The Latent Heat of Fusion of a Witch

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Anyone who has watched *The Wizard of Oz* has seen the phenomenon of the melting of the Wicked Witch of the West when Dorothy throws water on her. Because the Wicked Witch melts, she must have a calculable latent heat of fusion. However, to calculate this latent heat we must make some (reasonable) estimates about certain variables.

By using the videodisc version of *The Wizard of Oz*[1] I recently guided my students through such a calculation. In the process, we were able to emphasize the concepts of conservation of energy and of estimating variables. Further, when the students discussed errors in our analysis, they learned more about both thermal energy and the experimental method.

This exercise took place in a physics course at Kansas State that is taught in a learning-cycle format for students preparing to be elementary-school teachers.[2] Happily, they had just finished a learning cycle on specific heat capacity and latent heats, so we had a great summary situation for a week's activities.

To get your class involved in a similar exercise, watch the scene in which Dorothy throws water on the witch, and the witch changes state. You'll hear the witch say very emphatically that she is melting. The first question, of course, is whether that is a correct statement. We see no puddles of liquid on the floor (although those puddles might be covered by her dress that does not disappear). We do see some "steam" rising from her. So it is possible the witch does not understand the difference between melting and sublimating. We chose to ignore this particular point, however, and took the witch at her word that she was truly melting.

The second step is to determine how much energy was required to cause the witch to melt. To approximate this number we have to make a series of observations and assumptions. First, find a frame on the videodisc that gives a clear view of the bucket containing the water. I asked my students to estimate the size of the bucket and the amount of water it could contain. Prior to class I had estimated the bucket was approximately 5 gallons, but the students thought it was closer to 3 gallons. Because many of the students come from rural backgrounds, we concluded that they were more likely to know the size of a bucket than I, so we assumed the lesser amount. Using a very rough approximation, we decided that Dorothy must have thrown 12 kg of water on the witch.

Next, we needed to determine the approximate temperature change of the water in order to decide how much energy was transferred from the water to the witch. The students noticed that the bucket of water was sitting on the floor in the witch's chamber, so it quite likely was at equilibrium with the room, i.e., at room temperature. The initial temperature of the water was thus taken to be 20°C. (We assumed that this was a normal cold castle rather than a movie studio.) The final temperature of the water is much more difficult to ascertain. However, by looking at a frame on the videodisc showing a closeup of the witch, we were able to note that the water was dripping from her nose. It had not frozen. Apparently the water did not change state and must be somewhere between 20 and 0°C. To put an upper limit on the calculation, we assumed that the water was liquid but at 0°C. Thus, a temperature change of 20°C was assumed to take place.

The last step in determining the energy given up by the water to the witch is an estimation of the amount of water that actually hit the witch. Given the estimation level of our calculations we decided to assume that all of the water hit the witch or soaked through her garments to reach her. This clearly is somewhat in error but is well within the limits placed by other estimations in the "experiment."

The final necessary piece of data was the mass of the witch. We completed this estimation by looking at a couple of views of the witch and comparing her physique with that of students in the class. We concluded that her mass must be approximately 60 kg.

With this information we then proceeded to calculate the latent heat of fusion of the Wicked Witch of the West. Our conclusion is that an approximate upper limit on the latent heat of fusion of the Wicked Witch is 7.8 kJ/kg. (Compare this with the latent heat of fusion of water, which is 335 kJ/kg!) With this calculation in hand, we continued on to discuss the errors in the various estimates and attempted to put a limit set of error bars on our calculation. However, it became quite clear that the instructor was having more fun with this than the students, so we called a halt.

This short lesson is possible because of the capabilities of the videodisc player when used with a constant-angular-velocity (CAV) videodisc. To simplify the search procedures, before class I created a set of barcodes that instructed the player to search or to play significant segments. During class I used a barcode scanner connected to the player to provide quick access to individual frames. When students wished to see views slightly different from those I had selected, the step-frame capabilities of the videodisc player were used.

Perhaps this calculation is somewhat silly, but it did keep the students' attention and enabled them to look at several different aspects of the topic. They were able to discuss thermal energy transfer as it pertained to this somewhat unrealistic situation; they saw how observation skills and estimation can lead to a reasonable conclusion; and we followed a procedure a scientist would follow, which led to discussion of the methods by which the scientific endeavor proceeds. Overall, the activity seemed to be quite useful in reaching its goals and certainly entertained the instructor and his colleagues.

References

1. *The Wizard of Oz* videodisc ($100) is available from The Voyage Company, Santa Monica, CA 90401.
2. D. Zollman, *Phys. Teach.* **28**, 20 (1990).