Heat of Vaporization

This activity considers the latent heat of vaporization of water and various heat transport mechanisms that are involved in its experimental determination.

1. Consider a pot of water that is steadily boiling on a hotplate.

a) Why is it that the temperature of the water does not continue to increase despite the water receiving energy from the hotplate?

b) Which heat transfer mechanism is primarily responsible for the flow of energy from the hotplate to the pot of water? Which heat transfer mechanisms are responsible for the loss of heat from the water to the surrounding environment? Do you suspect one of these to be more dominant than the other(s)?

c) Suppose you have access to a thermometer, scale, stopwatch, pot, and water. Explain how one might estimate the rate at which energy is transferred from the hotplate to the pot of water.

d) For the method you outlined in part (c) what factors would render it an *estimation* rather than a precise determination? What steps might be taken to minimize these factors?

2. Obtain a metal pot and hotplate from the front of the room. Fill the pot roughly a third of the way with water and determine the mass and temperature of water in the canister. Plug in the hotplate, turn it on high, and let it preheat for around 5 minutes.

a) Once the hotplate is preheated, re-measure the temperature of the water, place it on the hotplate, and start your stopwatch. As the water temperature increases measure the time it takes the temperature to change from 30°C to 35°C, and from 35°C to 40°C. By considering each of these time intervals determine the average rate of energy transfer from the plate to the water over each of these time intervals. How do the rates over each time interval compare? Do these rates overestimate or underestimate the true rate?

b) Continue heating the water taking care to keep track of the total elapsed time. Record the time required to achieve a boil. Boil the water for an additional 5 minutes. Immediately following this measure the mass of the remaining water. Record the remaining mass of water and the amount lost to vapor.

3. In part **1**(b) you found that in addition to receiving heat from the hotplate the water loses heat to the environment by way of conduction and radiation. Denote these respective heats by Q_R, Q_C and the heat transferred from the plate by Q_P.

a) Consider the 5-minute time interval during which the water was boiling. Write down a relation that expresses energy conservation for the water system over this time interval.

b) Now make the approximation that the rate of heat flow to the water from the plate is the same as you found in part **2** (a) and the heat losses due to radiation and conduction can be ignored. With these assumptions calculate the heat of vaporization for water.

c) Discuss the approximations you made in (b). Is the latent heat they lead to too large or too small? Explain.

d) Write down an expression that represents the net loss of heat to radiation. Look up the appropriate emissivities in the reference at the front of the room and estimate Q_R during the 5-minute boiling period. When you believe you have the answer have me check your result.

e) Consider the heat loss due to conduction. You will show later that $Q_C \approx \frac{k A \Delta T}{R}$ where R is the mean dimension of the object. Using this result and part determine Q_C.

f) Using your result for Q_R and Q_C, modify the estimate you found for L_v in part **3**(b).

g) Consider now the assumption on the rate of heat flow into the water. The boiling water is *warmer* than when you measured this rate and it is likely that the conduction rate will be less. Suppose the temperature of the hotplate running with nothing on it is T_P. Explain the rational behind revising the estimate for the heat-flow rate Q'_P into the boiling water to: $Q'_P \approx Q_P\,(T_P - T_B)/(T_P - T_0)$, where $T_B = 100$°C, and $T_0 = 35$°C. What assumptions are implicit in such a correction?

h) Given recourse to a small metallic sample of known specific heat, a pot of water, a scale, and a thermometer, explain how you might estimate the temperature of the hotplate. When you believe you have the answer have me check your result.

j) Use the procedure you devised in part (h) to determine the hotplate temperature and use this to revise your estimate for the heat flow rate into the boiling water. Put your results together and determine the revised heat of vaporization of the water. Compare with the accepted value of $L = 540$ Cal/g.

4. Now consider the *entire* heating/boiling process. There is an additional problem with your revised estimate of part (j). You assumed that all the lost water occurred entirely during the boiling process.

a) What is wrong with this assumption and how might it affect your latent heat estimate?

b) For the entire heating process write down the appropriate modification of the equation you stated in part **3**(a).

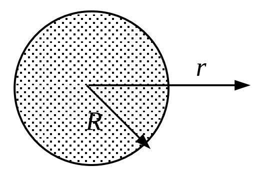
c) Break the heating process up into two segments: one to raise the water to boiling, and the other boiling the water for 5 minutes. For the first segment use the same analysis you did previously, but now for the radiation and heating corrections assume the water is at an average temperature of 60°C.

d) Use your results to part (c) to revise your estimate for *L*. Compare your results with your previous analysis. Does your estimate improve? Can you think of any other modifications/corrections that might be made in this experiment?

5. Consider the following heat conduction problem: A sphere of radius R at temperature T_H is in an air-filled room of temperature $T_C < T_H$. Assume the conductivity of air is k.

a) Using dimensional analysis show that the rate of conductive heat loss from the sphere is $H \propto kR\Delta T$. Where $\Delta T = T_H - T_C$.

b) Using the law for conductive heat flow, determine how the temperature $T(r)$ varies away from the surface of the sphere. *Hint:* Explain why $H = k\,A\,dT/dr$ must be constant. Use this and your knowledge of $T(R)$ and $T(\infty)$ to determine $T(r)$.



c) Use your result to part (b) to determine the heat flow rate H away from the sphere. Does your result agree with your previous dimensional analysis?