

Chapter 1

Dealing with Entropy on a Daily Basis

In elementary and even high school education, a great deal of time is spent teaching students the basic notions of force, energy and power, but the word “entropy” is often not even pronounced. It is only those who specialize in the sciences who will become familiar with it. This is a dramatic shortcoming of our education system, as without some understanding of what entropy means it is essentially impossible to comprehend what is going on in the environment and to make the right decisions for its defense.

Historically, the notion of entropy was developed to understand what happens when one transforms heat into mechanical energy. This is what one did in the steam engine: one burned coal and the engine produced work. But it appeared that only a fraction of the energy stored in the fuel being burnt was transformed into mechanical energy. Where did the rest go? On the other hand, mechanical work can be transformed into heat without any loss. Why is this? Before we deal with these questions in a further chapter, it may be useful to show by a few examples taken from our daily life that, just as Monsieur Jourdain in the play by Moliere “Le bourgeois gentilhomme” was speaking in prose without knowing it, we are every day dealing with entropy without knowing that this is what we are doing.

1.1. Entropy in the household

Physicists like to do what they call a “gedanken experiment”, which consists in imagining doing a certain experiment and drawing consequences from its (virtual) outcome.

So let us do the following gedanken experiment. Imagine that in our home we stop doing all the things that we do everyday to keep it in good order. We do not make our beds anymore; do not give the children their bath; we do not clean the dishes; we use up

all our clean sheets, underwear, shirts, dresses and so on and just pile them up, or rather let them lay anywhere in the house when they are dirty; we never use a broom, vacuum cleaner or other instruments developed to keep the house clean of dust and dirt; we never put back a paper that we have taken out of a file; never get rid of the garbage; stop paying our electricity, gas and water bills; never paint the house, inside or outside; never do any repair work; and so on. Sounds like paradise, doesn't it? But how long do you think you could hold on, before running out of the house and looking for shelter somewhere else?

Of course, remember, this is a gedanken experiment: I am not really suggesting that you do it to find out what the outcome is. This is precisely the beauty of a good gedanken experiment: you do not have to do it to see the consequences.

So what have we learned? Something we knew of course all the time, namely that our daily life can only be sustained if we keep putting things back in order. Not that we like doing it, but one quickly learns that there simply is no other way. The reason we do not like doing all these things is also pretty obvious: they all require work, or money that we usually earn by doing work (although I am aware that this may not be true for everybody, but those people who do not have to work also have servants that do all these things for them, so they are not concerned by our gedanken experiment anyway).

Restoring order, or reducing the amount of disorder, requires work. Physicists say that an energy input is necessary to lower the entropy of the system. Disorder in a household is not a quantity that we can define exactly, although we well understand what it means. Physicists have of course an exact definition for entropy, which the interested reader can read about in a later chapter.

Before giving more scientific examples of how an energy input is necessary to fight disorder, let us however continue a little bit with our example and illustrate the meaning of an entropy crisis.

1.2. An example of an entropy crisis at home

So far, our gedanken experiment was implicitly assuming that we were stopping doing all these things from our own will, simply because we did not like doing them. But what if we really *could not* do them?

Many of us have experienced how minor problems, such as our cleaning person suddenly not being available, or the momentary absence from home of the mistress of the house, can disturb our daily life. Usually things do not get out of hand, but a sense of impending crisis may be felt.

Things can be more serious. We may suffer from a long illness; we may lose our job. We may indeed not be able to pay our bills. Such situations are not uncommon, and are well known to social workers. If the mother is so depressed, or tired because she works night shifts, that she does not get up in the morning, children do not get their breakfast, nor the sandwich they are supposed to take to school; soon they will stop doing their homework, and get into trouble in many ways. If society is unable or unwilling to extend the necessary help to this family, it may eventually disintegrate with children becoming delinquent and the parents (often a single one) homeless on the street. These things do happen. Entropy has won, because insufficient resources were available from the outside world.

1.3. Where does all the disorder go?

Let us go back to our well ordered household, where the parent in charge does get up every morning, does the needful, everybody is fed, and the house is kept clean. Water, electricity and gas flow freely since we pay our bills, all appliances such as dishwasher, washing-machine and drier are operating, floors are vacuum-cleaned, life is beautiful. But where did all the disorder go?

Well in fact we know that too. Garbage was collected, used waters containing the dirt that came out from dirty dishes and laundry and chemical used for those purpose were evacuated. In

short, disorder was transferred from our home to the outside world. And the outside world — society — will have to deal with it in some way. Garbage and used water will increase what we call pollution of the environment, unless more energy resources are spent to recycle or treat them. But in many locations on earth, garbage is not collected, and used water not treated because the necessary resources (in the end energy) are insufficient. Streams get contaminated, water is below drinking quality, dangerous diseases are rampant.

Control of disorder and use of energy are two aspects of the same problem. The less disorder we produce, the less energy we shall need to put things back in order. In Japan, tradition requires that shoes be left at the door step: dirt left out of the house will not need to be cleared. Likewise in my childhood in France it was customary to take your shoes off when entering an apartment and you would be given a couple of “patins” over which you would glide on the beautifully clean and shining wooden floor. If we drill a hole in a wall, it is best to collect dust immediately rather than to have to vacuum-clean the entire floor later on. A good housewife and her husband know for sure many tricks to reduce disorder to a minimum in their activities. They will also try to teach one or two things to their children so that they will not mess up too much.

The amount of disorder that can be tolerated is of course a matter of local customs and standard of living. Some housewives will not feel comfortable unless the house is cleaned from top to bottom every morning. Others will be more lenient. The amount of disorder that will be tolerated will also depend on what machines are available to help the housewife in her work, provided electricity is available and affordable to operate them, and water and the chemicals needed can be purchased at little cost. When there were no washing-machines, for instance, and the laundry had to be cleaned by hand, I imagine that underwear, shirts and so on were not declared “dirty” as quickly as they are now in western countries, and still households would operate reasonably well. So, fortunately, one does not have to be very strict as to the degree to which disorder must be controlled.

1.4. Disorder and pollution

What we have called disorder applies to all scales, from macroscopic objects down to molecules, but so far we have only mentioned specifically disorder on a scale that is visible to the naked eye, such as dirty dishes in a sink and dirty laundry. Disorder on a microscopic scale is often called pollution. We may define a polluted medium, such as air or water, as one that contains small particles and molecules, which are not supposed to be there — just as dirty dishes in the sink. Examples are easy to come by, such as too many CO_2 molecules in the atmosphere that are believed to be at the origin of global warming, or small black particles in the air of our cities that we find at the end of the day on the collars of our shirts and possibly could be seen in our lungs, if we were looking for them. Underground water reservoirs can be polluted for example by chemical products, by heavy metals, or by a high degree of salinity, due to exaggerated depletion, and become unsuitable for consumption.

We have given here examples of pollution due to human activity, but the tendency of small particles and molecules to move around and invade a medium is very general, and in a sense unbeatable. While heavy objects such as pieces of furniture will not move around by themselves and will be found exactly where we left them even years later, small particles and molecules are all the time on the go. In a ray of light entering through a window, we have all seen dust particles dancing around in an incessant ballet — up and down, left and right. Dust particles move around by themselves, or so it seems. If you use your broom to collect some in a corner of the house, chances are that if you come back a few days or weeks later you will find that many of them (the smaller ones) must have gone somewhere else because they are not where you left them. If you wait long enough, all the dust particles that you had so carefully collected, maybe with the exception of the heavier ones, will be found everywhere in the room if its door was closed, or anywhere in the apartment if doors were not closed. This

is not a gedanken experiment, it really happens by itself all the time. Put the dust back in a corner, it will escape again.

1.5. Entropy and the second law of thermodynamics

We may call this the nightmare of the housewife. She is fighting a powerful genius, named entropy. This genius sees to it that if dust has been carefully collected in one corner of one room, that room and later all other rooms in the house will get dusty in the long run. Alas, nobody has ever seen dust getting collected by itself into a neat little corner. Exactly for the same reason, salt molecules in sea-water will never regroup by themselves so as to leave us with a nice fraction of desalinated water fit for our consumption. These are all aspects of the same law of nature which physicists call the second law of thermodynamics: in a closed system that does not benefit from an energy input, entropy (disorder) can only go up, never down. Energy is conserved, this is the first law of thermodynamics; but entropy is not. A corollary is that an energy input is necessary if one wants to lower entropy.

1.5.1. *Water desalination*

A good and important example is water desalination. If we add salt molecules to a container filled with clean water, they will quickly spread around in the entire container: this is the state of maximum entropy. Now suppose that the container is a cylinder in which we have placed a piston bearing a membrane that is permeable to water molecules but not to salt molecules. Water molecules can move freely through this membrane, but salt molecules cannot. Initially, the cylinder is filled with pure water, and the piston sits somewhere about the middle of the cylinder. If we add our salt molecules on one side of the piston, they will want to fill the entire cylinder. The piston will be submitted to a pressure which will move it to the other side. *Mutatis mutandis*, if we apply to the piston an inverse pressure we can collect back the salt molecules at one end of the cylinder. Water desalination has been achieved —

or order restored — at the cost of the work that we have done to push back the piston. Reducing entropy requires work.

1.5.2. Heat transfer

Another important example is that of heat transfer. Suppose you take a bottle of milk from the refrigerator, pour milk in a glass that you leave for a while on the table while returning the bottle to the refrigerator. You know from experience that if you wish to drink your milk cold, you had better drink it quickly because after some time the milk in the glass will have warmed up to the temperature of the room. After that you can wait for any amount of time you wish, the glass of milk will never get cold again. This is in fact the reason why you quickly returned the bottle of milk to the refrigerator. In a closed environment temperature will always tend to be uniform. We say that heat always flows from hot to cold regions, never the other way around.

But what exactly is heat? This is a difficult question that even Isaac Newton, probably the most remarkable scientific genius of all time, was unable to solve. He proposed that “heat particles” were doing the job, a view that should not surprise the reader since after all such particles would just behave in the same way as our salt molecules in water or dust particles in the room, spreading heat evenly in the apartment. Also, Newton liked particles, having explained how light propagates by assuming that it consisted of elementary “grains of light”. In that case he was proven right, these are the photons. But in the case of heat, there are no extra particles that transfer heat through a medium. As was shown by Boltzman much later, in the second half of the nineteenth century, heat transfer in a gas is due to the motion of the molecules that constitute the gas itself. At the time of Newton no one seriously believed in the existence of molecules. This state of affairs persisted until Boltzman, and even then his theory was strongly debated.

Motion of the molecules that constitute the gas is precisely what lies behind the strange ballet of the dust particles that we saw

dancing in the ray of light. Gas molecules kick small dust particles around, as we can see from their incessant ballet (although we do not see the molecules because they are too small). To go back to the mechanism of heat transfer, molecules move faster in hot regions than they do in cold ones. When fast and slow molecules collide, which they will necessarily do since they share the same space, it turns out that on the average faster molecules will transfer to the slower ones more energy than they get from them (energy of motion or kinetic energy), so that eventually the distribution of velocities will be the same everywhere and temperature will become uniform. This is the mechanism by which the system maximizes its entropy. The spontaneous flow of heat from hot to cold regions is of course very useful as this is how heat can be transformed into work and eventually into electricity. More on this in Chapter 4.

1.5.3. Entropy and the states of matter

Matter exists in different forms, as gas, liquid or solid phases. The highest degree of disorder is found in low density gases where molecules can occupy a very large number of different positions. Next comes the liquid phase, which is much denser and gives less “choice” to the moving molecules. Last comes the solid, where the molecules are basically fixed in space. According to this classification, the entropy counted per molecule is highest in the gas and lowest in the solid phase. When a gas cools down and transforms into a liquid — like steam transforming into water — entropy is reduced. It reduces again when the liquid phase transforms into a solid phase — like when water transforms into ice. Changes of entropy when matter is transformed from one phase to another play an important role in the global changes occurring in the biosphere.

The second law of thermodynamics is the reason why, once small particles or molecules are released in the atmosphere, they will spread, and eventually will be found anywhere in the biosphere. This is how entropy is maximized. Pollution is a global

phenomenon, not a local one. This is not like our neat household that we have kept clean and in good order. We can do that even if our next door neighbor is less careful and his house is a real mess. This nice separation does not work for small particles and molecules released in the outside world, either by us or by our neighbor. We shall both have to suffer the consequences. Here the problem has gotten out of hand. There is no piston that we can push on to restore order.

1.6. From the household to the biosphere

Let us go back to our household. An energy input is necessary to keep it in good order: we take in energy from the outside world and release entropy into it. Here, the inside is the household and the outside is the biosphere. In the long run this increase in entropy in the biosphere may become problematic, as happens when garbage and used waters are not properly collected. Let us give one more example of an unhealthy increase of entropy: we need food for ourselves (energy input necessary to keep our internal entropy level from rising), which we burn with oxygen from the air, and as part of this combustion process we eject carbon di-oxide. In this process the overall entropy of the system (which comprises ourselves and the contents of the house, including stored food and oxygen) has increased. If we keep our doors and windows closed, and do not let fresh air in, we are eventually going to suffocate and we shall die although we still have stored food (energy). This is an entropy, not an energy crisis. Similarly, if the biosphere becomes too polluted life may become endangered even if we still have plenty of energy resources available.

An additional worry is that entropy is also ejected into the biosphere by most of the energy production methods used today. We do need energy to keep our house in good order, and also to keep it warm in the winter, cool in the summer, to light it up at night and so on. But methods of producing energy that increase entropy in the biosphere, such as burning fossil fuels, are dangerous and should be avoided as much as possible. We can

usefully classify the various methods of energy production according to the amount of additional entropy they produce. Such a classification will be given in a later chapter.

Running out of energy supplies may indeed be a concern, but increasing the entropy in the biosphere may be an even more serious and more immediate one.