Entropy in Your Coffee Can

Scientists use the term entropy to describe the amount of disorder or randomness in a substance at a molecular level. Entropy is important in the science of thermodynamics, which is the study of the relationships between various forms of energy, such as heat and mechanical work. There are three basic laws of thermodynamics:

1) Energy may change form (e.g., from chemical energy to mechanical energy in a car gasoline engine), but it is never created or destroyed ("conservation of energy").
2) Heat energy flows from hotter to colder substances unless work is done..
3) There is a theoretical temperature where matter would have the least possible internal energy and no disorder. However, it is impossible to reduce the temperature of any system to this temperature, called absolute zero, 0 K (-273°C, -459°F).

The second law indicates that on its own accord, heat will flow only from a hotter material to a cooler one, and not vice versa. Heat flowing into cool material will increase the entropy of the material by causing the motion of its atoms and molecules to become more disorderly. As a result, the temperature of the cool material rises; or, if a solid material is at melting temperature, the solid bonds between molecules break – the solid material melts.

It is possible for entropy to decrease in a substance, but this is offset by increasing entropy in a connected substance. For example, when a pond of water freezes, its entropy decreases, but the thermal energy released by the freezing process increases the entropy of the surrounding air, resulting in a positive change of entropy for the entire ice-pond-surrounding-air system.

1. Think about the experiment you performed with ice melting in the coffee can.

a) Explain what happened to the motion of and bonds between the ice molecules.

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b) How can you express this in terms of entropy?

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c) What about the water that was there at the beginning of the experiment? Did its entropy change? How did it change?

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d) What happened to the total entropy in your classroom (or in the universe!) as a result of this experiment? Did it increase or decrease? Why? ______________________________

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The change of entropy in thermodynamic processes can be expressed mathematically. To calculate the entropy change between two thermodynamical states, you first find a reversible path between them. (Reversible path is one which you can really reverse: for example, to change ice to boiling water, you first melt the ice and then heat the water; you do not just suddenly change the ice to boiling water.) A change in entropy is defined as the reversible heat flow q (change in thermal energy) divided by the temperature at which the heat flow occurs (T):

$$\Delta S = q/T,$$

To calculate the total change in entropy when changing from thermodynamical state A to B, you integrate to get the total change in entropy:

$$\Delta S_{A \rightarrow B} = \int_A^B \frac{dq}{T}$$

For a phase change, the change in thermal energy is:

$$q = \Delta H,$$

where ΔH is the change in the heat content (also called "enthalpy ") of the substance. For example, to melt ice, ΔH is the latent heat times the mass of the melted ice.

Note that the sign of the entropy change determines whether entropy is gained or lost in that part of the system.

1. What is the change in entropy for the amount of ice that melted in your shaded can? Is the change positive or negative?
[Hint: $\Delta S = \Delta H\ /T$, and now ΔH = 334 kJ/kg x (mass of melted ice)]

2. The amount of solar energy arriving on top of the atmosphere of Earth is 1370 $J/s/m^2$ (= the solar constant). That is, in one second, 1370 J of energy arrives from the Sun per square meter of Earth's atmosphere on top of the atmosphere. How much does the entropy change in transferring that amount of thermal energy for the Sun? The Earth? The Earth-Sun system? [Hint: The temperatures of the Sun and Earth do not change appreciably during the process, so that $\Delta S = q/T$]

3. Heat is a form of energy. The amount of energy required to melt the ice (the latent heat) is 334 kJ per kg of ice. We can compare this amount of energy with the amount of potential energy released when a 1 kg block of ice is dropped from a certain height. How high would you have to drop the block of ice in order for it to release the same amount of energy required to melt it? [Hint: The potential energy, PE, of a system is given by the equation PE = mgh, where m is the mass of the object, g is the gravitational acceleration of the Earth, and h is the height of the object.] [Note that this question does not have to do with entropy but is a neat way to compare different forms of energy.]

<u>Constants you need:</u>

Latent heat of water ice = 334 kJ/kg

Temperature of the Sun = 5800 K

Temperature of the Earth = 288 K

Gravitational acceleration of the Earth = 9.8 m/s^2