Question:

What is a simple definition of the laws of thermodynamics?

Thermodynamics is the study of the inter-relation between heat, work and internal energy of a system.

The British scientist and author C.P. Snow had an excellent way of remembering the three laws:

1. You cannot win (that is, you cannot get something for nothing, because matter and energy are conserved).

2. You cannot break even (you cannot return to the same energy state, because there is always an increase in disorder; entropy always increases).

3. You cannot get out of the game (because absolute zero is unattainable).

Answered by: Dan Summons, Physics Undergrad Student, UOS, SouhamptonIn simplest terms, the Laws of Thermodynamics dictate the specifics for the movement of heat and work. Basically, the First Law of Thermodynamics is a statement of the conservation of energy - the Second Law is a statement about the direction of that conservation - and the Third Law is a statement about reaching Absolute Zero (0ï¿½ K).

However, since their conception, these laws have become some of the most important laws of all science - and are often associated with concepts far beyond what is directly stated in the wording. To give you a better understanding on how these laws came about and their modern scope of coverage, you have to understand when and why these laws were generated.

Our story begins back in the mid-seventeenth century. Society prior to the eighteenth century favored developments in the life sciences (largely for medical research) and astronomy (for navigation and a record of the passage of time - also a source for early mythology and folklore). Science was viewed as purely a philosophic endeavor, where little research was conducted beyond the most useful fields. Indeed, philosophy and science were inseparable in several emerging disciplines (this is always true of new fields where no firm basis of study has yet been conducted).

However, European society was about to experience unforeseeable rapid changes. Prior to the mid-eighteenth century, the general European populace randomly dotted the land in small agricultural communities, industry was run out of country cottages, and scientific developments were nearly at a standstill. Suddenly, without much of a transition, new pockets of industry arose, focusing towards large-scaled machines rather than small hand tools; large industrial corporations often crushed small agriculturally centered commerce; and in many areas, city life rendered country farm cottages obsolete. Coinciding with an era of vast social and political changes, this historic event would later come to be called the Industrial Revolution.

If necessity were the mother of all innovation, then the Industrial Revolution would be the mother of all necessities. Horrible living conditions in the overcrowded industrial cities bred a plethora of diseases and viruses. This along with other results of spontaneous urbanization demanded science again to address the problems of an ever-changing human civilization.

Science of the Industrial Age responded to such needs by centering on medical advances in the early stages of the revolution. Such was the era of crucial medical breakthroughs, and age of greatest physiologists - such as Marie Curie (radium), Wilhelm Roentgen (x-rays), Louis Pasteur (pasteurization), Edward Jenner (smallpox vaccination), Joseph Lister (bacteria antiseptic), and Charles Darwin (evolution).

Once the medical crisis was rectified, science could concentrate on the heart of an industrial society - large-scaled machinery. True of nineteenth century mass industry, the company with the greatest machines produced more products, made more money, and was consequently more successful. It is natural, therefore, that fierce competition arose to find the most industrious machinery possible, and how far the limits of these machines could be pushed as to achieve maximum productivity (without consuming much energy).

Again, society would fuel scientific advancement. Nineteenth century scientists were encouraged to study the machine, and its efficiency. To do this, physicists analyzed the flow of heat in these machines, and the chemical changes that transpire when they perform work. Thus was the establishment of modern thermodynamics. First on the agenda of this new discipline was to find a means convert heat (as produced by machines) into work with full efficiency. If such a flawless conversion could be accomplished, a machine could run off its own heat, producing a never-ending cycle of heat to work, rendering heat, converting to work, and so forth ad infinitumï¿½

The idea of such a machine that could run continuously off its own exhaust, or 'perpetual-motion' machine as it was dubbed, excited the industrial corporations, who contributed much funding for its development. However, as the research was completed, the results were all but pleasing to the sponsors. As it turned out, the very same research oriented to create a perpetual-motion machine proved that the very concept is not possible. The proof lies in two theories (now three) that are currently considered the most important laws in the whole body of science - the First and Second Laws of Thermodynamics.

The First Law of Thermodynamics is really a prelude to the second. It states that the total energy output (as that produced by a machine) is equal to the amount of heat supplied. Generally, energy can neither be created nor destroyed, so the sum of mass and energy is always conserved. A mathematical approach to this law produced the equation $U = Q - W$ (the change in the internal energy of a closed system equals the heat added to the system minus the work done by the system). By its nature, this finding did not restrict the use of perpetual-motion machines. However, the next law would deal a blow to all believers of such a wonder machine.

The first law, a bellwether in the frontier pastures of Thermodynamics, contained one major flaw that rendered it inaccurate as it stood. This law is based on a conceptual reality, one that does not take into consideration limits placed by transactions occurring in the real world. In other words, the first law failed to recognize that not all circumstances that conserve energy actually ensue naturally. As the impracticality of the first law (to describe all natural phenomenon) became apparent, a revision became essential if science hoped fully to understand thermal interactions, and thus keep pace with a machine-driven society.

Born as a modification to its older sibling, the Second Law of Thermodynamics made no early promises of importance. Further research into the natural tendencies of thermal movement in the latter nineteenth century developed a code of restrictions as to how heat conversion is achieved in the natural world. Physicists attempting to transform heat into work with full efficacy quickly learned that always some heat would escape into the surrounding environment, eternally doomed to be wasted energy (recall that energy can not be destroyed). Being obsolete, this energy can never be converted into anything useful again.

One physicist noted for significant experiments in this field is the Frenchman, Sadi Carnot. His ideal engine, so properly titled the 'Carnot Engine,' would theoretically have a work output equal to that of its heat input (thus not losing any energy in the process). However, he fell into a similar trap as in the first law, and failed to conduct his experiments as would naturally occur. Realizing his error, he concluded (after further experimentation) that no device could completely make the desired conversion, without losing at least some energy to the environment.

Carnot created an equation he employed to prove this statement, and currently used to show the thermodynamic efficiency of a heat machine: $e = 1 - TL / TH$ (the efficiency of a heat machine is equal to one minus the low operating temperature of the machine in degrees Kelvin, divided by the high operating temperate of the machine in degrees Kelvin). For a machine to attain full efficiency, temperatures of absolute zero would have to be incorporated. Reaching absolute zero is later proved impossible by the Third Law of Thermodynamics (which would surface in the late 19th century).

These findings frustrated the believers of a perpetual motion machine, and angered the industrial tycoons who sponsored the whole endeavor. Yet, not all was completely lost. Carnot's equation helped industrial engineers design engines that could operate up to an 80% efficiency level - an enormous improvement over prior designs, increasing productivity exponentially. Moreover, by reversing the heat-to-work process, the invention of the refrigerator was made possible! Yet, the greatest overall fruit of this venture was the development of the Second Thermodynamic Law, which would later achieve a legendary status as a fundamental law of natural science.

Let us shortly return to Carnot and the heat engine. The irrevocable loss of some energy to the environment was associated with an increase of disorder in that system. Scientists wishing to further penetrate the realm of chaos needed a variable that could be used to calculate disorder. Thanks to mid-nineteenth century physicist, R.J.E. Clausius, this Pandemonium could be measured in terms of a quantity named entropy (the variable S). Entropy acts as a function of the state of a system - where a high amount of entropy translates to higher chaos within the system, and low entropy signals a highly ordered state.

Like Carnot, Clausius worked out a general equation, his being devoted to the measurement of entropy change over a period of time: (change)S = Q / T (the change in entropy is equal to the amount of heat added to the system [by an invertible process] divided by the temperature in degrees Kelvin). The beauty of this equation is that it can be used to compute the entropic change of any exchange in nature, not solely limited to machines. This development brought thermodynamics out of the industrial workplace, and opened the possibility for further studies into the tendencies of natural order (and lack therefore of), eventually extending to the universe as a whole.

Applying this knowledge to nature, physicists found that the total entropy change (change in S) always increases for every naturally occurring event (within a closed system) that could be then observed. Thus, they theorized, disorder must be continually augmenting evenly throughout the universe. When you put ice into a hot cup of tea (aristocrats of the Victorian era were constantly thinking of tea), heat will flow from the hot tea to the cold ice and melt the ice in the beloved beverage. Then, once the energy in the cup is evenly distributed, the cooled tea would reach a maximum state of entropy. This situation represents a standard increase in disorder, believed to be perpetually occurring throughout the entire universe.
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