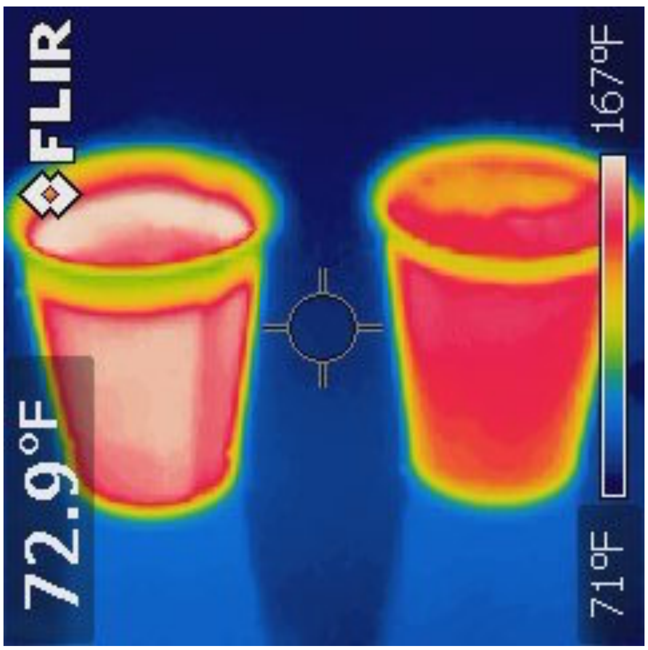
Cooling Hot Tea and Milk Experiments April 7, 2016

John Pickle and Luke Dewees, Concord Academy

Which will be warmest after 10 minutes: hot tea sitting on a table and cold milk added after 10 minutes or hot tea with cold milk added immediately and left to cool for 10 minutes. The volumes and starting temperature for both samples of hot tea and cold milk were identical, and the liquids were poured into identical paper cups.

Since heat loss is controlled by **c**onduction, **r**adiation, **a**dvection, **c**onvection, and **l**atent heat (which Concord Academy students have nicknamed CRACL), we used a thermal infrared camera to visualize heat loss from all of the surfaces from the two drinks rather than measure the temperature of the liquids at a point. See text after the pictures to see descriptions of these processes.

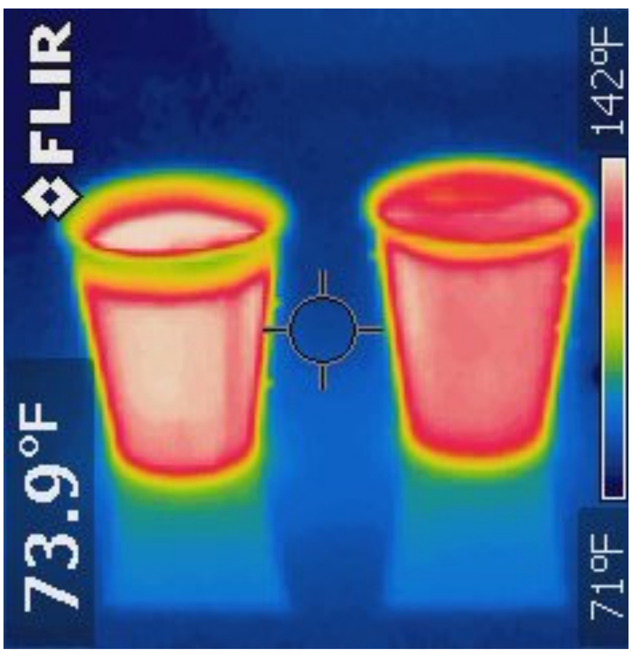


Time 0: both hot teas are poured, cold milk added to drink on right (notice the liquid is closer to the top of the paper cup than the drink on the left). Using the color key on the right of the image to convert colors to temperature, notice the drink on the right is considerably cooler than the drink on the left (only hot tea).

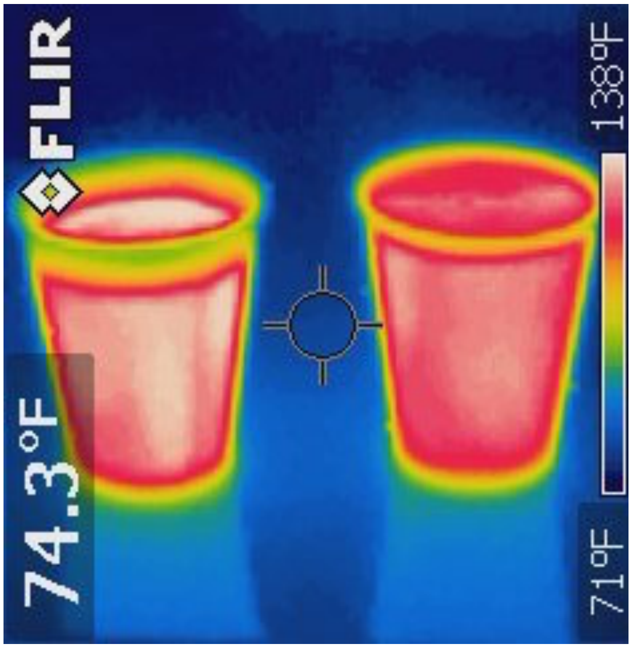
Time 60 seconds: Notice the edges (top, sides, and bottom) of both drinks are cooling most. This is due to conduction of heat into the surrounding air, radiation away from the hot liquid, and evaporative cooling at the top.
The cooler water at the top of the drink on the left has begun to sink (see the cooler vertical column on the right side of the cup). Notice the color scale on the right of the image is changing from the Time 0 sec image: the temperature of the white color is 161°F now, but it was 167°F 60 seconds prior. To interpret the images properly, note the range in temperature represented by the color key of each image.

Time 120 sec: continued cooling from the boundaries of the drink, but the hot tea on the left is considerably warmer than the tea and milk on the right.

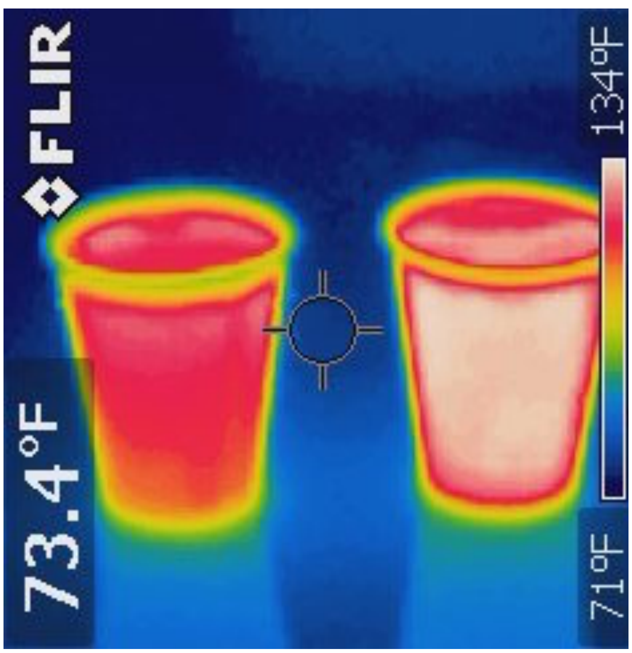
Time 300 sec.



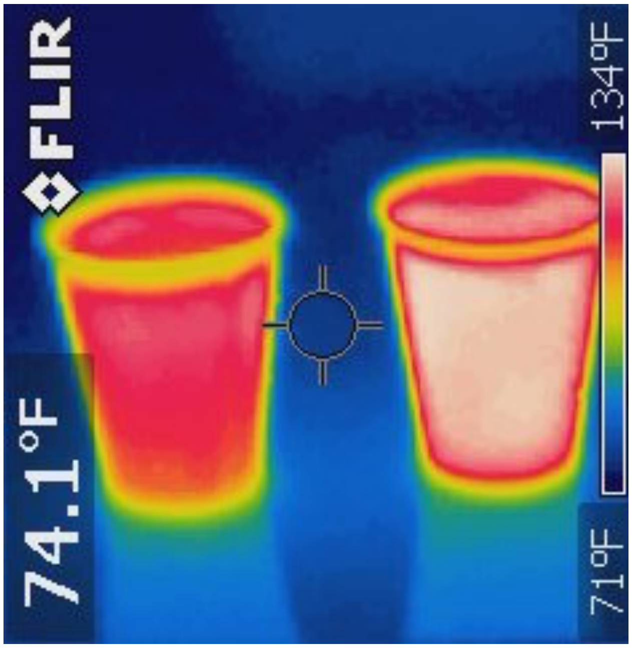
Time 480 sec.



Time 540 sec: The drinks are getting quite close in temperature.



Time 570 sec: The hot tea on left has now become cooler (on the order of 10°F) than the tea with milk added at the beginning. Notice the drink on the left is considerably cooler at the bottom than the top compared to that on the right. How did this happen? Because the hot drink (milk added after 10 minutes) had the greatest heat loss initially due to conduction, radiation, and evaporative cooling. This set up strong convection cells, which created the most efficient way to move heat inside the drink to the edges/boundaries, where conduction, radiation, and evaporation could be maximized compared to the initially cooler drink.



Time 600 sec: Cold milk added to drink on left, which mixed the drink to some extent.

Overview of Processes Controlling Heat Transfer

Conduction is heat transfer through molecular collisions, and the rate is heat transfer is proportional to temperature gradient or ΔT (amount of temperature change over distance).

Radiation refers to black body radiation, which is the electromagnetic radiation (essentially light) given off by all materials with a temperature greater than absolute zero. The amount is proportions to the fourth power of the temperature ($T(°K)^4$).

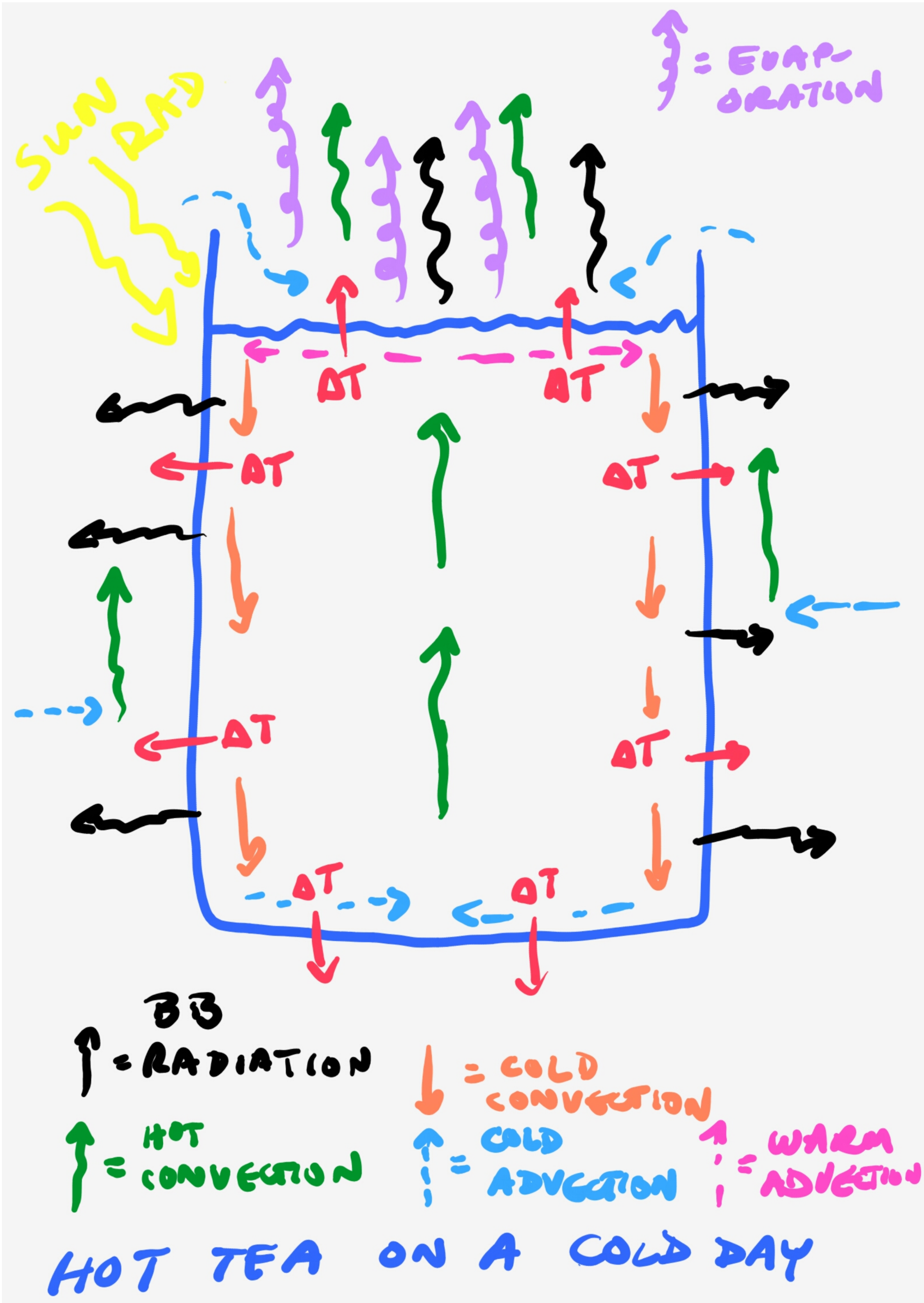
Advection is the horizontal movement of fluids with temperature difference (e.g. warm liquid moving into liquid with cooler temperature).

Convection is the vertical movement of fluids with temperature difference (e.g. cold liquid moving sinking into liquid with warmer temperature).

Combined, advection and convection create *convection cells*, which tend to be the most efficient way to transfer heat in a fluid (liquid or gas).

Latent heat is the heat given off or taken in during phase change. In this case, evaporative cooling occurred at the top of both warm drinks.

An illustration how these processes cool a hot drink follows.



= EVAP-ORATION
SUN RAD
ΔT
ΔT
ΔT
ΔT
ΔT
ΔT
ΔT
ΔT
BB
= RADIATION
= COLD CONVECTION
= HOT CONVECTION
= COLD ADVECTION
= WARM ADVECTION
HOT TEA ON A COLD DAY