Leprechauns and Laser Beams

A leprechaun uses information entropy to hide his pot o' gold, and how a laser works by the same trick.

My fourth grade teacher was a child of Irish immigrants, and sometimes told stories in class. My favorite starts like this: leprechauns are bound by a law that obliges them to do whatever you say if you catch them. One day, a man caught a leprechaun and ordered him to reveal the location of his pot of gold. The leprechaun was furious, but he had no choice. He led the man through the forest to an old tree and said, "There. Me treasure is buried under the roots of that tree; and that was the truth. →

The man needed an axe and a shovel to get at the gold, so he tied a ribbon around the tree to mark it while he went back to town for some tools. He commanded the leprechaun not to take down the ribbon or move his gold or anything like that.

The leprechaun, still under obligation, ~~sighed and~~ grumbled but agreed. When the man came back with his tools, the tree was still marked by its ribbon, but so was every tree in the whole forest. He never found that treasure.

~~I am reminded of this story whenever I'm looking for a simple piece of information in a long, complex manual.~~

The beauty of the leprechaun's trick is that the completely ribbonned forest has exactly as much information as the unribbored forest. A ribbon on every tree except one would convey as much   as a ribbon on one tree.

This "amount of information" is called entropy, and is as much a physical quantity as length, voltage, and temperature. In fact, I think that entropy is a more fundamental concept than temperature —   knowing about entropy makes it easier to understand what temperature is.

The most useful physics to know for cooking is the fact
is different from temperature.
that heat ~~and temperature are different~~. Heat is a thing,
it's a form of energy,
almost a substance. It flows from the burner to the pot of

boiling water, but it is neither created nor destroyed. It can

change into other forms of energy, or even matter — a
on the other hand,
nuclear power plant turns matter into heat. ¶Temperature, is

more abstract. It is a quantity that is equalized when things

touch: Ice and tea will exchange heat until they have the

same temperature. So will fudge and a candy thermometer, but
arbitrary
the candy thermometer assigns numbers to this mysterious

quantity. Liquids boil and foods burn at particular temperatures,
not amounts
of heat, so it is an important concept. ~~An easy~~ way to stop a sauce from burning is to
A quick
to a safe level.
add more to the pan: the heat spreads out and the temperature drops.

¶ Though we use temperature every day, it has no meaning other than marks on a thermometer unless we first know about entropy. Entropy is sometimes described as disorder or randomness, but this is not always a useful way to think of it. When I add memory chips to my computer, it is to increase the computer's entropy, but I don't want the computer to become more random or disorderly!

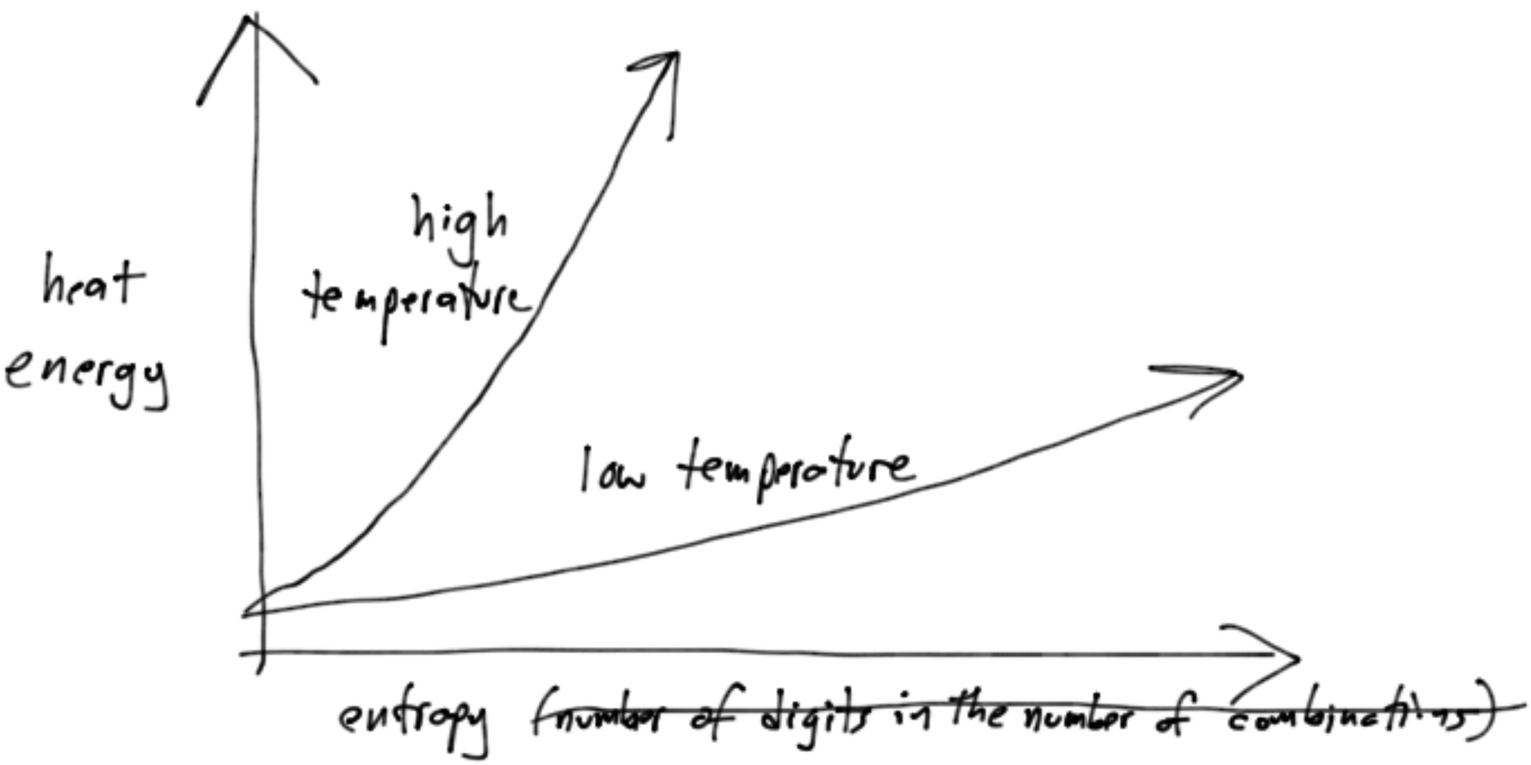
The leprechaun's trick provides a great example of entropy. The forest's entropy can be defined as the number of ways to fit ribbons on trees, with a given restriction. For instance, if the restriction is that the leprechaun can only use one ribbon, then there are as many ways to do it as there are trees in the forest. A meaning could be associated with the tree that gets the ribbon, such as "thar be gold here," but it is not necessary. ¶ If the leprechaun is allowed to use two ribbons, then there are many more ways to do it: a thousand-tree forest has $1000 \times 999 = 999{,}000$ (almost a million) ways to hang two ribbons. With enough ribbons, the leprechaun can encode complex messages. Ribboned and unribboned trees could represent ones and zeros in a binary sequence, as in a computer. But if he is forced to use nearly as many ribbons as there are trees, his options become limited again. With 999 ribbons in a thousand-tree forest, there are only a thousand ways to pick the tree that doesn't get a ribbon. And there's only one way to tie a ribbon on every tree, so if he must use one thousand ribbons, one per tree, the leprechaun can convey no information at all. "To the constant consternation of extortionists and theives," he says, tamping his pipe.

A description of entropy as "quantity of information" may sound more applicable to computers than a pot of water heating on the stove, but it's useful for both. A pot of water is made of atoms, and atoms have locations and velocities: that is, information.

There are so many atoms in a pot of water and so many ways to arrange them that the number of combinations is beyond astronomical. Instead of dealing with these big numbers, we just count digits: one million is six, ten million is seven, etc. entropy is proportional to the number of digits in the number of combinations.

Not every possible set of atom velocities is relevant for a pot of water. Fast-moving atoms have more energy than slow-moving ones, so some combinations would add up to too much energy, others too little. Only the combinations with the right total energy should be counted. This restriction is like specifying the number of ribbons that the leprechaun must use in the forest. Just like the ribbons, the amount of energy dictates the number of possible combinations. As more energy becomes available, the number of combinations typically grows, though it may grow faster in some materials than in others. This is the essence of temperature.

Temperature is the amount of heat energy we'd have to add to a material to change its entropy by a given amount. If you are familiar with calculus, it is the derivative of heat with respect to entropy. If not, just look at the graph below. Entropy is the horizontal axis, energy is the vertical, and two different materials follow the two curves. Temperature is the steepness of the curves.



A substance containing a lot of heat often has a high temperature, but not always.

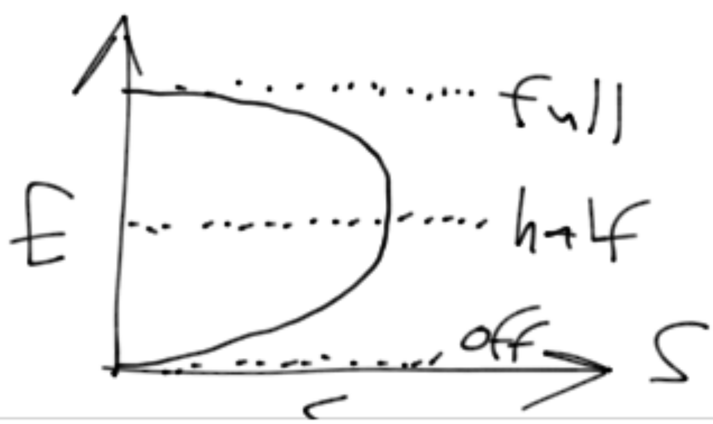
The most direct physical analogue of the leprechaun's firest is a laser beam. In a laser, a substance is restricted to only two energy levels (or a small number). The laser light comes from atoms dropping from the high energy state to the low energy one. Think of atoms in the high energy state as trees with ribbons on them and those in the low energy state as trees without ribbons.

When the laser is off, all (or most) of the atoms are in the low state. Turning on the laser involves adding energy to the system, like a forest with a small number of ribbons. Each new ribbon increases the number of combinations, so the relationship between energy and entropy looks like this:

~~The pitch of that rising slope is the temperature.~~

As the device continues to pour energy into the system, the number of possible atomic combinations grows — up to a point. When the laser reaches half-power, there are as many high-energy atoms as low energy atoms, all jumping up and down, rapidly exchanging energy. As with the ribbons in the forest, this is the point of maximum entropy. Adding more energy reduces the number of combinations. At full power, nearly all of the atoms are in the high-energy state, so the number of possible combinations is small again, like a forest full of ribbons.

The ~~curve~~ graph looks like this:



Since the curve has doubled back on itself, ~~the slope, which is~~ the temperature (slope), is negative — less than absolute zero! The laser in your CD player routinely breaks the supposed law that nothing can be colder than absolute zero. (The actual law is that nothing can reach exactly zero. The laser strives toward it from below.) It doesn't feel cold because it has a lot of heat, and when that heat is transferred to your body, it increases your entropy in the normal way: positive temperature. This is because the atoms in your body, like most materials, are not limited to two energy states.

The laser is an unusual example, but it shows us what a weird concept temperature can be, and how it has as much to do with information as it does with heat.

Since temperature is such an abstract concept, I'd like to try to convince weathermen to report the daily warmth in a more natural way — ~~for instance~~, the rate of heat transfer through skin. As a unit of energy per time, it would be measured in watts, and ~~and it would already include factors like humidity.~~

~~* No one would have to say, "Ah, but it's a dry warmth..." *~~

~~warmth~~ a chart would ~~go~~ look a bit like this:

-500 watts	Naked in outer space (all heat leaves the body)
-200 watts	Too damn cold!
-100 watts	Cozy (we have to expell our excess calories)
0 watts	Like bathing in warm blood (literally)
anything more than that	Too damn hot!

~~People with different metabolisms would have different opinions about what's comfortable, but remembering our personal calibrations would be easier than mentally correcting for important factors that are not contained in temperature, such as humidity.~~

It would be a very human-centric scale, since factors like body temperature and the way that humidity interacts with skin would have to be included in the calculation (or experiment, using a NIST-standard human). Leprechauns would just have to calibrate.