Entropy Demystified:

Potential Order, Life
and Money

Valery Chalidze

Universal Publishers/uPUBLISH.com
USA • 2000

ISBN: 1-58112-768-5

Universal Publishers/uPUBLISH.com
USA • 2000

www.upublish.com/books/chalidze.htm

About This Book

Although the concept of entropy has been under discussion for one and a half centuries, its philosophical depth has still not been properly explored and it is still one of the most complicated and controversial concepts of science. Its application to the study of social processes has started only in recent decades and no doubt this trend will continue. The author's first goal in this book is to provide those who are interested in social studies, but not familiar with physics, with a comprehensible explanation of the concept of entropy. The value of the knowledge of entropy for the social scientist is at least two-fold:

1. Entropy is characteristic of a level of disorder in any statistical system and for this reason can be successfully used for the description of the communication process, music or economic activity as well as the behavior of inanimate matter. In this use, one is dealing with the order and disorder of a system independently of physics: entropic characteristics can be used no matter what makes a system orderly or disorderly, be it the laws of mechanics or our manipulations with symbols, like the alphabet letters of musical notes. The example of the use of the entropy concept as a characteristic of any statistical system is the well known Shannon's Theory of Information which found its application not only in the technology of communications but in biology, linguistics and other areas.

2. Whenever we are dealing with matter and energy be it heat machines, biology, economy or the use of natural resources, we must take into account the second law of thermodynamics, which states that the level of disorder (entropy) in an enclosed system can not decrease and that one has to spend energy to decrease disorder in any part of the system. The processes of life and social life are characterized by increasing local order, but are still subject to limitation as dictated by the second law of ther-

modynamics. This brought scientists to the development of the physics of open systems thanks to the ideas of Schrodinger, Prigogine and others. Now we understand that the world is a place where destructive tendencies coexist with creative forces.

For many decades the traditional topic for passionate debate among scientists and moralists has been whether we are masters of our behavior or whether and to what extent we follow biological prescription - instincts. In this book, the author tries to go one step deeper, to the following inquiry: *what are the inevitable consequences of the fact that we are built from matter, and how much our willing - together with instinctive - behavior is defined and limited by the laws of physics?* Limitations imposed on life, social life, economics and the use of environment by the second law of thermodynamics are particularly interesting.

After an extensive explanation of what entropy is as a measure of disorder, the author shows how entropy can be used as a bulk characteristic to measure order. He introduces the concept of *potential order*, which characterizes the ability of an open system to become orderly or to create order in another system. Potential order is a property of fields of subatomic particles and atoms which provide for the primary organization of matter. It is also a property of complex molecules within the living cell which provide for the organized behavior of living entities. Further, human will and economic enterprise possess potential order to increase order around us, be it material order or the creation of information.

The author is showing that the second law of thermodynamics is fundamental in putting limitations on certain automatic behavioral patterns of all living creatures - including humans - such as entropy lowering activity and self-isolation from the disorderly matter surrounding us.

The entropic approach permits the author to do further inquiry into the connection between physics and economics. It is well known that the ideas of classical mechanics provided the basis for the development of mathematical economics since the time it was established in the nineteenth century. In recent decades more economists started to realize the limitation of such an approach and started to connect economic thinking with a thermodynamic approach as well as with systems' theory.

The concept of entropy in relation to economics and sociology was under discussion in the works of Faber, Georgesku-Roegen, and others. More authors started to see the deep analogy of economic development and the behavior of a thermodynamic system. After all, human activity, which is the subject of economic study, is a local entropy lowering process and it is exactly physics which can permit us to see the unavoidable limits of this activity.

The author shows that the low-entropic component of an economy, which is the order producing activity of people, should not be treated in theory the same way as the purely energetic component. On the basis of this, the author shows the limitations for the use of variational calculus in economics, discussing particularly the maximization of utility function.

In his analysis of the monetary measurement of order and potential order, the author shows that some important problems connected with the evaluation of goods produced by economy, inflation and monetary policy come from the fact that the same measuring device—money—is used for both—the purely energetic and low-entropic components of the economy.

CONTENTS

CHAPTER 1:
Entropy and Disorder[1]

The Fall Of Mechanical Philosophy

In the late eighteenth and early nineteenth centuries, scientists had a good reason for celebration and even arrogance about their understanding of the world. The laws of mechanics were formulated in all their perfection, and the world looked potentially explainable by solving sets of equations for the movement of particles, similar to what had been done to calculate the precise movement of the planets.

Many centuries earlier, at the dawn of the development of mechanics, the arrogance of science found its expression in the following proclamation, ascribed to Archimedes: “Give me a place to stand and I will move the Earth”. The triumph of science as it was known in the nineteen century led Laplas to popularize a much more arrogant teaching of mechanical determinism: if we were to know the initial coordinates and momenta of all particles in the Universe we could, by solving equations of mechanics, predict the future.

The further development of science placed a veil of doubt over this simplified picture of the world. The twentieth century brought the knowledge that what was considered a particle for purposes of mechanical calculations

---

[1] I assume that the reader is familiar with the elementary approach and conclusions of probability theory, and with the elements of combinatorial calculus. As to the introduction to the statistical concept of entropy in this book, I am giving only the most elementary formulas necessary to my discussion, as there are many books that discuss it in detail. An elementary yet quite accurate introduction into statistical mechanics is set forth in Johan D. Fast, *Entropy*.

actually has a complicated internal structure and in some respects behaves not as a particle at all, but as a wave. The development of quantum mechanics and subatomic experimental physics left little remaining of the classical belief in the mechanical determinism of the physical world.

But even in the middle of the nineteenth century, when there was a sacred belief in the overwhelming power of the equations of mechanics, practical problems made physicists look for other ways to describe multi-particle systems; one can write equations for many particles, but there is no way to solve them. Even a general solution of the equation for three interacting particles has not yet been found. Thus how can one describe the behavior of gas, each cubic centimeter of which contains $2.7 \cdot 10^{19}$ molecules?

To describe such multi-particle systems, scientists resorted to bulk characteristics like temperature, pressure, heat energy and so on. The technology of heat machines required the additional scientific study of the nature of heat. Scientists discovered limitations in our ability to extract useful energy by means of heat machines: no matter how we may perfect our technology some energy will be lost to us, in the form of heat spreading into the surrounding environment. It was also discovered that heat travels irreversibly: only from a hot body to a cold body unless we are willing to spend energy to extract heat from the cooler body. This was the discovery of the famous second law of thermodynamics. (The first law of thermodynamics states energy conservation that is not specific to thermodynamics.)

The second law of thermodynamics was a discovery of epic proportions for mechanical philosophy, which was based on equations that did not allow for irreversible processes; in theory all mechanical movements can be put in reverse in accordance with the same equations. To illustrate: if we put a planet's movement on film and then watch the film backwards, there would be no violation of mechanical laws. Yet a backward movie about the work of a heat machine would not make any sense: we would see heat traveling from a cold body to a hot body, which is thermodynamically impossible.

The German physicist Rudolf Clausius in the middle of the nineteenth century was the first to introduce a new and rather mysterious characteristic of physical systems: *entropy*. This characteristic had no analogy in mechanics, and its property is that in all natural processes in any isolated (closed) system it irreversibly grows until it reaches the maximum when the system reaches thermodynamic equilibrium. Only in some processes it may remain constant—though only approximately so. This function—entropy—is to characterize energy losses in heat machines, the spread of heat from hot to cold bodies, and other irreversible ways in which a physical system behaves.

It took the genius of Ludvic Boltzman to explain part of entropy's mystery by introducing the methods of statistical mechanics. He showed that entropy is a measure of disorder in the system, that a multi-particle system has a tendency to develop to a more probable state, and such a more probable state is a state of higher disorder. This development (toward disorder) continues until a system reaches thermodynamic equilibrium, which is the highest state of disorder for any given system.

The introduction of statistical methods into physics was quite disturbing for many whose way of thinking was trained on the beauty of the precise equations of classical mechanics. This triggered a rather painful reevaluation of philosophical principles in science. Physics had earlier been thought of as the refuge for those who seek to study orderly relations within Nature, as opposed to the uncertainty and disorder of human existence. Now with statistical methods, the probability approach and the study of disorder of many kinds are as naturally a part of physics as the equations of mechanics or an electromagnetic field. Despite the great body of results in statistical physics and its technological applications, some basic problems connected with uncertainty and probability in science are still the subject of debate.

Entropy As A Measure Of Disorder

The crucial question in the statistical description of any physical system is: how many possibilities exist for the arrangement of the elements of the system in a given space, the elements being atoms of gas, ions in crystal or stars in the galaxy. Knowing the number of possibilities, one can calculate the probability of certain positions and certain velocities for the particles. This is crucial, as systems of particles interact with each other through the interaction of particles.[2]

It makes a big difference if we are dealing with the same particles or those which can be distinguished from each other. Indeed, the probability of finding a child in the school yard is usually high but the probability of finding a certain child can be quite low. If in a vessel with air we are looking for any atom, the probability of finding it is high, yet, the probability of finding an atom of Hydrogen is much lower as there is small percentage of that gas in the air. This of course affects the physical and chemical behavior of the air in the vessel.

The concept of the indistinguishability of elements of a system is crucial in statistical physics and here is a sim-

---

[2] The analogy is a game of roulette: each time we are dealing with only one number as a result of the game, but to calculate the odds for our bet, we need to know all the possibilities of outcome.

ple experiment to illustrate this concept and its relation to order among the elements of the system. If we put a few layers of small vitamin pills of the same color and other physical properties in a glass, there will be only one arrangement of those pills even if we shake the glass and try to rearrange it. No doubt some individual pills will change position during shaking but to us they are indistinguishable, and the order of all the pills on the bottom of the glass will look the same after shaking.

If we put a few layers of N small red pills and then, above them, a few layers of M green pills of the same size in the glass, they may remain in that order indefinitely if undisturbed. But if we shake the glass thoroughly, the pills will mix and, after each good shake, the positions of the pills in the glass (or microstate, as it is called in statistical mechanics) will change.

If we continue to shake the glass indefinitely, we will witness the basic fact of disorderly changes of any system: the pills will not resume their initial order again. This irreversibility is an observable fact of nature and gave birth to passionate philosophical debates during the last one and a half centuries. The simplest way to explain irreversibility is that the quantity of possible disorderly distributions of pills is incomparably larger than that of orderly distributions, so the probability of disorderly microstates is much larger than that of orderly microstates.

Indeed there are

$$W=(N+M)! / N!\, M! \qquad (*)$$

possibilities of distribution of pills altogether, according to combinatorial calculus. Even for a small number of pills, if $N=M=50$, W equals about 10^{29}. Yet the quantity of possibilities for arrangements which we would call orderly—like in separate layers of color—is only a tiny fraction of this huge number, so the odds against reaching the initial orderly distribution of pills accidentally are astronomically small.

Our experiment with the pills gives us a good illustration of what will happen if we connect two vessels with different gases, let's say Oxygen and Nitrogen. In this case there is no need to shake the container, as molecules of gas are in constant movement. The gases will mix and there is no chance at all (or practically no chance) that they will separate again without our interference. Of course, the quantity of possible microstates of molecules of gas in any container is much much larger than the quantity of arrangements of pills in our experiment.

The classic elementary approach to the calculation of the quantity of microstates of gas is to break the space of the container into cells large enough to house one molecule. If there are Z cells and N molecules in the container, the quantity of possible arrangements of molecules in space is

$$W_p = Z! \,/\, N!\,(Z-N)! \qquad (**)$$

This number is so huge that one author[3] stated: in statistical mechanics we are dealing with numbers which are the "largest that arise in any scientific context, swamping astronomical numbers to insignificance". Nevertheless, this is the order of numbers of possibilities of molecular arrangements. Accordingly, the probability of each arrangement of molecules in space at a given moment is $1/W_p$.

This is not simply an exercise in combinatorial calculations. It was discovered that the physical properties of matter, its energy and ability to produce work, depends on the quantity of possible arrangements of particles in space and also on the distribution of the particles' mo-

---

[3] Goldstein, Martin & Ingre, *The Refrigerator and the Universe*, 1993, p. 168.

mentum. The latter is characterized by the number W_m which accounts for all possibilities of momentum distribution among particles. In the case of the pills in a glass, the momenta of the pills during each shake will depend on how energetic we are in our shaking effort. With gas, the momenta of the molecules depends on the temperature of the gas, and each molecule at each given moment will have a momentum between zero and some maximum defined for this particular temperature. For each arrangement of molecules in space there are W_m possibilities of momentum arrangements, so the total number of microstates is

$$W = W_m W_p$$

Accordingly, the probability of each microstate is 1/W. Logarithms of huge or very small numbers are handier to use than the number itself. So physicists use lnW and call it the *entropy* of a particular gas in a particular vessel.[4]

$$S = \ln W$$

Because the logarithm of the product equals the sum of the logarithms, we may split full entropy:

$$S = S_p + S_m$$

and deal with positional entropy $S_p = \ln W_p$ separately. This is convenient for us because the momental part of entropy S_m in most cases will be outside of our interest

---

[4] I omitted Boltzmann constant $k=1.38 \cdot 10^{23}$ J/deg°K—in the formula above—in order to concentrate the attention of the reader on the relation of entropy and probability. If one is to look at tables of the entropy of certain substances, one needs to know that in thermodynamics entropy is measured in units of energy divided by the degree of temperature. Unlike thermodynamics, in information theory entropy is measured in bits. Also note that information theory usually deals with logarithms with a base equal to 2, which simplifies the formulas of that theory and does not affect the conclusions in substance.

in further discussion. We will see that in most cases order in our world is actually *positional order*. Examples are:

arrangements of atoms in molecules and crystals,
molecules in a living cell,
living cells in an organism,
letters and words in a text,
houses in a city and so on.

Of course, particles of matter are usually in movement, including atoms in molecules inside of living cells. But if they are in an orderly arrangement their movement is limited by the field of other particles unless their kinetic energy is excessive and order is destroyed[5]. The key factor for the existence of order around us is that the kinetic energy of particles (temperature of the system) is kept within certain limits.

Formula (**) shows an unusual and interesting property of entropy as it is not simply proportional to the number of molecules in the container—the quantity of possible arrangements growing with N very fast. This means that generally entropy is not characteristic of this or that substance, but characteristic of the system of particles of that substance. Unlike many other physical properties, *entropy is not characteristic of matter but characteristic of the state of matter*. Indeed matter, like the gas inside a vessel, is sufficiently characterized if we know what kind of gas it is and how many molecules there are. But the same gas can be found in many different states depending on the temperature or volume of a vessel. For example, it can be in a state of liquid or even of a solid body with low entropy, if the temperature is low enough; and it can have very high entropy if it is very hot

---

[5] Excessive kinetic energy is the most usual but not the only cause for the destruction of order: a strong enough outside force field, for example an electric one, can also be destructive.

or if the molecules are spread over a large space. Gas in the vessel also can have temporary low entropy if the gas in one end of the vessel is hot and in the other is cold. Temporary because according to the second law of thermodynamics in time the temperature will equalize throughout the vessel and entropy will increase.

Positional Disorder

This elementary introduction to the concept of entropy shows that entropy is characteristic of disorder: entropy grows with the increase of the number of possible arrangements of elements in the system. In the case of gas, disorder (and entropy) is higher:

1. if we put the same portion of gas in the larger vessel, because the number of possible arrangements in space will be larger; and
2. if we increase the temperature, because the quantity of possible momenta for each molecule will be larger.

Liquid is more orderly than gas, as the molecules' movement, though disorderly enough by itself, is limited in space: in formula (**) Z is smaller as the space is smaller, so W_p is smaller accordingly. A solid body has a smaller entropy yet, as its particles are more limited in movement.

A crystal is an example of a low entropy system, as the atoms or molecules are positioned in mutual order. They are still moving but they are generally not mixing; their movement is limited as they are vibrating around certain points in space. As a result, the entropy of a crystal is considerably lower than for a solid body with an irregular structure. Still, it is not just structural order that counts in the level of entropy; it is also how closely the particles are packed to each other. Crystals of ice with poorly packed molecules have a higher entropy than a diamond with carbon atoms being close to each other.

The example of crystals, which are orderly bodies, shows that entropy—introduced historically as a measurement of disorder—may be used to characterize the level of order as well: the lower the entropy, the higher the order.

Irreversibility

As mentioned before, far reaching conclusions about the thermodynamics of any isolated system was expressed in the law that the entropy of such a system goes up or stays the same. Let's illustrate what this means in different isolated physical systems.

Let a system contain two vessels of equal volume, one with gas which has entropy S_1, another empty so entropy $S_2 = 0$. This means that the entropy of the system is $S=S_1$ as entropy is an additive value: the entropy of the system equals the sum of entropies of the subsystems.

Let us connect the two vessels. Gas from the first vessel will expand to the second vessel, and soon the pressure in each will equalize and thermodynamic equilibrium will be achieved. At that point the quantity of cells Z available for molecular arrangement will be doubled, with the quantity of molecules N remaining the same as it was in the first vessel at the beginning of the experiment. Entropy will be higher than in the beginning of the experiment, as W grows with Z.

This is a classical example of an irreversible process. Entropy grew in accordance with the second law of thermodynamics, which is also called the Entropy Law. Once entropy is increased, there is no way back, no way for the system itself to regain the initial state when all the gas was in one vessel and the other vessel was empty.

The best minds in the scientific world were bewildered about why this is irreversible. The prevailing view, at least in our day, is that randomness is an inherent part of atomic and molecular behavior and the laws of mechanics at this level work only statistically, so that we cannot expect a system to go back to its initial state despite the fact that mechanical laws would permit it. The classical explanation of irreversibility is that there is some probability of reaching the initial state, but that the probability is diminishingly low.

Thermodynamical Equilibrium

When the second law says that entropy goes up, the question is how far up? Well, for each isolated system it goes up to a point of thermodynamical equilibrium and then remains constant. If there is a higher density of particles on one end of the vessel than on another it means that entropy is lower than if the concentration would be uniform throughout the vessel. So, the concentration will equalize with time, entropy will grow until the uniformity of concentration is achieved. The same if there are different temperatures in the parts of the vessel—in the state of equilibrium temperature is the same throughout the system. As equilibrium is the ultimate end of the development of an isolated system, it is a more probable state than any other.

A following note about equilibrium is in order here. Often we depend too much on the language, taking the terms of one art and not applying it properly to another. The term equilibrium is widely used in sociology and economics. The meaning ranges from the purely mathematical understanding of it as in “equilibrium market price” to the picture that “all is well and God is in his heaven”. I have to warn the reader, that human activity is actually opposed to the state of equilibrium in the thermodynamical use of this word even when we sleep. Human activity is aimed at keeping order within the human body and the surrounding world. As we go through life we are spending energy arranging things (be it molecules or ideas) in ways exactly opposed to reaching equilibrium. If occasionally society goes through periods of tranquil life it is not because such a state of human affairs is more probable and represents equilibrium, but because the harmonious effort of many defended us from mishaps of a more probable development with growing entropy and reaching thermodynamical equilibrium.

There is a rather dramatic history in the development of the perception of the term “equilibrium” in sociology. Herbert Spencer apparently took it from classical mechanics. Then he learned in 1858 the meaning of equilibrium in thermodynamics (I assume, together with all the gloomy interpretations of that time) and this caused his “being out of spirits for some days afterwards”.[6]

On The Subjectivity Of Entropy

The following experiments are illustrative of another problem that caused debate among the creators of statistical mechanics. The problem is called the Gibbs Paradox, and demonstrates the importance of what we choose as elements of the system for the purpose of entropy calculation.

Let the first vessel contain Oxygen, and the second Nitrogen of the same pressure and temperature. When the vessels are connected the gases will mix and will never separate by themselves. Entropy will grow as in any irreversible process. This is similar to our experiment of shaking the glass with the red and green pills.[7]

---

[6] For a detailed account see Kenneth D. Bailey. *Social Entropy Theory*, 1990, p. 53-65.

[7] For calculations see Fast, J. D. *Entropy*, 1962, p. 219.

If we connect two vessels as in the previous experiment but both with the same gas, no change of entropy will occur, similar to our experiment with pills of the same color.[8]

James Maxwell asked: what if we mixed two gases thinking they are identical and later discovered they are different? We would have to correct our evaluation of the entropy in this experiment, which means that entropy is not an observable property, but depends on our knowledge about the system.[9]

This question is very important for understanding how different entropy is in comparison with other physical properties. Indeed, for a daltonic (someone who is color-blind), our experiment of shaking the red and green pills is the same as an experiment in which there were only red pills. Yet if we know that the pills are different, the entropy after shaking is different in these two experiments. For Maxwell himself, with all the laboratory equipment that existed in his time, two isotopes of oxygen would be indistinguishable yet entropy grows when they are mixed.

Consider a different approach. If we number each red pill in some orderly fashion in our red pills shaking experiment, we would have to conclude that after shaking the positional entropy increased, as the initial order

---

[8] These experiments are a good illustration of the fact that entropy is the measure of disorder among elements in a system; it is a property of a system which may contain matter, and not a property of matter as such. This immaterial character of entropy permits us to use it to characterize a system of any elements, be it particles, information, logical statements and so on.

[9] Maxwell's article "Diffusion" written for *Encyclopedia Britannica*. See discussion on Gibbs Paradox in Stephen G. Brush, *The Kind of Motion We Call Heat*, 1976, p. 592.

would be destroyed. So Maxwell's question is not trivial at all, and cannot be answered by a recommendation to examine the elements more carefully before mixing them. The depth of his question is in the concept of indistinguishability. If one day we discover that each molecule of the same gas has individual traits, the result of our calculation of entropy and our criteria for order of a system of those molecules will be different.

Of course, in this case one must remember the difference between theoretical knowledge—that elements of the system differ from each other—and the physical consequences: if there are none of those, there is no reason to treat those elements as distinguishable for the purpose of calculating entropy. Indeed, if there is a sequence of molecules A,B,C,D but the molecules are absolutely the same, that sequence will behave physically just like sequence D, B, C, A. In other words, it is for us to choose what to count as elements of the system, but it is not for us to dictate to nature what produces the physical effect. If gas with numbered molecules behaves the same as with indistinguishable molecules, physical entropy will not be affected by the fact that we can distinguish the molecules.[10]

This is a problem which arises only in the statistical approach to entropy. Indeed in the thermodynamical (not

---

[10] Often it is important to know in which sense elements are indistinguishable. Socially we are dealing with two portions of humankind: those we know as individuals and those we know from opinion polls and other social statistics. The majority of elements of the system called humankind is indistinguishable to us, so we accept a statistical description of that system. If persons A and B are of the same qualification and general behavior, replacing one with another in a production line will not affect the production process so for that matter they are indistinguishable. Yet, they are different to those who know them.

statistical) approach if there was a change of energy ΔE due to a change of entropy ΔS, then

$$\Delta E = \Delta S\ T,$$

where T is temperature. Peculiarities of entropy definition simply do not exist in thermodynamics if there are no corresponding changes of energy as a function of temperature.

Maxwell's question gave birth to a discussion on the extent to which entropy is subjective. In this discussion one should remember the difference between the following two questions:

1. Does the state of a physical system depend on our knowledge of the initial state of that system? and
2. Does our knowledge of the state of a physical system depend on our knowledge of the initial state of that system?

Since Maxwell's time, the extent to which our knowledge of entropy is subjective remains an open question.[11]

In physics the thermodynamical meaning of entropy is a good guaranty against subjectivity: we are dealing there with measurable quantities of temperature and energy and it is not for us to choose what brings a measurable effect.

In cases outside of thermodynamics, when we want to use the concept of entropy for evaluating disorder and order, the choice of elements of the system can be arbitrary and depends on our needs and understanding of a particular system. Disregarding particles of dust when we want to evaluate the order of the movement of billiard balls is an easy choice under average conditions, but in a precise game dust may interfere with the interactions of the balls. Statistically this dust is similar to noise in the

---

[11] See valuable overview of this problem in "How subjective is entropy?" Kynnet Denbigh in *Maxwell's Demon. Entropy Information Computing*. Harvey S. Leff and Andrew F. Rex, ed.

information flow—noise can be of a level that we can easily disregard, or it can interfere with communication. Analysis of the interaction of noise and useful signals actually brought to life Shannon's theory with its first use of the concept of entropy outside of physics[12].

Depth of Knowledge

There is another potential confusion we should keep in mind: entropy depends on the level we care to take into account in our description of disorder in the system. In our discussion about gas, following the great thinkers who developed statistical mechanics, we ignored many things that could interfere with the calculation of entropy: quanta of light and other radiation that go through the gas and might interfere with the behavior of molecules; and high energy particles of cosmic rays that may from time to time hit the molecule and change its momentum. We also dealt with atoms as a whole and ignored the movement of electrons and other particles inside the atoms of that gas. In calculating the entropy of pills in the glass we did not take into account the particles of dust that might cover the pills. So it is for us to identify the elements of a system that are under discussion when we describe the level of disorder of that system. This is an example of typical scientific idealization of the system under study.

The real question is not about the depth of our knowledge of a system. We can go as deep as our abilities to calculate carry us: we may choose to count each particle to be found within the system. The real question is: what is important to count for the noticeable effects we care about? Indeed, in an explosion of fuel mixture with air in

---

[12] Claude E. Shannon, The Mathematical Theory of Communication.

an engine, our calculation of entropy is good enough without taking into account passing cosmic rays, because their effect is discountable. Yet if we are to calculate the state of vapor in a device for the observation of high energy particles—a Wilson camera—cosmic rays are exactly what should be taken into account.

A simple example from an entropy-lowering activity of humans: by weeding the garden we produce order. The system here is the garden, and the elements of the system are the cultivated plants and the spaces between them. Weeds are creating disorder; by removing them we decrease entropy in this system as far as an aesthetic evaluation goes. Yet from the point of view of physics, by replacing weeds with air we actually increase the entropy of the garden, due to the fact that weeds are living organisms built from organized matter having entropy lower than that of air.

At least we gave an answer to one part of the question about the possible subjectivity of entropy: if the choice of elements of a system is subjective, then the level of entropy calculated is also subjective. As we proceed with our discussion on the entropy of life and social life, we will see many examples of the subjective nature of entropy: literally, one man's order can be another man's mess.

Where Is That Isolated System?

The second law of thermodynamics is well proven and helps to calculate the behavior of statistical systems.[13]

---

[13] There are voices of doubt about the applicability of the second law of thermodynamics to the processes of life. I don't see a reason to join the critics and in this book the econd law, as far as a truly insulated system is concerned, is treated as one of the major commandments of Nature.