HUMAN SOCIETIES

A Curious Application of Thermodynamics

ERICH A. MÜLLER
Universidad Simón Bolívar • Caracas 1080, Venezuela

There is a loose analogy between the intermolecular forces that govern the observable behavior of fluid systems and the social forces that drive human behavior. Based on this premise, at least in principle, we can use thermodynamics to describe social systems. This paper will put forth some ideas, basically similes, that will help understanding of some common social situations, such as divorce and racism, through thermodynamic reasoning.

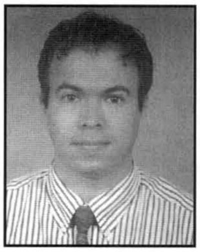
The origins of classical equilibrium thermodynamics as we now know it rest on the early findings of Watt, Clausius, Carnot, Joule, and Gibbs, along with many others. The results obtained by these early thermodynamicists were based on careful and systematic study of idealized thermal systems. Curiously, none of these "founding fathers of thermodynamics" had an appreciable comprehension of the exact constitution of matter. As an extreme example, one can point out how Sadi Carnot established the second law of thermodynamics without knowing the law of conservation of energy or the molecular nature of matter. In fact, he had an erroneous idea of what heat was, even though that quantity was the basis of his analysis. The relations and results obtained in this early classical thermodynamic period are independent of the actual nature of the systems studied and are, indeed, very general. This happy occurrence is the reason we can extrapolate the fundamental concepts of thermodynamics to other modern disciplines (*e.g.*, geology,[1] information science,[2] and medicine[1]) if the analogies are carefully made.

Nowadays, we have elucidated many secrets of the nature of matter. Statistical thermodynamics faces the challenge of predicting macroscopic behavior of systems through knowledge of intermolecular interactions and appropriate averaging among the large number of molecules that constitute a system. It is fascinating to see how the statistical mechanical predictions line up perfectly with the earlier classical results. For example, for early scientists pressure was simply a property that described a system and could be related to work or energy. Today, we understand pressure as a result of forces between molecules in a fluid. In other words, today we can somehow understand the collective behavior of the system if we comprehend the interactions on an individual level.

THE INTERMOLECULAR POTENTIAL

In nature, molecules interact among themselves by means of forces that translate into the observable behavior of common substances. A few examples are the existence of a particular temperature at which liquid boils, the reason that two substances mix while others do not, and peculiar behavior such as ice floating on water—all of which can all be explained once we understand the molecular forces.

Even the most insignificant molecule of the simplest compound interacts with its neighbors by means of specific forces. The underlying cause for the presence of these forces is the physical separation of positive and negative charges in the atoms. The fundamental electrostatics and quantum mechanics needed to fully explain the nature and form of intermolecular forces are beyond the scope of this discussion. It will suffice to understand that if two atoms attempt to come too close to each other there will be an electrostatic repulsion between them. A macroscopic manifestation of this is the fact that matter cannot occupy the same space; in a simpler fashion, we witness this repulsion when two billiard balls collide. On the other hand, in atoms and molecules the electrons are not fixed in their orbits but rather move around in average locations. These fluctuations in position lead to fluctuating molecular dipoles, and they account for a weak type of attraction among molecules (sometimes called dispersion, or van der Waals forces). It is this attraction that accounts for the existence of condensed phases in which



***Erich A. Müller** is Professor at Simón Bolívar University (USB). He received his engineering and MSc degree at USM and his PhD at Cornell University. His research programs include molecular simulation of complex fluids and the production of software for chemical engineering applications. He is author of the text* Termodinámica Básica *(editorial Equinoccio, 1991).*

molecules are closely packed. These attraction forces are of rather short range and are basically imperceptible if the centers of the molecules are separated by more than three or four molecular diameters. At larger distances, the majority of molecules do not interact directly.[*] (See Figure 1.)

Instead of speaking of forces, thermodynamicists prefer to talk about potentials, whose variation with respect to distance represents the force. Potentials have the advantage of having units of energy; thus a discussion of some concepts is simplified. A typical potential function has basically three zones. At short distances, the potential is positive and becomes larger in magnitude as molecules come closer together (indicating an increasing repulsion). At intermediate distances there is an attraction. The potential is negative and, in fact, presents a minimum corresponding to a distance at which the molecules find a balance between attractive and repulsive forces. Lastly, at large distances, molecules do not interact directly and the potential is effectively zero.

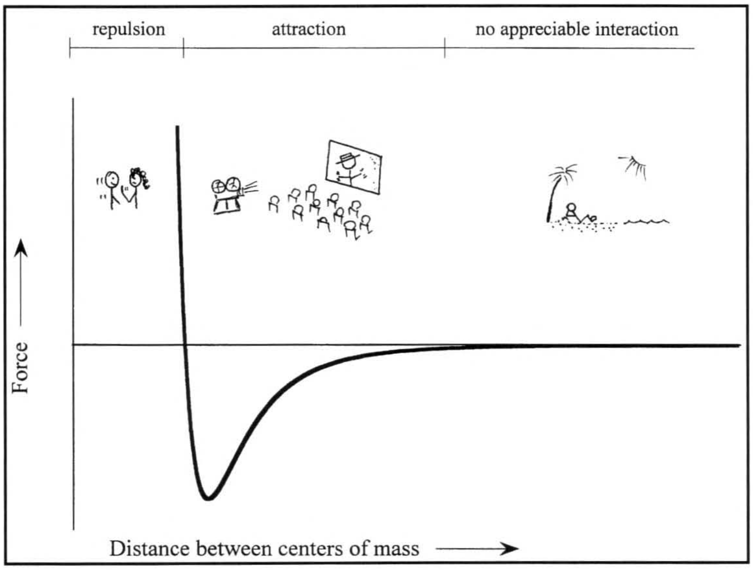


Figure 1. *The solid line shows in a qualitative way the intermolecular force for two simple molecules as a function of the distance between their centers. A positive value indicates repulsion among molecules, and a negative value, attraction. The relation to human interactions is evident. An isolated individual (the sunbather) is at peace without interactions from other humans. Nevertheless, he may come relatively close to other individuals for certain occasions (like going to the movies). Too close an encounter, however, usually leads to repulsion.*

THE INTERHUMAN POTENTIAL

The central point of this essay is that with a little bit of imagination, one can see that the social behavior of humans may be governed by an "interhuman potential" similar to that of insignificant molecules. To explain, let us assume we are studying people at a large fancy party. As guests enter the ballroom, the first thing they do (after serving themselves a drink) is to mingle, wandering without direction. They place themselves at judicious distances, not too close but not too far away, from others—a distance corresponding to the minimum of the interhuman potential. If we attempt to get too close to an individual, there will be an inherent repulsion. It is the typical discomfort we feel when we are approached by a "close-talker" and are compelled to take a small step back, thus regaining the appropriate distance. It is clear that two people cannot occupy the same space; thus repulsion becomes infinite at extremely short distances. On the other hand, one will rarely be isolated at a large party and somehow will be attracted to some of the clusters. Humans are social beings, attracted to their fellows. Lastly, the presence of persons at a large distance away will not affect us. We do not know, and usually do not care, who is at the other end of the ballroom.

An interesting point of this logic is that both at a human and a molecular level, even when the individual interactions may be somehow different and the fluctuations around the mean significant, the ensemble will have seemingly homogeneous properties if the number of individuals studied is extremely large.

FLUIDS AND SOCIETIES

If we start from the premise that molecules and humans are governed by roughly similar potentials, thermodynamics (which serves to study and comprehend the former) may well describe the latter. Moreover, the thermodynamic laws applicable to fluids may possibly describe some aspects of human society.

In a multicomponent fluid, each type of molecule will have its own peculiar interaction. Even though the qualitative shape will usually be similar, there are differences among species (*e.g.*, if there are two types of molecules, say type A and type B, the potential minimum might be deeper between self-self A-A and B-B interactions than with unlike A-B interactions). Additionally, other types of specific interactions may also be present due to multipolar forces (dipoles, quadrupoles, etc.), association forces (hydrogen bonds, for example), and others. In a complex fluid there might also be symbiotic relations—two molecules may bond for mutual benefit (as exemplified by electron-transfer bonds), or there may be a strong repulsion due to dissimilar cross-interaction forces. Similarly, in human society, our own individuality will draw us to some other people while we strongly dislike others.

Racism • Segregation (or intermolecular racism) is common in fluid systems. A classical example is an oil droplet in water. An oil molecule, being so different with respect to its

---

[*] *An exception to this comment are the forces among ionic fluids (salts dissolved in water, for example) and polar fluids where long-range forces, due to strongly anisotropic charge distributions, are present.*

immediate surroundings, will tend to migrate to a border, avoiding unfavorable interaction with the homogeneous water majority. If other oil molecules are present, they will attempt to aggregate, thus achieving a more stable system and forming a "molecular ghetto." If oil molecules are present in significant numbers, a phase separation will occur, creating a region where all interactions will be favorable (since all of the members of the phase are compatible). The border with the aqueous phase will not be free from a high interfacial tension. The analogy with a homogeneous society, where a small racial, cultural, and/or religious group appears is obvious. World history is plagued with examples such as the persecution of our native inhabitants during the colonization of the Americas, the separation of Pakistan and India, the Arab-Israeli conflict, and the disintegration of the Balkan states.

A very heterogeneous fluid may mix under one of two conditions: 1) by constantly adding a high influx of energy, or by 2) modifying the interactions between the molecules. Following the above example, we can vigorously shake a water/oil mixture, forming a homogeneous system during the process (much in the way one mixes a salad dressing). But the result is not the most stable equilibrium state, and as soon as the energy flux is suspended, the system will spontaneously phase separate, independent of the previous effort to keep it homogeneous. The old Soviet block comes to mind; it disintegrated into its "natural" communities once the stronghold of a central government ceased to exist. All the homogenizing efforts through the decades were futile since they did not alter the basic relations between the republics.

The second method to obtain homogeneity is to modify interactions between molecules by adding amphiphilic molecules (molecules that present one type of behavior on one side of the molecules and a different behavior on the other side). Common examples are soaps and detergents. These molecules, when added to oil/water systems, may convert the system to a stable emulsion. This suggests a rather foolproof way to eliminate racism and intolerance among divided societies. It is essential to maximize the number of people that can be accepted by both conflicting groups, thus minimizing the formation of distinct "phases."* In South American societies, existing races have crossbred since colonial times and the majority of inhabitants have some amount of racial mixture in them. In these societies, racism as such is unheard of since this mixed group does not differentiate by race and "accepts by equal." In a similar fashion, the existence of a large middle class in a country is the only sensible thermodynamic path to obtain social stability.

Love • Other important interactions among molecules are those of association. They are characterized by being specific, discriminatory, and producing a much stronger attraction than van der Waals forces. A typical example is the formation of hydrogen bonds. At a molecular level, two molecules forming a hydrogen bond will maintain themselves at a much closer distance than that expected for normal molecules and will be bonded for a longer time than two non-associating molecules. Again, the analogy between this behavior and that of humans is apparent. There are certain humans who form tightly bonded pairs or clusters for relatively long times. Buddies or lovers, certain humans form bonds among themselves that have the same characteristics as hydrogen bonds.

Hydrogen bonds are not chemical, but physical, in nature and thus may be fragile. Usually, the collision with a third molecule produces a perturbation large enough for the bond to break. To keep the energy at a minimum (the thermodynamic equilibrium condition), it is possible that one of the molecules of the broken pair bonds with the third one (molecular infidelity and divorce). There are also metastable and short-lived bonds (molecular one-night stands).

Macroscopically, an associating fluid is denser and will persist as a condensed phase at higher temperatures than its' non-associating counterpart. In a similar fashion, societies where the concept of family is deeply rooted tend to be more solid and stable. Models of collective societies like the classic Spartan or the modern Israeli kibbutz are based on the thermodynamically inconsistent idea that they are solid due to their number and collective behavior. The solidness of a society depends on the strength of the particular bonds among their members. Here, for example, is the understandable force of the Mafia. There is no human force greater than love, and therefore it must be the base of a stable society. Hate, on the other hand, is a clearly repulsive force, and it tends to disintegrate societies the way a high temperature disperses a liquid into a gas by boiling.

Resistance to Change • Another aspect of society that can be considered from the viewpoint of thermodynamics and statistical mechanics is the ability to relate the capacity for change to transport coefficients. It takes a while for society to move from one state to another. The laws of irreversible thermodynamics indicate that the rate of change depends basically on two parameters: the driving force and the transport coefficient,* which is a property of the substance. In a society, the driving force is the real need for change. The transport coefficient depends on the overall cultural level of the members, their education, and their willingness to undergo change. Large changes may be due to large values of the driving force, of the transport coefficient, or both. Political revolutions are characterized by large driving

---

* *Strictly speaking, only a small amount of surfactant is needed to emulsify oil and water. Therefore, only a small "middle" class would be needed to get some mixing of society as stated. A large amount of surfactant is needed to form a microemulsion where the mixing is at a fine level, thus obtaining a stable society.*

* *For example, the flow of a liquid will depend on the pressure gradient (driving force) and its viscosity (transport coefficient).*

forces; on the other hand, the so-called German and Japanese miracles following WW II can be explained by high transport coefficients.

The heterogeneity seen in all societies has clear resemblance to fluid transport, say through a pipe where molecules move at very different relative velocities, even when the flow seems uniform. We notice that molecules near the wall do not move while those at the center move with the highest speeds. In society, we have individuals who cling to the walls of the "status quo" while other, more progressive types, usually lead the way.

THE LAWS OF LIFE (AND THERMODYNAMICS)

Among the first things a student of thermodynamics learns are the statements of the laws of thermodynamics, postulates written in stone that indicate the way in which energy is transferred. The first law guarantees that we cannot create energy—a lesson all humans have experienced. Things are not done by themselves; someone has to do them. The second law is more difficult to put into human terms and is therefore frequently ignored, with tragic results for society. It places restrictions on the flow of energy, giving it a preferred direction. This is done by defining a mathematical quantity called entropy, which upon being measured during a spontaneous change in an isolated system must increase (almost in the same fashion as that thing we call time). A common, albeit undesirable, analogy of entropy is as a measure of disorder in a system.

The second law tells us there is no reasonable expectation that an isolated system may order itself spontaneously. The janitor of our school knows this quite well since every day he places chairs in a perfect Cartesian ordering, only to find them in total disorder at the end of the day. The only way to order either molecules or humans is through a transfer of energy between the system and its surroundings. Societies, being a collective of human beings, cannot escape the consequences of the second law. To obtain an ordered society (low entropy), one has to balance the entropy generation by inputting large quantities of work into the system via a strong government. The Marxist experiment has lasted for over eighty years, but was thermodynamically inconsistent and doomed to failure from the start. Dialectic materialists believed that societies would eventually tend to become ordered and organized systems in which the government would eventually disappear. The second law states quite the opposite—a society without government tends to total disorder and anarchy. Curiously enough, Marxist societies evolved according to thermodynamic postulates, evolving into strong dictatorships. It seems that large empires (complex systems with lots of order and very low entropy) may not survive without disordering the environment and will eventually collapse when the energy transfer through its boundaries is stopped.

Civilization • Human society has evolved from a rather chaotic ensemble of cavemen to organized civilizations with a large number of specialized individuals. Energetically speaking, the more complex a society becomes, the higher its energy dissipation rate. This seems to contradict the second law in the sense that isolated systems seek chaos and a homogeneous energy condition. But human societies are open systems, with significant interactions with their surroundings. They can only be maintained by an abnormally large amount of energy. One can easily imagine the catastrophic consequences of a city left without electricity. The fact that some societies tend to decrease their entropy while increasing their energy consumption implies that there must be some parts of the biosphere that suffer the consequences, increasing their entropy in a corresponding way. In fact, the appearance of civilization is regarded as a mechanism to hasten the thermal death of our universe.[3] Individuals themselves[4] and other animal societies, such as ants,[5] can be studied in the same way.

TO OTHER FRONTIERS

The obsession of a thermodynamicist to explain the world in which he lives in terms of his basic laws is an old, long, and endless one. Many of us attempt to explain economy, understand computers, analyze art and poetry, or prove the existence of God through our skewed optic. The article by Kyle[6] does a nice job reviewing some of these attempts.

In spite of this, and without wanting to appear ostentatious, it may be suggested that sociological studies must recognize the existence of two points of view: a global, or collective, one and an individual one. Generalities or laws can be applied on the larger scale since they conform to ensemble averages of individuals' behavior. In this sense, human communities parallel simple fluid systems, which we believe are better understood.

ACKNOWLEDGMENTS

The author is grateful for the comments and discussions with Professors N.F. Carnahan of Rice University, N. Ruiz of the Universidad Central de Venezuela, and J.-M. Ledanois, K. Jaffé, and S. González of the Universidad Simón Bolívar.

REFERENCES

1. Bevensee, R.M., *Maximum Entropy Solutions to Scientific Papers,* Prentice-Hall, New York, NY (1993)
2. Janes, E.T., "Information Theory and Statistical Mechanics," *Phys. Rev.,* **106**, 620 (1957)
3. Zotin, A.I., and I. Lamprecht, "Aspects of Bioenergetics and Civilization," *J. Theor. Biol.,* **180,** 207 (1996)
4. Schrödinger, E., *What Is Life?,* Cambridge University Press, Cambridge, UK (1944)
5. Jaffé, K., and C. Fonck, "Energetics of Social Phenomena: Physics Applied to Evolutionary Biology," *Il Nuovo Cimento,* **16,** 543 (1994)
6. Kyle, B.J., "The Mystique of Entropy," *Chem. Eng. Ed.,* **18**(2), 92 (1988) ❐