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Cappuccino and Specific Heat Versus Heat of Vaporization

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A cappuccino is prepared by adding about 50 mL frothing, foaming milk to a cup of espresso. Whole milk is best for foaming and the ideal milk temperature when adding it to the espresso is 65 °C. The espresso itself may be warmer than that. During the heating the milk should not burn, as that would spoil the taste. The best way is to heat the milk slowly while stirring to froth the milk and create foam. But modern cappuccino machines in restaurants do not have time for slow heating. Could we heat the milk by just adding hot water?

That's the question we pose to our high school students first. How many mL of 90 °C hot water would be needed to heat 50 mL of milk from a refrigerator temperature (say 4 °C) to 65 °C? Assume that the specific heat of milk is the same as that of water. Students answer the question on a worksheet and practice their computation skills. The answer: 122 g. This would mean an unacceptable dilution of the milk, 2.5 mL of water for every mL of milk. What would the answer be if we use boiling hot water of 100 °C? Students calculate again, then the answer is 87 g, still an unacceptable dilution. What then? What if we use steam?

Fig. 1. A cup of cappuccino.

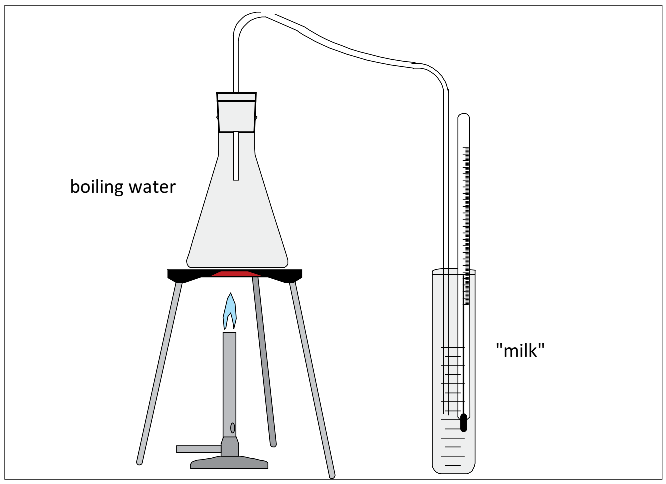

Fig. 2. Experimental setup.

Demonstration

While the students were calculating, the teacher already preheated water to almost boiling in the setup of Fig. 2.

Needed

- A large Erlenmeyer flask
- Measurement cylinder of 100 mL
- Thermometer
- Cork or rubber stop with hole
- Rubber hose
- Water
- Burner
- Heat-resistant gloves (to handle the hot rubber hose)

Setup

Steam is produced in the large Erlenmeyer flask and led through the rubber hose into the 50 mL of milk. Instead of 50 mL of milk, one may want to use 50 mL of water at refrigerator temperature. The use of water is more convenient and the thermometer is better visible. Meanwhile a student watches the thermometer in the "milk." At 62 °C the burner is switched off, and when the temperature reaches 65 °C the hose with steam is withdrawn (handle with heat-resistant glove). Then measure the increase in the volume. How much additional water did the steam produce? In our trials it was a 5-8 mL (computation 5.3 g). That seems acceptable for 50 mL of milk, a 10–20% dilution. What a difference with the 87–122 g of hot water earlier! Where does the extra energy of steam–as compared to hot water–come from? The huge difference between using boiling water and steam is due to the heat of vaporization, which for water is 2256 J/g as compared to the specific heat, which is 4.2 J/g °C. If there were no vaporization, how hot would 5 g of water have to be for heating the 50 mL of milk? 675 °C! With 100 °C steam the computation comes to 5.3 g, assuming 4 °C milk to start with.

Explanation

As is clear from the demonstration, 5.3 g of steam of 100 °C when mixed with 50 mL of milk at 4 °C can release the

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same amount of energy as 87 g of water at 100 °C. For vaporization in the Erlenmeyer flask, the water molecules absorb a huge amount of energy, which is used to break the bonds between water molecules. When condensing in the milk, the bonds are formed again and the energy is released. A cappuccino machine uses steam to heat the milk. We can clearly hear the noise of the steam. Some machines (see references to YouTube) have a separate steam outlet and there are expert instructions on how to direct the steam in order to get optimal frothing and foaming. Some coffee shop worker-artists ("baristas") even produce pictures of Christmas trees with the foam. Have a cuppa!

Safety

Steam can cause very bad burning, so be careful. Handle the hose with a heat-resistant glove.

References

1. Making cappuccino is illustrated in quite a few short YouTube films, which you may like to show after the demo.
2. Including thermometer: www.youtube.com/watch?v=RsBYOY-32S0&feature=related.
3. www.youtube.com/watch?v=i-LmmjdoAms.
4. www.youtube.com/watch?v=u4pBo4hOEhk&feature=related.
5. www.youtube.com/watch?v=05mH6q1kdIU&feature=related.
6. www.youtube.com/watch?v=snZTnkgykcs&feature=related.

Jorn Boomsma and Frits Hidden are teaching physics at the Hermann Wesselink College in Amstelveen. Anton Schins is teaching physics at the Rijnlands Lyceum in Oegstgeest. Ed van den Berg trains physics teachers at the Free University in Amsterdam and is involved in elementary science teaching at the Hogeschool of Amsterdam. Both Jorn and Anton first obtained PhDs in physics and then decided to teach physics in a secondary school. They are now in their second year of teaching.

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