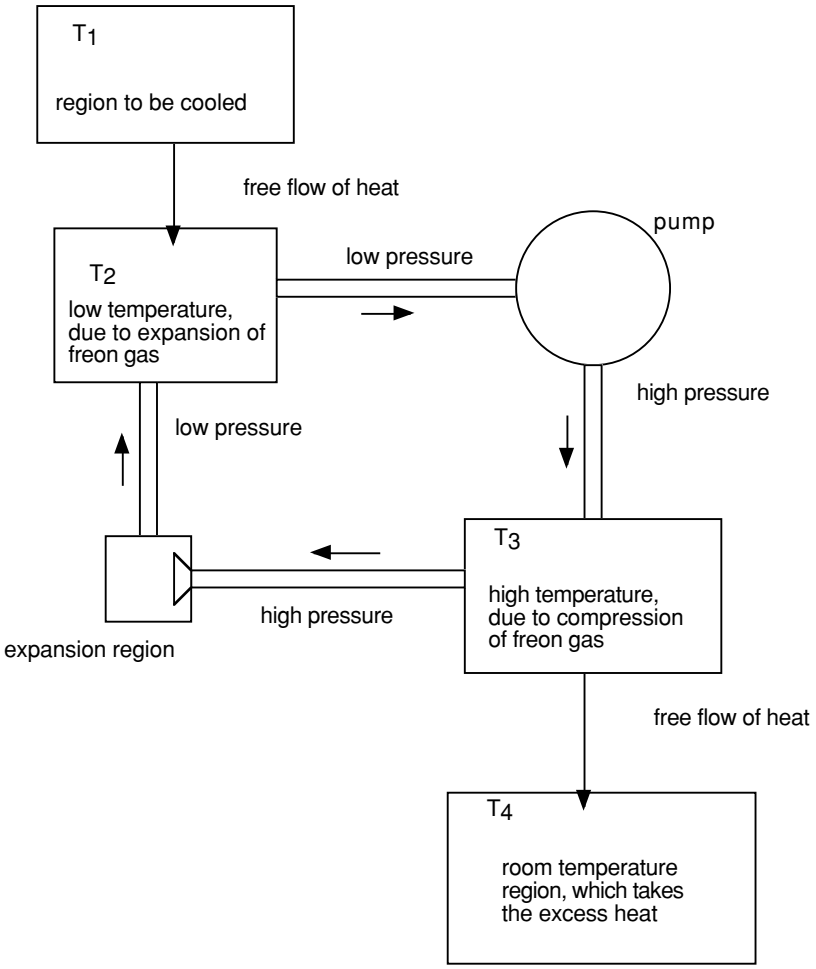
4.17 How Does a Refrigerator Work?

We saw in Section 4.16 how expanding gases cool off. This is the basis of how a refrigerator, dehumidifier, or air conditioner works. These devices use a *cycle* to continually cool something. The following figure shows the basic method:



As discussed in the previous section, the adiabatic expansion of the gas cools it off. Heat from the inside of the refrigerator will then flow into the cool gas (because $T_1 > T_2$). A pump then takes the low-pressure gas and pumps it up to high pressure, which also means it will have high temperature. This high temperature will be above room temperature ($T_3 > T_4$), which means that heat can flow from the gas into the room. The gas is then allowed to expand again, completing the cycle.

The condition of adiabatic expansion means that no heat should flow into or out of the

gas during its expansion stage. Heat should only flow in and out in the two places shown. This means that parts of the refrigerator must be well insulated.

There is no special reason why freon gas must be used except that it has the nice property that its temperature depends strongly on its pressure. Therefore, when it expands, it cools off a lot, and when it is compressed, it heats up a lot. Both of these properties are good, since the rate of heat flow in the places of heat exchange is faster the greater the temperature difference, so we want between T_2 much less than T_1 and T_3 much greater than T_4. Freon actually becomes a liquid when the pressure drops in the expansion region. This does not change the basic way the refrigerator works described here.

From this description you can see how the second law enters in. The heat removed from the inside had to go somewhere, which is the region at T_4. That is why every refrigerator has a hot radiator on the back. The refrigerator reduces entropy inside, but pays for it in two ways. First, the pump requires energy. Second, the heat given off of the back of the refrigerator *increases* the total entropy of the room. The heat given off causes more disorder, ultimately, than the increase of order gained inside the refrigerator.

Thought Questions:

1. A refrigerator does not violate the second law of thermodynamics when it operates. But does the existence of a refrigerator violate the second law? Where do refrigerators come from? Where do designers of refrigerators come from? Do natural refrigerators exist anywhere that are not produced by living things?

2. The same principles can be used to make a steam engine. You start with two regions at different temperatures (a hot region created by burning something, and a region at room temperature) and let expanding gas at high pressure push a wheel. Instead of a pump, you need a coil of thin pipe which allows the pressure of a gas to be high at one end and low at the other end. See if you can draw a diagram similar to the above to show how a steam engine works.