

## **In Praise of Entropy**

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In an exceptionally edifying book entitled “The Jesus I Never Knew” by Philip Yancey I was startled to find several references to an arcane thermodynamic property, the entropy. I was even more disturbed to discover that a fundamental concept of chemistry was included in the list of evils: “Death, decay, entropy, and destruction are the true suspensions of God’s laws;”(p.182). What caused entropy to be used in such a pejorative way? In the following essay I will explain what the concept of entropy means in scientific terms and then reflect on its place in God’s Creation. Rather than an evil to be condemned, the entropy will be shown to be an essential property of a world in which life has been created by God.

Thermodynamics is one of the triumphs of 19<sup>th</sup> century science. As part of a detailed consideration of the behavior of gases contained in pistons it was found that a fundamental property of the system was the entropy, usually denoted by the symbol S. Some other thermodynamic quantities necessary to complete the discussion include temperature, T, volume, V, pressure, P, amount of substance, m, energy, U, heat, Q, and work, W.

The First Law of Thermodynamics concerns changes in the energy for a system composed of a fixed amount of substance. It is customarily expressed by the mathematical equation:  $\Delta U = Q + W$ . Energy can be changed only by doing work on the system or by allowing heat to flow in or out of the system. There are no known exceptions to this empirical law and it forms the basis for many sciences and technologies.

The Second Law of Thermodynamics concerns changes in the entropy. For a reversible isothermal change in volume brought about by a heat flow Q, the entropy change is given by:  $\Delta S = Q / T$ . If no heat flows, a so-called adiabatic process, there is no change in the entropy for a reversible process. However, there are many processes which are called irreversible. One example is the free expansion of a gas against no pressure. The entropy change for such a process depends on the ratio of the initial and final volumes. The Second Law is often written as:  $\Delta S \geq 0$ , but it must be remembered that the conditions for such a change are for an

adiabatic irreversible process. If the science of Thermodynamics had ended its development in the 19<sup>th</sup> century, perhaps theologians would not have chosen to slander the entropy. However, attempts to understand the macroscopic laws of Thermodynamics in terms of the microscopic behavior of the constituent particles led to the development of Statistical Thermodynamics.

Whereas, classical Thermodynamics focused on ideal gases, Statistical Thermodynamics included ideal solids as well. One of the important results of this analysis is called the Third Law of Thermodynamics. The absolute entropy of an ideal monatomic crystalline solid at absolute zero ( $T=0$  K) is equal to 0. This is the state of ultimate perfection, but in the real world there are no perfect crystals and it is impossible to reach absolute zero. As the temperature is raised, the entropy increases. The value of the entropy can be calculated in terms of the vibrational motions of the atoms in the crystal. In spite of popular notions that all motion ceases at  $T=0$ , the crystal retains a ground vibrational state at the lowest temperature. At higher temperatures the crystal undergoes vibrational motions at more frequencies and the amplitudes of each mode increase in discrete amounts. The state of the crystal at  $T>0$  can be described as more disordered than the ground state, but from a thermodynamic perspective this is good (the chemical potential of the crystal decreases with increasing temperature).

Because an increase in entropy is associated with an increase in disorder (used here in a highly technical sense), popular notions of entropy have focused on the popular meaning of disorder. From a scientific perspective, consider a typical process that is of great importance to life on earth. Take a thermally isolated box of volume  $V$  and place in it an amount of pure liquid at temperature  $T$  that does not fill the box. Now watch the box and see what happens. The initial pressure in the box is  $P=0$  because there is no gas phase present. As time increases, some of the molecules of the liquid evaporate. The temperature of the materials in the box decreases because it takes energy to convert liquid molecules to gaseous molecules. The process continues until all the liquid evaporates or until the pressure of the gas in the box rises to the vapor pressure of the liquid at the now decreased temperature. When the process stops (reaches equilibrium) the entropy of the system is higher than at the start, and the system is more disordered, since liquid has been converted to gas. Is this bad?! If liquids did not spontaneously evaporate, there would be no rain. Gases are not morally inferior to liquids.

When crystals melt, the entropy of the system increases because liquids have a higher entropy than the corresponding solid at the same temperature ( the entropy change on melting is equal to the heat of melting divided by the melting temperature). Liquids are more disordered than crystalline solids, but does this mean that liquids are evil?! If there were no liquids, there would be no life as we know it. Biological life requires temperatures high enough to produce liquid water, but low enough to avoid boiling. Liquids allow biological systems to change. Biological cells are very complicated, but they look nothing like monatomic crystals. When a cell ceases to change, we say that it is dead (just like a battery).

In the physical world, the concept of disorder is not pejorative. As crystals are heated, local disorder is introduced in the form of “defects” in the crystal structure. Thermodynamically this is a good thing because the overall chemical potential of the crystal is lowered by the increase in entropy associated with the structural disorder more than it is raised by the increase in lattice energy associated with the defects. Some disorder is a necessary part of the world in which we live.

As liquids are heated under conditions where the gas pressure is equal to the vapor pressure, the system approaches a condition known as the critical point where there are large fluctuations in the local density. Life would be quite difficult under these conditions. At the critical point the entropy of the gas and the liquid are identical and it no longer makes sense to distinguish two phases. The study of the phase behavior of gases, liquids and solids is of great scientific and technological importance. Is this fascinating phenomenology an affront to God?

Rather than being an evil to be avoided, actual physical systems change until the entropy reaches its optimal value. Consider a gas placed in a closed container at a temperature below the value expected for a system in equilibrium with a liquid with a vapor pressure given by the initial gas pressure. Some of the gas will condense until the pressure attains the vapor pressure. During the condensation heat is released and the temperature of the system rises. The spontaneous process continues until the gas pressure equals the vapor pressure of the liquid. The overall change in the entropy of the system is positive, since it was carried out as an adiabatic irreversible process. Is rain bad?!

God lovingly chose to make the material world as it is. There is a notion that anything but a perfect crystal is morally inferior. What God has called good, let not man call evil. There were those in the early Church that called matter itself evil. God was pleased with His Incarnate Son. There are those today who call one of the fundamental properties of matter evil. The entropy is no more wicked than the energy. God has ordained that both properties contribute to the observed behavior of matter. Popular misunderstanding of science is no excuse for Christian theologians to misapply scientific concepts.