

Workshop Tutorials for Introductory Physics

Solutions to T12: Heat and Energy

A. Review of ideas in basic physics.

Heat and Energy

Brent and Rebecca have decided to go to the beach. It is a really hot day and they want to take plenty of cold drinks, which they wish to keep cold. They fill their cool box with **ice** and put in their drinks. The temperature outside the cool box is much greater than the temperature inside.

As the day progresses **thermal** energy is transferred through the cool box walls. The flow of thermal energy will be from the outside to inside the cool box. Brent and Rebecca discuss whether the temperature changes as the cool box is heated. They discover that as long as there is some ice the temperature is **constant**. The heat, i.e. transfer of thermal energy, from the air outside is melting the ice. The thermal energy added is breaking the bonds between the ice molecules and water is forming. While this is happening the inside of the box stays at a constant **0°C**.

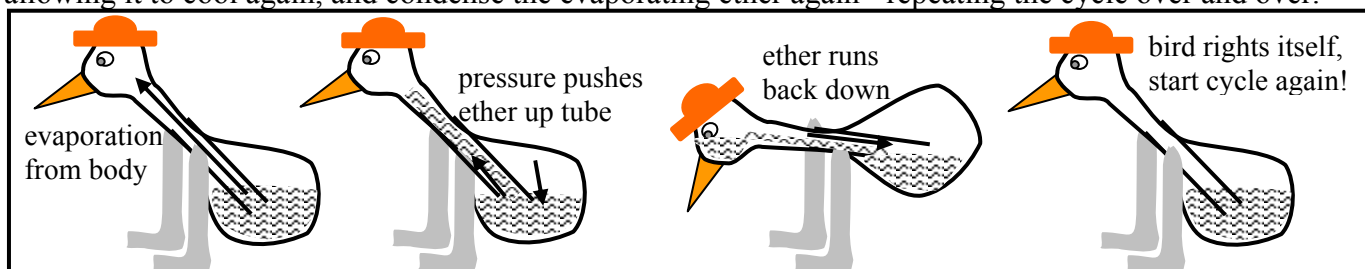
Rebecca tells Brent that the energy needed to change the phase of 1 kilogram of a substance is called the **latent** heat. For example 333 kJ of energy is needed to melt 1 kilogram of ice. When ice is forming, **333 kJ** per kilogram must flow from the freezing water. Not all substances have the same latent heat. Ethyl alcohol needs only 104 kJ per kilogram to freeze. But why then is a form of alcohol, glycol alcohol, used in antifreeze if alcohol needs **less** energy than water to freeze? The answer is that the melting (and freezing point) of alcohol is at least -100°C .

By the end of the day at the beach, all the ice is melted in the cool box. **Heat** continues to be transferred into the box but now the temperature of the drinks and melted ice starts to increase. The **specific** heat of the water and drinks will determine how quickly the contents heat up and the subsequent temperature change. Either it is time to go home or quickly finish off the drinks.

B. Activity Questions:

1. The drinking bird

The drinking bird works by evaporation of ether inside its body and evaporation of water outside its head. The liquid ether in its body evaporates at room temperature. As it vaporizes it creates an increased pressure inside the body, which pushes ether up the tube to the head. Ether in the upper bulb (the head) is cooled by the evaporation of water on the outside of the head, and becomes a liquid, thus there is a transfer of ether from the lower (body) to the upper (head) bulb. When enough ether has collected in the head it overbalances the bird which pivots forwards. When the bird pivots forwards the ether runs back to the body, which pulls it upright again. The pivot tips the head into a glass of water, which wets the head, allowing it to cool again, and condense the evaporating ether again - repeating the cycle over and over.



2. A hot bath

The energy gained by the water is the $E_{\text{match}} = 4180 \text{ J.kg}^{-1}.\text{K}^{-1} \times m \times \Delta T$. This is the energy supplied by the match. A bath tub contains around 300 l or 0.3 m^3 which is around 300 kg of water. A nice hot bath is around 50°C , and tap water is typically at around 20°C , so you need a temperature change of 30°C . This requires an energy of $E = 4180 \text{ J.kg}^{-1}.\text{K}^{-1} \times 300 \text{ kg} \times 30 \text{ K} = 38 \text{ MJ}$ of energy.

If one match gives you E_{match} , then you need around $(38 \times 10^6 \text{ J} / E_{\text{match}})$ matches to heat up water for a bath.

3. Keeping warm or cool

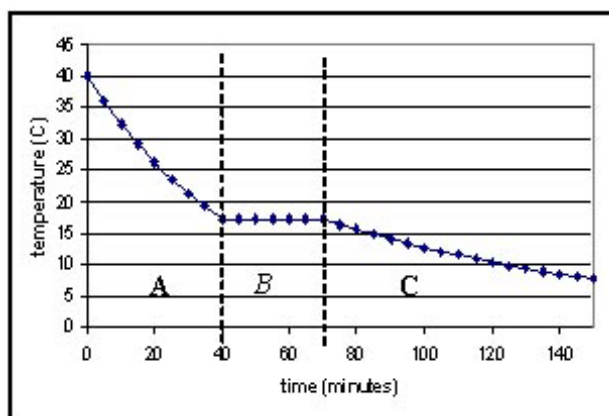
Hot water bottles and ice-packs rely on the high heat capacity of water to keep other items hot or cold. The water can lose or gain a lot of energy while changing temperature very little compared to most other substances. Other materials, such as wheat, are also used to fill heat packs.

4. Cooling by evaporation

Evaporative cooling is a very effective means of cooling, and the temperature of the wet face washer will be measurably lower. Temperature is a measure of the average kinetic energy of the molecules of the face washer and water. The actual kinetic energies have a distribution of values, and those molecules with a high kinetic energy may break the bonds linking them to the rest of the water, and leave the surface – this is evaporation. The remaining water molecules have a lower average kinetic energy, and hence a lower temperature. Another way to look at it is to say that it takes energy (latent heat) to evaporate the water, and some of this must come from the face washer, hence cooling it down.

C. Qualitative Questions.

1. Rebecca has left the margarine out on the kitchen bench, Brent finds it all liquid and puts it back in the fridge. In region **A** the liquid margarine is cooling, and loses heat in proportion to the temperature difference between itself and the air. As the margarine cools the temperature difference decreases, and it loses heat more slowly. Hence the graph is curved, and like many other physical processes (such as radioactive decay and capacitor discharge), it follows an exponential decay.



The rate of cooling also depends on the heat capacity of the material.

In region **B** the temperature is constant over time. In this region the margarine is solidifying so it continues to lose thermal energy ('heat') without changing temperature, this is the 'latent heat' associated with a change of state – from liquid to solid margarine. In region **C** the margarine has solidified and is again cooling. It is now cooling more slowly than it did as a liquid as the margarine approaches the temperature of its surroundings – we say that the margarine is coming into thermal equilibrium with its environment.

2. Heat can be added to a substance without causing the temperature of the substance to rise.

a. If there is an increase in temperature of a system then energy is transferred from the environment into the system: Heat is added to the system. This energy transfer, heat, increases the kinetic and potential energies of the molecules in the system thus increasing the temperature of the system. There can be energy transfer (heat exchange) with no change in temperature if there is a phase change. The energy is transferred into or released from energies associated with changing the bonds among molecules.

b. In ice the molecules are held tightly together. Supplying heat gives the extra energy required to break the bonds so the solid turns into liquid. This is the latent heat of transformation.

c. The water from the melted ice should be retained at least until all the ice is melted. The water allows heat to be conducted effectively from the food to the ice, and will also absorb heat from the food after the ice is melted until the food and water reach equilibrium.

D. Quantitative question:

If a small storm of 1 km radius precipitates 2 cm of water, the total volume of water precipitated is:

$V = \pi r^2 \times d = \pi \times (1000 \text{ m})^2 \times 0.02 \text{ m} = 63 \times 10^3 \text{ m}^3$. This is equivalent to $63 \times 10^6 \text{ kg}$ of water. The energy released is the latent heat of transformation, which for water is 2257 J.kg^{-1} , so the total energy released by the condensation during this storm is $E = 63 \times 10^6 \text{ kg} \times 2257 \text{ J.kg}^{-1} = 1.4 \times 10^{11} \text{ J}$.