Solutions to Midterm Examination

Physics 224A April 30, 2007

This was done well on the whole, with an average score of 40.1/50 and a standard deviation of 10.1. Most students performed well-organized calculations and interpreted them clearly. Some of the questions that required descriptive answers came out less well, with some vague or irrelevant remarks.

1. [16 points] *The mass of a piece of metal is measured by hanging it on a spring balance, which reads 3.02 kg when the metal is in air. When it is weighed again with the metal completely submerged in a beaker of pure water the result displayed on the balance is 1.90 kg.* Mean 12.1, standard deviation 3.3. Most people did the first two parts of this well, although there were more careless calculations than I like to see. The third part

   (a) [5 points] *What is the volume of the piece of metal?* The difference between mass measured in air and in water is 1.12 kg, and this measures the mass of water displaced, 1.12 kg with volume 1.12 l, so the volume of the piece of metal is 1.12 liters.

   (b) [5 points] *What is the density of the metal* The density of the metal is $3.02/1.12 = 2.70$ kg/l.

   (c) [6 points] *If you also had a beaker of an unknown oil, known to be less dense than water, describe what measurements you would need to make to determine the density of the oil, and how you would calculate the density from the measurements you made.* The dried piece of metal should be weighed again in the oil. The reduction δm_o of the mass weighed in oil rather than in air gives the mass of the 1.12 l of oil that has has been displaced by the metal, so the density is found by dividing δm_o by the answer to part (a). Those who said "measure the volume in a graduated cylinder, use a balance to find the mass of an empty beaker and of the beaker with the oil in it" got full credit. Those who said "measure the volume, measure the mass, divide one by the other" got less than full credit.

2. [17 points] Mean 12.3, standard deviation 4.8.

   (a) [6 points] *Mercury freezes at -38.9 C, and ethanol boils at 78.5 C. Give a brief description of one type of thermometer that can*

be used over a range that includes the range from -80 C to 120 C. I was not very charitable to those who evaded the question by suggesting using a double thermopmeter with mercury on one side and ethanol on the other, and justified that to myself by underlining the "one type of thermometer" in my wording of the question. A simple type of thermometer that works in this temperature range is based on a bimetallic strip, in which the differential of the two pieces of metal welded face to face is shown by the bending of the strip. The strip is clamped at one end, and the other end pushes against a spring-balanced pointer that displays the temperature on a circular scale.

Many other answers are possible, such as an electrical resistance based thermometer, constant pressure or volume gas thermometer, a thermocouple, etc.

(b) [5 points] *Describe briefly one process that involves transfer of heat by two or more different mechanisms, successively or simultaneously. The process can be natural, domestic, laboratory or industrial.* One simple example would be the boiling of water in a pan on an electric cooker. Heat from the ring is conducted through the bottom of the pan, and then to the water close to the bottom and sides of the pan. This hot water sets up convection currents in the water, that then carry colder water to the bottom, which in its turn gets heated and further mixed with the rest of the water until all the water is close to or a little above boiling point, when it vaporizes. I got too many answers here that fell short of what I would call a "description".

(c) [6 points] *Give one example of a process in which temperature or pressure changes, but there is no heat added to or taken from the system, and another in which temperature or pressure changes but there is no work done. Do not just use a technical word like 'isobaric', but explain what you mean.* If a gas is compressed fast enough that heat does not have time to flow out of the system, work is certainly done, but little heat can have flowed out of the gas which has raised temperature. This is an adiabatic process with no heat flow, but increase in temperature and pressure.

If a gas or other material is heated at constant volume there is no work done, but temperature and pressure increase.

Despite my warning not just to use technical words, some people simply quoted the words "adiabatic" and "isochoric", for which

they got no credit.

3. [17 points] *The thermal conductivity of glass is 0.84 W/m K, and of air is 0.023 W/m K.* Mean 15.7, standard deviation 4.9. This was done well on the whole. A few people did not understand how to deal with a thermal conduction problem, and there was very little partial credit that those people could get.

   (a) [5 points] *If the steady heat flow across a sheet of glass 3.0 mm thick is 20 W/m^2, what is the temperature difference between the two sides of the glass?* If the heat flow is 20 W/m^2 and conductivity 0.84 W/m K, then the temperature gradient is 20/0.84=23.8 K/m,. The temperature difference is therefore

   $$\Delta T = 23.8 \times .003 = .071 \text{ K}.$$

   (b) [5 points] *What temperature difference would produce the same heat flow by thermal conduction across a slab of still air 8.0 mm thick?* For thickness 8.0 mm, conductivity .023 W/m K, and heat flow 20 W/m^2, the temperature difference is

   $$\Delta T = \frac{20 \times .008}{.023} = 6.96 \text{ K}.$$

   (c) [5 points] *Compare the temperature difference needed to produce this heat flow of 20 W/m^2 across a single sheet of glass 6 mm thick, with that needed to produce the same heat flow across two sheets of glass separated by 8.0 mm of air.* For the single sheet 6 mm thick the temperature to produce the 20 W/m^2 would be twice the answer in part (a), or .14 K.

   For the double sheet trapping 8 mm of still air it is the sum of (b) and twice (a), or 7.10 K.

   (d) [2 points] *What does this tell you about the relative effectiveness of a single sheet of glass and of two sheets separated by an air gap for reducing heat loss by conduction through a window?* Therefore the single thick sheet lets out 50 times as much heat by conduction as the double glass with an air gap.