to get it to fit in the hole? (c) If I start with both pieces at room temperature and then turn up the thermostat and heat up the room and everything in it, including the both pieces of metal, how much do I need to heat up the room to get the copper to fit in the hole in the aluminum?

5. (6 pts) If I push on an object from all sides, it will compress a little bit. The amount it will compress by is given by the bulk modulus B. If it takes a pressure increase of ΔP to reduce the volume of an object from V to $V + \Delta V$ (where ΔV is negative because the object is getting smaller), the bulk modulus is defined as

$$B = -\frac{\Delta P}{\Delta V / V}.$$

Imagine that I make a copper sphere and embed it in a block of some super material which has an extremely high bulk modulus and a linear thermal expansion coefficient of $1.1 \times 10^{-5}\,{}^\circ\mathrm{C}^{-1}$. Assume that the sphere is in contact with the block at all points on its surface. Assume that the sphere is a perfect fit for the cavity in the block — it's a really snug fit, but the copper is not being compressed by the block. I then heat the block and the copper sphere inside of it by 20°C. With what pressure will the copper push on the block? The linear thermal expansion coefficient for copper is $1.7 \times 10^{-5}\,{}^\circ\mathrm{C}^{-1}$ and the bulk modulus of copper is 1.4×10^9 N/m^2.

6. (4 pts) (a) The specifications on a particular scuba diving air tank says that it should be filled to a pressure of 4350 psi (= 295.9 atmospheres). It also claims that the volume of air that it holds is 105.2 cubic feet, but what they really mean is that the air that it holds at 4350 psi, if expanded at the same temperature until it was at atmospheric pressure, would fill 105.2 cubic feet. What is the actual volume of the tank (in cubic feet)? (b) If the average mass of the molecules in the air is 4.81×10^{-26}kg, how much does the mass of the tank change when it is pressurized from 1 atmosphere to 295.9 atmospheres at 25 °C?

7. (3 pts) Consider a helium balloon. The gas in the balloon is always at a pressure which is just barely above the ambient pressure — the rubber isn't very strong, so it can't hold the gas if its pressure is much more than the pressure of the air around it. Imagine that I have a spherical balloon which is 10 cm in diameter. I let it go on a day when the temperature of the air is 300 K. It floats way up into the air to a point where the pressure of the atmosphere is 2/3 of what it is on the surface of the Earth. At this location the temperature of the air is just 270 K. Assuming that the air in the balloon is always at the same pressure and temperature as the surrounding air, what is the diameter of the balloon when it is at this altitude (assuming it hasn't popped).

Where did the equation for thermal expansion come from anyway? Remember, we didn't "derive" it in class, but we argued that it must be true for small temperature changes. So in the next problem we'll make sure you really understand the logic we used.

8. (2 pts) The number of molecules of oxygen N dissolved in a glass of water depends on the volume of water V in the glass. For example, if I had twice as much water, this is equivalent to having two glasses of water, so I would expect to have twice as many oxygen molecules dissolved in the glass. The number also depends linearly on the pressure of the air P around the water. If I double the pressure, I double the amount of oxygen dissolved in the water. The number also depends on temperature, but in a more complicated way. Using the same logic we used to come up with the equation for thermal expansion, write down an equation for the change in the number of dissolved molecules, ΔN, as the temperature changes by a small amount ΔT. This equation should be a function of V, P, ΔT, and an "experimentally determined" constant ξ.

Extra problems I recommend you work (not to be turned in)

- Imagine now that a copper ball with a diameter of 1 cm is embedded in a block of steel such that there is no gap between them. The steel ball is embedded in a block of something with a really high bulk modulus and a really low thermal expansion coefficient. I then heat the block up by 20°C. If the bulk modulus of steel is $6 \times 10^{10}\mathrm{N/m^2}$ and the bulk modulus of copper is $14 \times 10^{10}\mathrm{N/m^2}$, how much will the volume of the ball change by?
- Sometimes parts are assembled and held together by making one part a little too big to fit into the hole of the other part, and then heating or cooling one of the parts and sliding them together. They then come into equilibrium and bind tightly. Imagine that you want to drill a hole in a copper plate and then use this technique to bind it to a copper rod which is precisely 2 cm in diameter. If we are going to insert the rod into the plate when the plate is at room temperature (300 K) and the rod is at the temperature of liquid nitrogen (77.2 K), what is the minimum diameter that we should make the hole?
- In our vacuum chamber in the underground lab we typically obtain pressures lower than 10^{-6} Pa. At this pressure, how many atoms are there per cubic cm?
- The volume expansion coefficient for mercury is $1.82 \times 10^{-4}\,°\mathrm{C}^{-1}$. So how can the mercury level in a mercury thermometer go from almost one edge of the tube to almost all the way to the other when the temperature changes by less than 100 °C?