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State Functions via Art

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In a previous article published in this magazine chemical engineering processes were demonstrated by art*work*s. The basis of chemical engineering is thermodynamics that is the branch of physics that deals with the relationships between heat and other forms of energy. Historically, thermodynamics developed out of a desire to increase the efficiency of early steam engines, particularly through the *work* of French physicist Nicolas Léonard Sadi Carnot (1824) who believed that the efficiency of heat engines was the key that could help France win the Napoleonic Wars. As with other important laws of science, the Laws of Thermodynamics were developed through a combination of observation, experimentation, and innovation. Development of the Laws of Thermodynamics actually began thousands of years ago. Early observers and innovators took advantage of natural laws they could see every day and turned them into standards. During the nineteenth century, the Laws of Thermodynamics took leaps and bounds from theory and suggestion into accepted scientific fact. Since then, science has refined these laws into their current form.

Thermodynamic is based on four basic laws.

The first law states that the amount of energy added to a system is equal to the sum of its increase in heat energy and the *work* done on the system. The first law is an example of the principle of conservation of energy.

The second law states that heat energy cannot be transferred from a body at a lower temperature to a body with a higher one without the addition of energy. Thus, warm air outside can transfer its energy to a cold room, but transferring energy out of a cold room to the air outside requires extra energy.

The third law states that the *Entropy* of a pure crystal at absolute zero is zero. Since there can be no physical system with lower *Entropy*, all *Entropy* is thus defined to have a positive value.

The zeroth law states that if two bodies are in thermal equilibrium with some third body, then they are also in equilibrium with each other. This law has its name because it was implicitly assumed in the development of the other laws, and is in fact more fundamental than the others, but was only later established as a law itself.

A depth observation in the laws reveals that they are strongly associated with the concept of thermodynamic system that is a precisely specified macroscopic region of the universe defined by boundaries together with the physical surroundings of that region. The state of a system is described by variables known as State Functions. These are variables that depend only on the state of the system and not on its history or how the system was brought to its present state. A quantitative presentation of the laws requires the definition of basic functions such as volume, enthalpy, *Entropy*, etc. (Figures 1 and 2) where combination of these functions makes it possible to define additional ones. The major aim of this article is to illustrate these functions by means of the art*works* that make them tangible and easy to percept.

We start with *Pressure* P, the force per unit area in applied in a direction perpendicular to the surface of an object. It is demonstrated by the art*work* of Hanoch Piven, cartoonist, who was born in Uruguay. It is interesting to note that the concept of pressure appeared for the first time in Genesis 19:9: “They kept bringing Pressure on Lot …” (Figure 3).

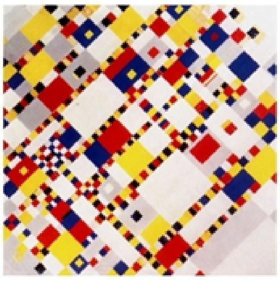

Figure 1: Enthalpy.

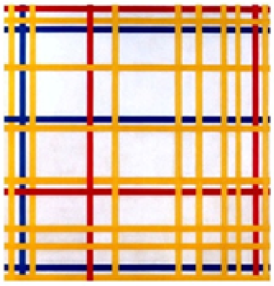

Figure 2: Entorpy.

Figure 3: Pressure.

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Volume V, the amount of space occupied by a three-dimensional body, is demonstrated by “Campbell’s Soup I” (1968) of Andy Warhol (1928-1987), an American pop artist (Figure 4).

Absolute temperature T means temperature measured on a scale, Kelvin and Rankine, with absolute zero as 0. The latter is the lowest temperature, which could occur naturally, while there is no limit to how hot an object can become. It is astounding how the art*work* “Homo Vitruvius” (c.1490) by Leonardo da Vinci (1459-1519) demonstrates this function T (Figure 5). The art*work* is also a study of the proportions with the human figure inscribed in a circle and square.

Heat Q is the energy transferred from one body or system to another as result of a temperature difference. It is demonstrated by “Eruption” (1990) of the Polish artist Jacek Yerka (1952) (Figure 6). It was Benjamin Thompson, also known as Count Rumford of the Holy Roman Empire (1753-1814), who discovered the true nature of heat as a form of energy while operating a factory for boring cannon. In the process of boring the hole in the barrel the metal got hot. Rumford was able to show that the only explanation for this phenomenon was that the *work* being put into turning the drill bit was being converted into heat.

Work W, the force times the distance through which it acts, is established for two cases. Like heat, *work* is energy in transfer formed or invested during when a process takes place between two states. W=0 is demonstrated by “Noon Rest” (1890) (Figure 7) of Vincent van Gogh (1853-1890) a Dutch Expressionist, while “The Gleaners” (1857) by Jean-Francois Millet (1814-1875), a French realist painter, illustrates W > 0 (Figure 8). The *work* function is very ancient. Already in Genesis 2:2 it is emphasized that by the seventh day God had finished the *work* he had been doing; so on the seventh day he rested from all his *work*.

Internal Energy U is that energy that a substance possesses because of the motion and configuration of its atoms, molecules, and subatomic particles. In other words, it is the energy related to the inside of a body, thus, U of a system is the sum of all the microscopic forms of energy. The internal energy of a system can be changed by a flow of *work*, heat or both, and when these are added to a thermodynamic system, they are stored as an internal energy. The “Girl With Gloves” (1929) by Tamara de Lempicka, Polish (1898-1980) illustrates this function noting that the inside of the body is convincingly emphasized (Figure 9).

Potential Energy mgh, the energy that a body possesses by virtue of

Figure 4: Volume, Warhol.

Figure 5: Absolute temperature.

Figure 6: Heat.

Figure 7: *Work*, Van Gogh.

Figure 8: *Work*, Millet.

Figure 9: Internal Energy.

Figure 10: *Potential* Energy=0.

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its position, is demonstrated by two art*work*s. mgh = 0 was advertised by Wm (Figure 10). Wrigley Jr. Company (1999) where that for mgh > 0, "The Idea" (1966) was painted by Rene Magritte (1898-1978) a Belgium Surrealist (Figure 11).

Kinetic Energy $mv^2/2$, the energy that a body possesses by virtue of its motion, is demonstrated by Magritte's art*work* "Time Transfixed" (1938) (Figure 12). The surrealistic presentation of a tiny locomotive emerging incongruously from the vent, where its smoke is nearly disappearing up the chimney, enhances the impression of speed, i.e. *Kinetic Energy*.

Entropy S of a system is a measure of its degree of disorder or randomness on the molecular scale. This quantity was introduced in the first place to facilitate the calculations, and to give clear expression to the results. From this point of view, the first and second laws of thermodynamics help to set up the foundation or *Entropy*. Thermodynamic systems tend to react in ways that increase their *Entropy*, namely, the amount of energy that is no longer available for doing mechanical *work*. If the universe is considered as an isolated system, *Entropy* increases as matter and energy in it degrade to an ultimate state of inert uniformity. Human's life is related to the amount of *Entropy* in our body. Once the *Entropy* increases to a certain level, we are no longer able to complete our required functions. We constantly increase our *Entropy* from the day we are born. However, to maintain a (healthy) low *Entropy*, a state of order until old age, we should take into account the kind of food that we eat and other activities we perform. The art*work*s, by Piet Mondrian (1872-1944), Dutch Geometric constructivist are illustrations of this function. "New York City I" (1942) represents S = 0 and "Victory Boogie-Woogie" (1943/44) S > 0.

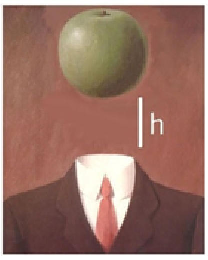

Figure 11: *Potential* Energy > 0, Magritte.

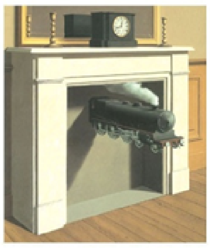

Figure 12: *Kinetic Energy*.

Figure 13: Gibbs Energy = 0, Magritte.

Figure 14: Gibbs Energy > 0, Botero.

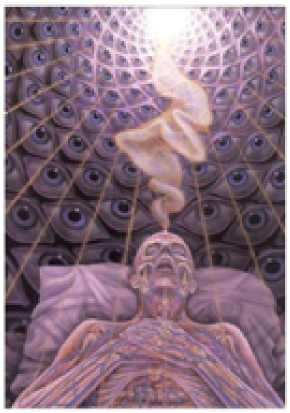

Figure 15: Dead State.

The *Gibbs function* G is the energy available to do useful *work*. It is also called Gibbs free energy and given the symbol G in honor of Josiah Willard Gibbs (1893-1903) who almost single-handedly developed both the concept and the quantitative equations that describe it. The art*work* by Magritte," Perspective: Madame Recamier de David" (1951) demonstrates the situation of G = 0 and that of Fernando Botero (1932) (Figure 13), Colombian, "Ball in Colombia" (1980) illustrates G > 0 (Figure 14).

The last function demonstrated is "Dead State", which is a state where the system has lost its capacity of delivering available energy. It is demonstrated by the art*work* "Dying" (1990) of Alex Grey (1953) an American artist of anatomy of the body (Figure 15). In conclusion it is believed that the presentation of thermodynamic functions via art makes them clearer and more perceptible.