Heat of Fusion

You have probably had this experience a hundred times. It's a warm day, and you are at a party or a picnic. You are thirsty, so you go to the ice chest and take out an ice-cold soft drink. You pop the top and take a swallow. So cold and refreshing! One of life's small pleasures.

The ice chest is a great invention. It is simple to maintain, easy to use, and very efficient for cooling drinks. But did you ever think about how it works? It is not quite as simple as it seems.

How Does Ice Make Things Cold?

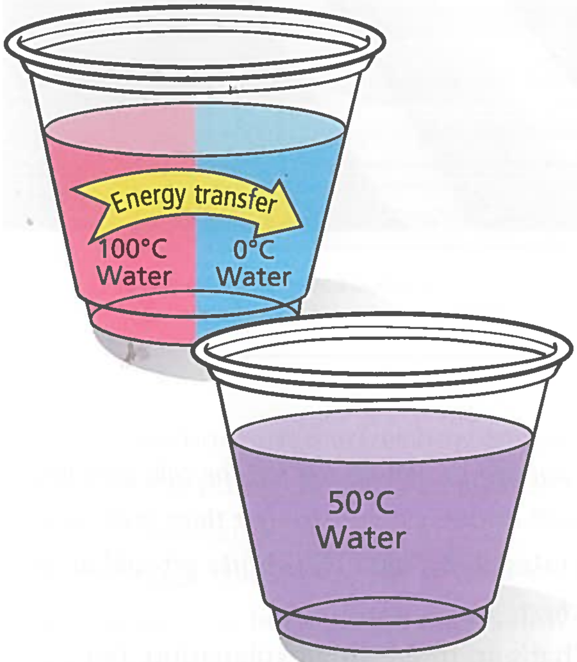
If you ask your little brother how an ice chest works, he might have this idea.

Ice is cold. When you put it in an ice chest, it makes the whole inside of the chest cold. When you put drinks in with the ice, the cold goes into the soft drinks. Cold is stronger than heat, so it just takes over. That's why drinks get cold in an ice chest.

That's an interesting explanation, but it is not true. We now know that cold is not a substance, and cold can't transfer to the warm soft drink. Cold just means that particles have a lower energy. The lower the energy of particles, the cooler the material. Objects become cooler when energy transfers from them to another location. Soft drinks in an ice chest get cold because energy transfers from the soft drinks (particles with higher energy) to something else (particles with lower energy). The "something else" in the ice chest is the ice itself. And what happens to the ice? It melts.

What Really Happens When Ice Melts?

Boiling water is 100 degrees Celsius (°C). Ice that has just formed is 0°C. Ice that has just melted is 0°C, too. If we mix 100 grams (g) of 100°C water with 100 g of 0°C water, in a moment the mixture will reach equilibrium. We will have 200 g of water at 50°C.



Energy transfers from particles in the hot water to particles in the cold water.

The equation that lets us predict the final temperature when we mix equal volumes of water of two different temperatures looks like this.

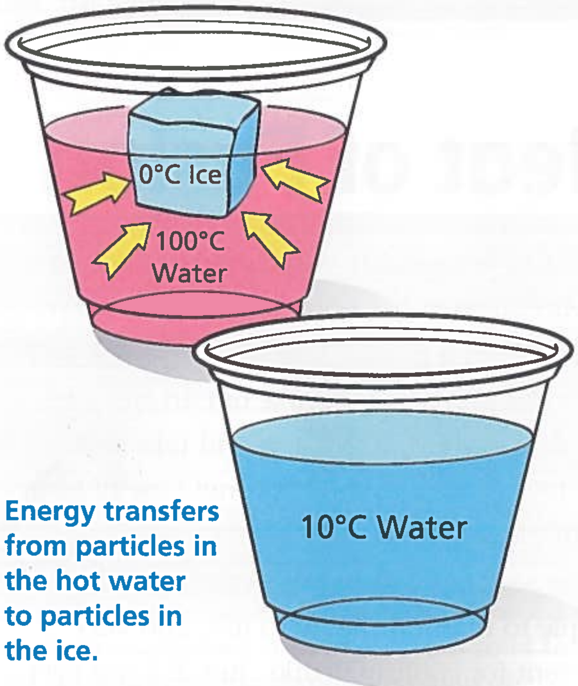
$$T_f = \frac{T_h + T_c}{2}$$

T_f = final temperature
T_h = temperature of hot water
T_c = temperature of cold water

We can use the equation to predict that the final temperature of the mixture described above will be 50°C. The final temperature is also known as the equilibrium temperature.

$$T_f = \frac{T_h + T_c}{2} = \frac{100°\text{C} + 0°\text{C}}{2} = 50°\text{C}$$

Now let's mix 100 g of 100°C water with 100 g of 0°C ice. The starting temperatures are 100°C and 0°C. So we might predict that the temperature of the mixture at equilibrium will again be 50°C. But it is not. The equilibrium temperature is only 10°C. Why?



Energy transfers from particles in the hot water to particles in the ice.

It takes a lot of energy to melt ice. Ice is the solid phase of water. Water particles in ice are held in place by forces called bonds. In order for solid water to turn into liquid water, the bonds must be broken. It takes energy to break bonds. That's where most of the energy transferred from the hot water goes. The energy breaks the bonds between particles and changes water from a solid to a liquid.

Melting ice

But the energy that melts the ice does not change its temperature. Ice is 0°C, and the liquid water it turns into is also 0°C. The energy that transfers to ice doesn't change the kinetic energy of the water particles. It just breaks bonds. The energy that breaks bonds to change solid water into liquid water is called **heat of fusion**.

Calculating Heat of Fusion

We can calculate the heat of fusion using the equation for calculating **calories**. We know that the hot water went from 100°C to 10°C. That is a change of 90°C. Let's use that to calculate the heat transferred from the hot water. We will refer to this transferred energy as cal_h.

$cal_h = \Delta T \times m$

$\Delta T =$ temperature change

$m =$ mass

$cal_h = 90°\text{C} \times 100\text{ g} = 9{,}000\text{ cal}$

We also know that the ice went from 0°C to 10°C. That is a change of 10°C. Let's use that to calculate the heat transferred to the ice (cal_c).

$cal_c = \Delta \text{T} \times m$

$cal_c = 10°\text{C} \times 100\text{ g} = 1{,}000\text{ cal}$

It appears as though the number of calories transferred from the hot water exceeds the number of calories transferred to the cold ice by 8,000 calories. But we know that energy is conserved. No energy is ever created, destroyed, or lost during energy transfers. So what happened to the 8,000 calories?

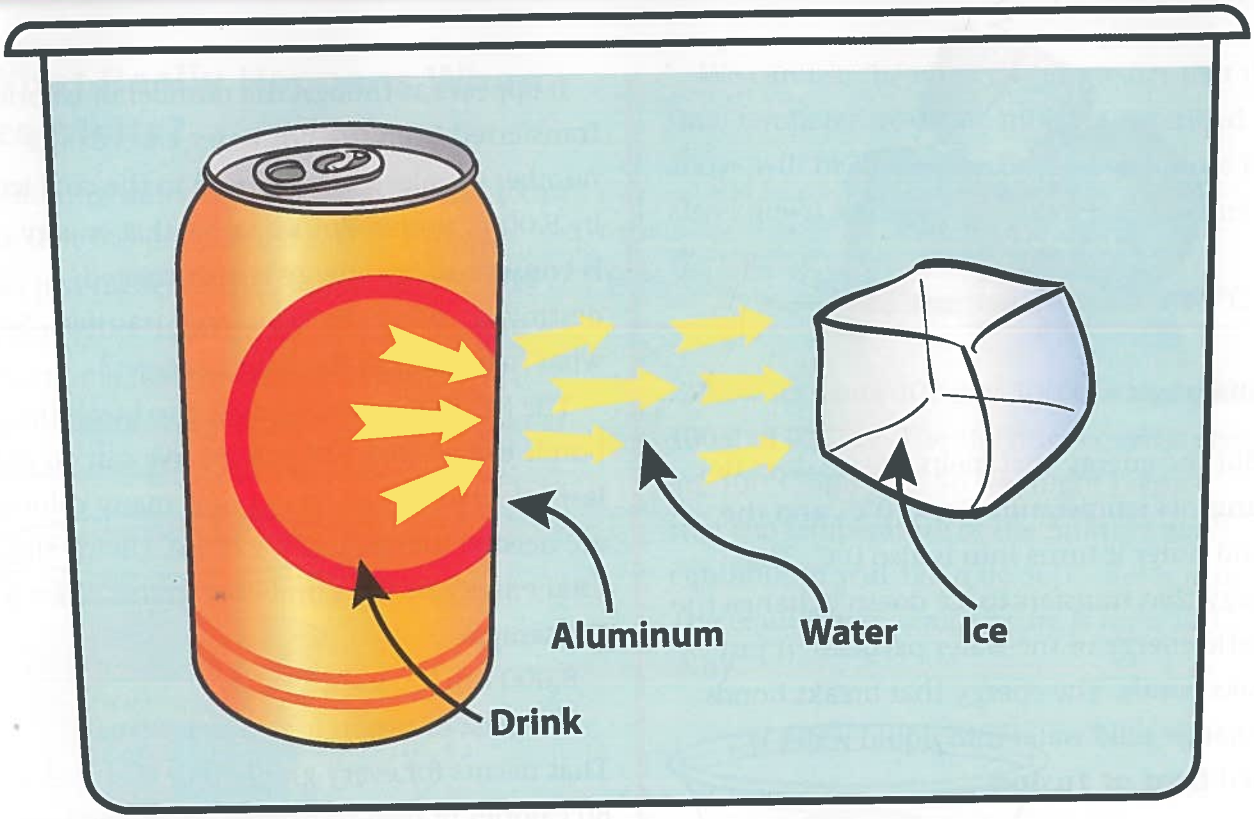
The 8,000 calories were used to break the bonds to melt the 100 g of ice. We can do one last calculation to find out how many calories are needed to melt just 1 g of ice. Divide the total energy by the number of grams of ice in the sample.

$8{,}000\text{ cal}/100\text{ g} = 80\text{ cal/g}$

The heat of fusion for water is 80 cal/g. That means for every gram of ice that melts, 80 calories of heat transferred from someplace to make that happen.

Using Energy Transfer to Make Things Cold

Heat of fusion is what makes the ice chest so good at cooling soft drinks. The best way to set up a cooler is to fill it about half way with crushed ice. Then pour in just enough water to float the ice. That will maximize the area of contact where energy can transfer out of the soft-drink containers through conduction. The water will transfer energy to the ice, and some of it will melt. But as soon as the water gets down to 0°C, ice will stop melting. Why? Because the kinetic energy of the particles in the 0°C water will be the same as the kinetic energy of the particles in the 0°C ice. No more energy transfer. The system is in equilibrium at 0°C.



Energy transfers from drink particles to aluminum particles. The drink cools down. Energy transfers from the aluminum particles to water particles. The aluminum can cools down. Energy transfers from water particles to ice particles. Water cools down and ice melts.

In go the room-temperature soft drinks. They sink down into the ice and water. Energy starts to transfer from the surface of the 20°C cans to the 0°C water surrounding them. As a can transfers kinetic energy to the water, the drink inside the can starts to transfer energy to the can material. The water warms up as the can and the drink inside cool down.

But the water doesn't stay warm. It transfers energy to the ice. Ice melts, keeping the temperature of the water at 0°C. Energy continues to transfer from the soft drinks to the ice until everything in the cooler is at 0°C.

What has changed? Energy has moved from the soft drinks to the ice. The drinks are cold, and some of the ice has melted. The ice-chest system uses kinetic energy from the soft drinks to melt ice. The result is cold drinks. The ice chest uses energy transfer to cool the drinks.

Think Questions

1. What is heat of fusion?
2. What happens at the particle level when you put ice cubes in a glass of room-temperature lemonade?
3. Explain how a thermos filled with ice and tea keeps the tea cold. (Hint: Think about heat of fusion and the design of the thermos.)