PHY 131 Fall 2018

Test #10: *Thermal Energy*

NAME ________________________

c_{water} = 4184 J/kg°C	c_{ice} = 2108 J/kg°C	c_{gold} = 129 J/kg°C
c_{steel} = 500 J/kg°C	$c_{soapstone}$ = 980 J/kg°C	$c_{whiskey}$ = 3400 J/kg°C
$L_{f\ water}$ = 334,000 J/kg	$L_{v\ water}$ = 2,260,000 J/kg	$L_{f\ gold}$ = 63,000 J/kg
Q = mL	Q=mcΔT	Room temp. = 23°C

SHOW ALL WORK & PUT YOUR ANSWERS IN THE BOXES PROVIDED

For each of these thermal energy transfers, assume that the transfer occurs only between materials given in the problem. Ignore Q transfer to the surroundings.

1. (30 points) A 50-gram chunk of gold is at 10 °C. The melting point of gold is 1063 °C. How much energy must be transferred to the gold to melt the entire chunk?

First heat to melting point…

$$Q = mc\Delta T = (0.050\text{ kg})(129\text{ J/kg°C})(1053\text{ °C}) = 6792\text{ J}$$

Then melt

$$Q = mL = (0.050\ kg)(63{,}000\text{ J/kg}) = 3150\text{ J}$$

The total is

$$Q = 6792\text{ J} + 3150\text{ J} = 9940\text{ J}$$

9940 J

2. (30 points) Forging a Damascus Steel blade requires forge welding two different pieces of steel at high temperature and repeatedly folding the metal. A master blacksmith can repeat this process dozens of times, resulting in a blade with hundreds of layers of steel. This requires heating the steel to near its melting point, 2300 °C. When the refining and shaping process is complete, the temperature of the blade is lowered to 900 °C, the blade is removed from the forge and quenched in oil to harden the edge. The specific heat of the oil is 1.67 kJ/kg°C and its density is 0.85 g/cc. What volume of oil would be required to cool a 2.5 kg Damascus steel Claymore (the type of sword shown here) from 900°C to 100 °C? Assume that the initial temperature of the mineral oil is 20°C and the final equilibrium temperature of the mineral oil and the sword is 100°C. Express your answer in units of cc's to two significant digits.

The energy lost by the sword is:

$$Q = mc\Delta T = (2.5\text{ kg})(500\text{ J/kg°C})(800\text{ °C}) = 100{,}000\text{ J}$$

It must take this much energy to take the oil from 20°C to 100°C.

$$Q = 100{,}000\text{ J} = mc\Delta T = \text{m}\left(1670\frac{\text{J}}{\text{kg}}\text{°C}\right)(80\text{ °C})$$

Solving for the mass of the oil gives

$$m = \frac{100{,}000\text{ J}}{\left(1670\frac{\text{J}}{\text{kg}}\text{°C}\right)(80\text{ °C})} = 7.485\text{ kg}$$

This has a volume of

$$\text{V} = \frac{m}{\rho} = \frac{7.485\text{ kg}}{.00085\text{ kg/cc}} = 8800\text{ cc}$$

8800 cc

3. (40 points) A bartender pours two glasses of whiskey. Each pour is 100 grams and is at room temperature, which we'll call 20. 0 °C. In one glass he puts two soapstone cubes; the stones each have a mass of 10.0 grams and start at -15.0 °C in the freezer. In the other glass he puts two ice cubes, each of which has a mass of 10.0 g. Note that the melting point of water is 0 °C, and the melting point of soapstone is 1600 °C.
a) Find the final temperature of the stone-cooled whiskey.
b) Find the final temperature of the ice-cooled whiskey.

a) The expression for the thermal energy gained by the soapstone is

$$Q = mc\Delta T = (0.020\ \text{kg})(980\ \text{J/kg°C})(T_f + 15\ \text{°C})$$

The expression for the thermal energy lost by the whiskey is

$$Q = mc\Delta T = (0.100\ \text{kg})(3400\ \text{J/kg°C})(20\ \text{°C} - T_f)$$

Since no thermal energy is lost to the surroundings, the thermal energy lost by the whiskey must be equal to the thermal energy gained by the soapstone.

$$(0.020\ \text{kg})(980\ \text{J/kg°C})(T_f + 15\ \text{°C}) = (0.100\ \text{kg})(3400\ \text{J/kg°C})(20\ \text{°C} - T_f)$$

$$(19.6\ \text{J/°C})T_f + 294\ \text{J} = 6800\ \text{J} - (340\ \text{J/°C})T_f$$

So...

$$(359.6\ \text{J/°C})T_f = 6506\ \text{J}$$

Which means that

$$T_f = \frac{6506\ \text{J}}{359.6\ \text{J/°C}} = 18.1\text{°C}$$

b) Let's see how much energy would have to be removed from the whiskey to cool it from 20 °C all the way to 0°C

$$Q = mc\Delta T = (0.100\ \text{kg})\left(3400\frac{\text{J}}{\text{kg}}\text{°C}\right)(20\ \text{°C}) = 6800\ \text{J}$$

Now let's calculate how much energy it would take to get the ice from -15°C to 0°C

$$Q = mc\Delta T = (0.020\ \text{kg})\left(2108\frac{\text{J}}{\text{kg}}\text{°C}\right)(15\ \text{°C}) = 632.4\ \text{J}$$

Now we can calculate how much ice we can melt with the entire 6800 J that can be removed from the whiskey by cooling it from 20 °C to 0°C.

$$6800\text{ J} = mL = m\left(334\frac{\text{J}}{\text{g}}\right)$$

This is

$$m = 20.3\text{ grams}$$

We conclude that there is enough thermal energy to get the ice from -15°C to 0°C, but there is not enough themal energy in the whiskey to melt all the ice.

In fact, even if the ice started at 0°C, the whisky at 20°C could not melt it all.

This means that the whiskey will end up at 0°C. It will be watered down and there will be some ice left.

$T_{f\ \text{stone-cooled whiskey}} =$ 18.1°C

$T_{f\ \text{ice-cooled whiskey}} =$ 0°C