

ENTROPY AS A MACROSCOPIC QUANTITY

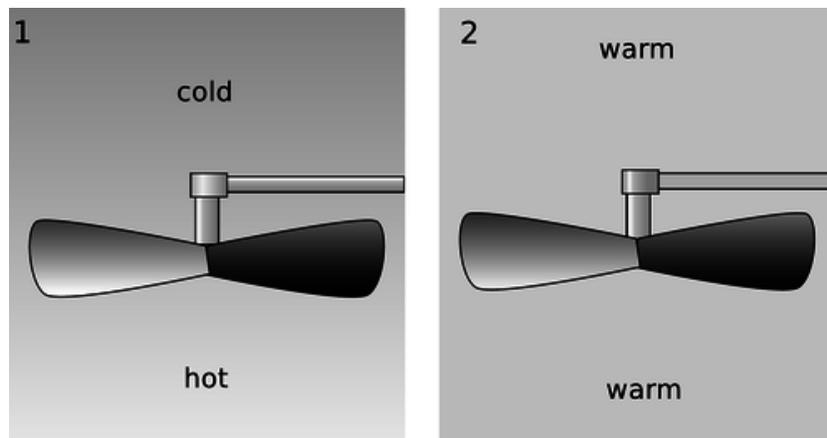
Efficiency and grades of energy

Some forms of energy are more convenient than others in certain situations. You can't run a spring-powered mechanical clock on a battery, and you can't run a battery-powered clock with mechanical energy. However, there is no fundamental physical principle that prevents you from converting 100% of the electrical energy in a battery into mechanical energy or vice-versa. More efficient motors and generators are being designed every year. In general, the laws of physics permit perfectly efficient conversion within a broad class of forms of energy.

Heat is different. Friction tends to convert other forms of energy into heat even in the best lubricated machines. When we slide a book on a table, friction brings it to a stop and converts all its kinetic energy into heat, but we never observe the opposite process, in which a book spontaneously converts heat energy into mechanical energy and starts moving! Roughly speaking, heat is different because it is disorganized. Scrambling an egg is easy. Unscrambling it is harder.

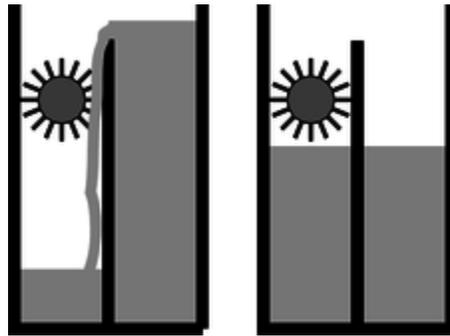
We summarize these observations by saying that heat is a lower grade of energy than other forms such as mechanical energy.

Of course it is possible to convert heat into other forms of energy such as mechanical energy, and that is what a car engine does with the heat created by exploding the air-gasoline mixture. But a car engine is a tremendously inefficient device, and a great deal of the heat is simply wasted through the radiator and the exhaust. Engineers have never succeeded in creating a perfectly efficient device for converting heat energy into mechanical energy, and we now know that this is because of a deeper physical principle that is far more basic than the design of an engine.



a / 1. The temperature difference between the hot and cold parts of the air can be used to extract mechanical energy, for example with a fan blade that spins because of the rising hot air currents. 2. If the temperature of the air is first allowed to become uniform, then no mechanical energy can be extracted. The same amount of heat energy is present, but it is no longer accessible for doing mechanical work.

Entropy



h / Entropy can be understood using the metaphor of a water wheel. Letting the water levels equalize is like letting the entropy maximize. Taking water from the high side and putting it into the low side increases the entropy. Water levels in this metaphor correspond to temperatures in the actual definition of entropy.

We would like to have some numerical way of measuring the grade of energy in a system. We want this quantity, called entropy, to have the following two properties:

- (1) Entropy is additive. When we combine two systems and consider them as one, the entropy of the combined system equals the sum of the entropies of the two original systems. (Quantities like mass and energy also have this property.)
- (2) The entropy of a system is not changed by operating a Carnot engine within it.

It turns out to be simpler and more useful to define changes in entropy than absolute entropies. Suppose as an example that a system contains some hot matter and some cold matter.

It has a relatively high grade of energy because a heat engine could be used to extract mechanical work from it. But if we allow the hot and cold parts to equilibrate at some lukewarm temperature, the grade of energy has gotten worse. Thus putting heat into a hotter area is more useful than putting it into a cold area. Motivated by these considerations, we define a change in entropy as follows:

$$\Delta S = \frac{Q}{T} [\text{change in entropy when adding heat } Q \text{ to matter at temperature } T; \Delta S \text{ is negative if heat is taken out}]$$

A system with a higher grade of energy has lower entropy.

Since changes in entropy are defined by an additive quantity (heat) divided by a non-additive one (temperature), entropy is additive.

Source:

http://physwiki.ucdavis.edu/Fundamentals/05._Thermodynamics/5.3_Entropy_As_a_Macroscopic_Quantity