**The Second Law of Thermodynamics!**
Q: Who cares about the second law of thermodynamics?
A: Anyone who wonders how the material world -- our world of energy and matter --works.

Q: Big deal?
A: The biggest, most powerful, most general idea in all of science. Why paper, trees, coal, gas and all things like them burn (and why people "should" spontaneously catch fire in air), why sand and dry ice even in pure oxygen can't ever burn, why the sun will eventually cool down, why iron rusts (but not why it rusts faster nearer the ocean), why there are hurricanes or any weather at all on earth, what makes things break, why houses get torn apart in tornadoes or explosions, why everything living tends to die.
That's for starters.

Q: Just STARTERS? OK, OK, I'm impressed. So, what IS the second law of thermodynamics? Well, wait a minute, what's the first law?
A: The first law is very simple and important but pretty dull: You can't create or destroy energy.

You can just change it from one form to another, for example, electricity to heat, heat that will boil water and make steam, hot steam to push a piston (mechanical energy) or rotate a turbine that makes electricity that in turn can be changed to light in a light bulb or to sound in an audio speaker system, and so forth. That's it. Important but dull.

    The second law of thermodynamics looks mathematically simple but it has so many subtle and complex implications that it makes most chem majors sweat a lot before (and after) they graduate. Fortunately its practical, down-to-earth applications are easy and crystal clear. These are what we'll talk about. From them we'll get to very sophisticated conclusions about how material substances and objects affect our lives.

Q: Sounds fair. I'm listening.
A: Look at the direction that energy flows in any happening or process or event. That is the first step to understanding what the second law of thermodynamics is and what it applies to.

*Energy spontaneously tends to flow only from being concentrated in one place
to becoming diffused or dispersed and spread out.*

(Later we'll come back to those two tricky words "spontaneously" and "tends".) That's it, the big idea.  The perfect illustration is: A hot frying pan cools down when it is taken off the kitchen stove. Its thermal energy ("heat") flows out to the cooler room air. The opposite never happens.

Q: Come on. All this build up for that dumb example?
A: Don't put me down. I could have snowed you with differential equations and diagrams instead of what you see everyday. We're being practical and visual rather than going the math route, essential as that is in chemistry.

    The big deal is that *all* types of energy spread out like the energy in that hot pan does (unless somehow they're hindered from doing so) They don't tend to stay concentrated in a small space; they flow toward becoming dispersed if they can -- like electricity in a battery or a power line or lightning, wind from a high pressure weather system or air compressed in a tire, all heated objects, loud sounds, water or boulders that are high up on a mountain, your car's kinetic energy when you take your foot off the gas. All these different kinds of energy spread out if there's a way they can do so.

    Get the picture? The second law of thermodynamics summarizes that totally different events involving all kinds of energy have a common cause. A blowout in a tire or a car battery shorting out or slowly running down -- what could seem to be more unlike than those! Yet the reason for their occurring is the same, the tendency for concentrated energy not to stay localized, to disperse if it has a chance and isn't hindered somehow.

    A major goal in life is to find true BIG ideas that describe how the world works, to understand why and how things happen around us in terms of a small number of basic principles. Principles that can be tested and checked. You can't do better than the second law of thermodynamics. And the direction of energy flow is just a tip of the iceberg of that law.

Q : Iceberg? Titanic iceberg?
A: Come on now. You know that's just a figure of speech to give a feeling for the size of this principle. But... OK, let's get literal: Run that Titanic movie as the ship hits the iceberg. See those steel plates ripped open and the ship begin to sink. Realistic, right? Can you imagine a real happening in which the reverse occurs? A sinking ship whose steel side heals up as it comes up out of the water and floats? Ridiculous. Too stupid to think about. But why is it stupid? Because it is so improbable from your and my experience. Only a movie run backward would show that kind of unrealistic fantasy. The second law isn't some weird scientific idea. It fits with everything common happening that we know.

*Our psychological sense of time is based on the second law.
It summarizes what we have seen, what we have experienced, what we think will happen.*

    Sinking ships are like rocks rolling down a mountain -- as they sink, their potential energy due to being high above sea-bottom is diffused, spread out to the water that they push aside (or, in the case of mountain rocks, diffused as they roll down to the valley and hit other rocks, give those a bit of kinetic energy, and warm them slightly by friction.)

    In a video that is run backward, you may have laughed at some diver who zooms up from the water to a ten-meter diving board, but you're never fooled that the video is going forward, i.e., that you are seeing an event as it actually happened in real time. Unconsciously, you are mentally comparing what you see now with your past practical experience -- and that has all followed the second law. Even though you may never have heard of the law before, in the years of your everyday experience you have seen thousands and thousands of examples of energy flowing from being concentrated to becoming diffused.

    A swimmer doesn't come shooting up out of the water to the diving board, rocks in a valley don't suddenly roll up a mountain, outside air doesn't rush into a flat tire, batteries don't get charged by sitting around. *Those events all would have energy spontaneously become more concentrated, the opposite of energy spreading out*. We sense that videos or movies are shown in the right direction of showing time going forward only if the events in them agree with our lifetime experience about the direction of energy flow: concentrated to dispersed and spread out. The second law points the direction of how we feel time goes.

Q: So that's why people call the second law "time's arrow"?
A: You got it. Now let's clear up those tricky words, "spontaneously" and "tends" in the statement of the second law, *"Energy spontaneously tends to flow only from being concentrated in one place to becoming diffused and spread out."*

Q: Why bother? "Spontaneously" means fast, quick, ad lib .......
A: Hold it! That may apply to people, but we're talking about how *things* and chemicals behave. In the second law "spontaneously" means only that any energy which is available in the object or substance for diffusing *will*spread out from it -- if given a chance. It doesn't have anything to do with how fast or slow that occurs after the dispersal of energy starts, or even when it might start. That's why "tends" is so important to understand as part of the second law.

    The energy available in a hot frying pan or in a loud BOOM from a drum immediately and rapidly begins to spread out to their environments. Nothing hinders that from happening. Lots of ordinary and also unhappy events are like that. But there are an enormous number of "energy diffusing" second-law happenings that are hindered *so* they don't occur right away. Here's a simple illustration: If I hold a half-pound rock in my fingers so it is ready to fall, it has potential energy concentrated in it because it is up above the ground. If the second law is so great and powerful, why doesn't the energy that has been concentrated in the rock spread out? Obviously, it can't do that because my fingers are "bonding" to it, keeping it from falling. The second law isn't violated. That rock *tends* to fall and diffuse its energy to the air and to the ground as it hits -- and it *will* do so *spontaneously* by itself, without any help -- the second I open my fingers and "unbond" the rock.

Q: Is that really so important?
A: Yes, it is. Many philosophers and novelists learned about the second law only from physicists.
    Unfortunately, physics emphasizes what happens in a closed or isolated system of tiny particles rather than in our real open-flow world of trees, shiny steel, sunshine, rocks and people, the world of sun energy and things made out of chemicals. Thus, many readers of popular philosophy articles and recent novels have been misled and frightened by talk about the second law as a fast-approaching doomsday. The writers pass too quickly over the fact that it is a *tendency* rather than a prediction of what will happen right away.

    In many real-world chemicals and things the second law can be obstructed or hindered for millions of years. Certainly, the mountains of the world haven't all slid down to sea level in the last several hundred centuries! Similar to my fingers holding the small rock (but millions of times more tightly), even overhanging stone in cliffs or mountains is bonded, chemically bonded, to adjacent atoms in the stone and so the stone can't obey the second law tendency for it to fall to a lower level. Here, as in countless other examples, the second law is blocked by the strength of chemical bonds. It takes a huge number of repetitions of outside energy input like freezing and thawing and earthquakes and windy rainstorms to break the bonds along even a weak bond-line, make a crack, and free particles or pebbles or rocks so they can follow the second law by falling to a lower level. (But even then, they may just fall into a mile-high valley and be kept from dropping any closer to sea level; so here in a different way the second law is further hindered.)

    Blockage of the second law is absolutely necessary for us to be alive and happy. Not one of the complex chemical substances in our body and few in the things we enjoy would exist for a microsecond if the second law wasn't obstructed. Its *tendency* is never eliminated but, fortunately for us, there are a huge number of compounds in which it is blocked for our lifetimes and even far longer.

Q: About time we got to something human. Are we through with rocks?
A: Yes, but don't forget what they have illustrated.

    I think it is helpful to see some of the ways the second law works in the ordinary dusty world of actual objects before looking at its relation to pure substances, the chemicals that make up those objects. Chem profs approach the second law the other way around, starting with atoms and molecules first. And that's certainly OK. Professors rightfully avoid much talk about the behavior of big visible things at all. In the limited time of a chemistry course they can only develop the nature of atoms and molecules and of chemical substances. Objects made from chemicals like a gear or a bridge or a wooden house or a book or a bone just have to be assumed to behave like their constituent substances. What they do because they are big things composed of tiny molecules just has to be left for other courses or our future experience.

    We'll go further to find how the second law affects common objects and how it is really the mother of all serious Murphy's Laws that apply to things. (We'll omit the zillions of humorous or stupid variations about the way fallible humans behave, as well as all the problems surrounding computers and programs!)

Q: The second law and Murphy's Law -- they're related?
A: Yes, but I shouldn't have mentioned it. First, we need to know more about bad things that can happen to us because of the behavior of chemicals in the objects around us. For a grim example, wooden houses burn down with disastrous financial loss even when people aren't killed. What's going on here in terms of energy flow?

    Wood and paper are both primarily cellulose. Paper is easier to experiment with so let's think about its burning in air. When paper catches fire and burns, there's a lot of energy given out as heat and some as yellow light. It's well known now that the products of the combustion of cellulose with the oxygen of the air are carbon dioxide and water. (The slight amount of black ash is due to the clay that was on the paper adsorbing a small amount of carbon.) Once started, the burning is spontaneous --i.e., the process goes on by itself without any further help after a match starts it -- and also the burning is really fast. Now, if all that energy is flowing out in this reaction of paper with oxygen, the paper and oxygen must have had a lot more energy inside them before the reaction than do the carbon dioxide and water after the reaction -- as shown in the diagram above.

    What's happening here is a beautiful illustration of the predictions of the second law. Systems (groups) of chemicals -- or objects made from them (like sheets of paper or houses) -- **tend to react if they have more energy bound inside their molecules than do the reaction products that they can form**. [[Note for Advanced students: "Energy change here means G, not just H".]] Thus, when systems react spontaneously, their reactant molecules are spreading out their internal energy in two ways: 1) part to the bonds in each molecule of the products because each of those has less energy concentrated in it than was in the molecules of the starting materials, and 2) a part to making all those product molecules move much faster (i.e., they have more kinetic energy than the original cellulose and oxygen). These faster molecules show a high temperature on a thermometer. We say they are hot, not because heat is a "something" but because heat is the process of energy transfer from one kind of matter to another -- from fast molecules of gas to the thermometer bulb or to one's hand if you get it near the flame.

Q: Wait a minute! Wait a minute!! You had to put a match to that paper to start it burning! What's spontaneous or second law about that??
A: Wait a minute yourself. Have you already forgotten that essential word "tends" in the second law?

    All the paper and wood and things made from them in the entire world tend right now to react with the oxygen in the air and form one gigantic fireball. Why don't they? Well, why don't all the mountains on earth spread out the potential energy in their high stone cliffs this second and collapse into spread out much-lower mounds of sandy particles? It's the strength of the chemical bonds (between silicon, oxygen, potassium, aluminum and other atoms and ions) that holds stone together and acts as an obstacle to the second law's immediate execution. The potential energy of high rocks/mountains is hindered from spreading out instantly.

    Just so, the strength of the chemical bonds (between carbon, hydrogen and oxygen) in cellulose holds it together and obstructs the instant spreading out of the energy inside the cellulose by reacting with the oxygen of the air. This strength prevents oxygen from instantly breaking into the cellulose molecules to form the even stronger bonds (of carbon dioxide and water) and to release large amounts of energy. However, it takes just a little extra push of energy from the hot match flame to begin to break a few quadrillion bonds in the cellulose of paper or wood so that oxygen molecules also striking those 'breaking bonds' can complete the breaks and make the first 'gazillion' CO2 and H2O molecules.

The initial energy push (usually from heat), shown by the small energy "hill" in the diagram below, is the activation energy, Ea, that is necessary to overcome the bond-strength obstacle to the second law in most chemical reactions. Thus, this requirement for input of an initial energy, the energy of activation, hinders both desirable and undesirable reactions from occurring.      An important idea is "Activation energies protect substances from change."

As these first "heated up" bonds are breaking, the oxygen from the air begins to grab carbon and hydrogen atoms to form carbon dioxide and water molecules. But the formation of new strong bonds in the CO2 and water gives out a lot of energy -- enough to start to break many many more quadrillions of bonds of cellulose (no bond being totally broken before oxygen has simultaneously begun to form a new CO2 and water molecule from the developing fragments). These new molecules of CO2 and water also absorb some of the energy from the new bonds as they are formed and many move faster than twice the speed of sound. We sense those fast moving molecules as hot gas and we call it "heat".

Q: Aha. I remember that in the Malibu fires a few years ago some houses started to blaze from the inside because heat from the nearby burning trees and brush ignited the cloth drapes inside the picture windows. Then there were others with big windows that didn't catch fire because they had aluminum blinds which were closed. That involved activation energy, right? Cotton cloth is cellulose, isn't it?
A: Yes to both questions. First of all, the glass of the windows probably got extremely hot, both from the heated air of the fire and the fire's infrared radiation. In addition, as you suggest, the intense IR radiation went right through the windows and heated the fabric drapes even more -- enough to exceed their activation energy that normally hinders their oxidation in air. They began to burn and this gave out enough energy to ignite the whole interior -- by exceeding the activation energy of oxidation of all the other flammable materials in the house.

    Just as does every idea that we've been talking about, the concept of activation energies gives us tremendous power in understanding how the world works, even in unusual events. For instance, you've heard about the dangers of nitroglycerin, a liquid that explodes violently just from being shaken hard or jarred sharply. Do you think that its energy diagram would look like the one for cellulose above? Of course not. It must have a very low activation energy, Ea.  That leads to an extremely fast formation of hot gaseous products, an explosion (despite the  relatively smaller difference in energy between "nitro" and the products).  Explosives form hot gases so rapidly because they all have oxygen atoms as part of their molecules. Thus, those molecules don't need to wait until some molecules of atmospheric oxygen happen to hit them -- the way most substances have to do. Alfred Nobel was driven to invent a safer explosive when four workers and his brother were killed in the family nitroglycerin plant. He made what he called "dynamite" when he mixed oily nitroglycerin with some powdery silica material to form a seemingly dry solid that could be pressed into stick shape. They didn't detonate just from being hit or dropped. Obviously, therefore, an energy diagram for dynamite must look like the dotted line, a considerably higher Ea indicating that more energy must be put in, e.g., by a blasting cap, to initiate the spontaneous decomposition of the nitroglycerin. (TNT, used in armor piercing shells, is about six times more resistant to shock than nitroglycerin. Thus, you can guess at TNT's activation energy for reaction.)  Dynamite has been mainly replaced by other explosives for excavation, etc., today.

    There. We've seen some substances with low activation energies but we don't often handle nitro or TNT! How about a more important problem to many of us, rusted iron, the result of iron reacting with oxygen to form iron oxide. Of course, I'm running the risk here of opening the whole can of worms about human activity and the second law.

Q: What do you mean, "can of worms about human activity and the second law"? What has that got to do with simple old rusting iron?
A: Mainly that we usually don't want it -- except for iron ore (which is a mixture of dirt or rock that has a lot of iron rust , i.e., iron oxide, in it). We really like millions and millions of tons of that because it's worth millions and millions of dollars! But before we start digging in an iron mine, let's look at how we humans use the second law for our purposes. Whenever we run a truck or any kind of engine, we're using the second law for our benefit:

[Note! From here on when I write "the second law", it is using those words as a code phrase or shorthand for "what the second law describes", namely: "some process in which energy disperses or spreads out"]

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| --- |
|       taking energy inside of substances that tend to spread out, but can't because of Ea,  |
|              (i.e, a high-energy mixture like oxygen (of the air) plus liquid gasoline (or solid coal), |
|      giving it the necessary activation energy (a spark or a flame or heating at high pressure), |
|      having the diffusing energy (in the form of hot expanding gases of CO2 and H2O) push a piston that turns  |
|             crankshafts, gears and wheels (with the exhaust gases, still fairly hot, but no longer |
|             available for any more piston-pushing in this engine going out the tailpipe). |

So in this example, it looks like the second law is a good deal for us. It is, whether in engines or in our biochemistry (where oxygen plus food is the concentrated energy source -- but with totally different "sparkplugs" in our bodies to start our oxidation reactions that are far more controlled and in very tiny quantities compared to the violent explosions in a car engine!) Nature's second law predicts that the energy concentrated inside a chemical mixture like oxygen with oil or coal (or food) tends to *spread out*. It *will* do so, if that necessary little energy push to overcome an activation energy barrier is applied to that kind of high-energy mixture compared to the lower energy products of CO2 and H2O.

    We make our whole technological world run by grabbing as much as we can of the energy flow available from concentrated energy mixtures like oxygen and fuels to run an infinite variety of machines, electrical generators and vehicles. (Our bodies, as we have said, use second-law energy flow from the oxidation of food for the synthesis of essential compounds and for all activity, from biochemical to muscular to mental.) However, when we change energy from one form to another, from energy in a fuel plus O2 to pushing a piston or even water running down from Hoover Dam to the dynamos below, it is impossible for us to get to use *all* of the energy in the concentrated energy source for the jobs we want it to do. Some always is diverted as the unusable energy due to faster moving molecules (i.e., "heat") to the environment. (That's where our body gets heat to maintain our 98.6º F/37º C.)

Q: OK, I get it. Every time I start our car, I'll think of the energy the gasoline's giving out by reacting with oxygen, making hot gases, pushing those pistons and turning that crankshaft….

A: And every time you breathe, don't forget the oxygen going all over your body and …well, let me do some more summarizing before talking about that biochemistry angle a little more:
     This minute all around the world there are tens of thousands of people who are "using" (transforming to mechanical work, losing some to waste heat spread out to the environment) the concentrated energy of a mixture of oxygen with coal, oil or gas to dig up the iron ore with giant scoops and transport it via trucks, trains, and ships from different mines to steel mills. Then, more energy is used by more thousands of people to change it into iron and finally to shiny steel...What a long parade of actions based on using the second law to get what we want!


Every step from the original rusty dirt in the ground requires transformation of concentrated energy (of oxygen plus coal, oil, gas) to do a lot of mechanical work (along with that dispersing of less concentrated energy in the hot exhaust gases of CO2 and water). Then bringing together thousands and thousands of tons of ore, coal and limestone to one place, the steel mill, is another enormous expenditure of concentrated energy in fuels (not counting the human effort in muscle and brain). Next, a totally different variety of energy transformation is done, changing the iron (oxide) *ore* to almost pure iron *metal* that has a *larger* internal energy content in its bonds than does the iron oxide. Wait a minute! Doesn't it seem against the second law to force a *dispersed-energy chemical* like iron oxide to change into a *concentrated-energy chemical*like nearly pure iron? Sure it is, but there's no problem. Just as in running all those truck, train and ship engines, we can take energy flow from a spontaneous process (here in this case, from two chemical processes):
The *spontaneous* reaction of carbon from coal with a little oxygen to form CO whose molecules are moving very fast (i.e., are very hot), followed by
the *spontaneous* reaction of CO with iron oxide to form fast moving CO2 molecules plus pure iron and cause the *non*spontaneous change of iron oxide to iron. Of course, in doing that we will lose a large flow of energy as waste heat. To give an idea of the size of it in iron making, a ton of near-pure carbon (coke from coal) reacts with four tons of air at around 1000 C in a blast furnace to form a ton of pig iron from two tons of ore. The energy price is *six tons* of hot flue gas that the process spews out, some of which isn't available for more changing of iron oxide to iron. Pretty big operation.

    Did we beat the second law? No way. But by *using* the second law (taking the energy from two spontaneous "downhill" reactions and transferring much of it to force a nonspontaneous process to go "uphill" energy-wise and make something), just as we take gasoline energy and change some of its energy into mechanical energy (to make pistons, crankshafts, and driveshafts turn the car wheels), we got what wanted: iron from which we can produce steel, the structural material for a near-infinite number of useful objects. Better than rusty dirt, right?

Q: Are you trying to make an iron man out of me?
A: No, no. Stick to the triathlon for that. The reason I went so long on that kick of ore to iron is that it's a perfect summary of the tremendous variety of what humans can do *with the aid of* the second law.

    We gather objects and mixed-up raw materials from all over the world. Just bringing stuff of all sorts from so many widely separated places to one spot as in iron and steel making is certainly not a probable occurrence in inanimate nature! It's a human act, especially when you consider the further elaborate arrangements that we make with all varieties of matter, from lining up botanicals in a National Arboretum in Washington, DC to joining metal and many other kinds of materials into building a skyscraper in Chicago or a Getty Center in LA: Those are big things.

    Equally as spectacular are the human actions in smaller things, bringing together the materials and fabricating a Boeing 747 or a jet engine with so much power that a couple of them could move a Titanic. Gathering, arranging, building, fabricating -- in all of these we use (what we can of) the directional energy flow from spontaneous chemical reactions such as the oxidation of petroleum and coal.

    Let’s finish this recap of human use of the second-law energy flow: Besides making concentrated-energy chemicals like pure metals -- iron, copper, chromium and silver -- from their diffused-energy ores (and innumerable objects from them), we make thousands of other high energy substances for our pleasure or our needs. Minor things like flavors for foods. Important pharmaceuticals that save millions of lives. It may take dozens of reactions (milder than that violent one for iron from iron oxide!) to change starting materials stepwise to the final chemical product, but the overall process involves diverting energy from spontaneous 'downhill' reactions to make the 'uphill', more concentrated-energy substance that we want.

Of course, this is the kind of coupled process (i.e., a spontaneous + a non-spontaneous) that nature uses – taking a tiny bit of sunlight energy and, with the aid of extremely complex processes in organisms like plants, changing lower-energy carbon dioxide and water and traces of minerals into thousands of higher-energy substances. But don’t think that "natural" or "from natural materials" has something to do with good or harmless! There are hundreds of harmful or even poisonous chemicals in nature – from strychnine to the extremely deadly compound in simple castor beans. (Also usually omitted when someone extols the beneficial qualities of everything "natural" is the fact that all terribly toxic viruses and bacteria are totally natural!)

Q: You're whipsawing me. A while back you said the second law was the mother of all Murphy's Laws. Now you show me that the second law is a good buddy because we can use it for energy to do what we want. That's double-talk isn't it? What's the story?
A: Come off it. You're not naive. Life is full of stuff that can be either good or bad. But get ready for a shock now: [Remember what I said about the words "second law" -- that they are often code words for what the second law *describes*, i.e. that energy spreads out, if it can, from being localized or concentrated to becoming dispersed.]

***The second law is the Greatest Good and the Biggest Bad to us.***

    The GOOD: Because of the second law about the direction of energy flow, life is possible.

* We can take in concentrated energy in the form of oxygen plus food and use some of that energy unconsciously to synthesize "uphill" complex biochemicals and to run our bodies, consciously for mental and physical labor, excreting diffused energy as body heat and less concentrated energy substances.
* We can use concentrated energy fuels (e.g., gasoline/coal, plus oxygen) to gather all kinds of materials from all parts of the world and, regardless of how much energy it takes, arrange them in ways that please us. Similarly, we can effect millions of non-spontaneous reactions -- getting pure metals from ores, synthesizing curative drugs from simple compounds, altering DNA:
* We can make machines that make other machines, machines that mow lawns, move mountains, and go to the moon. We can make the most complex and intricate and beautiful objects imaginable to help or delight or entertain us.

     The BAD: Because of the second law -- the direction of energy flow -- life is always threatened.

* Every organic chemical of the 30,000 or more different kinds in our bodies that are synthesized by nonspontaneous reactions within us is metastable. All are only kept from instant oxidation in air by activation energies. (The loss or even the radical decrease of just a few essential chemicals could mean death for us.)
* Living creatures are essentially energy processing systems that cannot function unless a multitude of "molecular machines", biochemical cycles, operate synchronically in using energy to oppose second law predictions. All of the thousands of biochemical systems that run our bodies are maintained and regulated by feedback subsystems, many composed of complex substances.

Most of the compounds in the feedback systems are also synthesized internally by thermodynamically nonspontaneous reactions, effected by utilizing energy ultimately transferred from the metabolism (slow oxidation) of food.

When these feedback subsystems fail -- due to inadequate energy inflow,
malfunction from critical errors in synthesis, the presence of toxins or
competing agents such as bacteria or viruses -- dysfunction, illness, or death results: energy can no longer be processed to carry out the many reactions we need for life that are contrary to the direction predicted by the second law.

How's that for starters? You can't get any better for good -- that living is possible due to the second law. And you can't get much worse for bad -- that death is always possible too, due to the second law.

Q: But what happened to Murphy's Law? That isn't about death, just about less bad things that hit us.
A: You're right. Murph doesn't get that serious very often, but there are at least five thousand illnesses, diseases, "things that can go wrong" with our bodies that may not kill us. That's 5K of Murphs. These are biochemical problems that humans suffer from. But how many do most people have? Did you ever see a PDR Medical Dictionary or an AMA Home Medical Encyclopedia? They'll make you very thankful for activation energies and feedback systems that keep your bod working as well as it does (and long as it will) to counter the second law, using food and oxygen intake as your energy source.

    However, let's look at the other annoyances (and disasters) that the mother of all Murphys is responsible for when things that are around us have energy concentrated inside them. That's always potential big trouble. All that has to happen, somehow, sometime, is for a little energy push -- a spark, a flame, an impact -- to get up over that activation energy hill. (Remember the energy diagram for cellulose, i.e., wood and paper? It applies to anything flammable and literally millions of other oxidation reactions, e.g., iron or any metal rusting or corroding because rusting is oxidation.)

First, problems caused by the thing or material having concentrated energy inherent in its chemicals:.
        Trees catching fire                              a house struck by lightning
                a curtain too near a candle...              the forgotten cigarette left on a sofa
                        Mrs. O'Leary's cow kicking over a lantern in straw and burning half of Chicago
                            the spark from a bulldozer that started a grass fire and then a forest fire
        These are all cases of exceeding *an activation energy, resulting in a spontaneous reaction.*

        And, of course, there are many less (or equally) dramatic examples in the oxidation of metals
                Rust on a tool, disfiguring or damaging it         rust in a machine, hindering operation
                        copper oxide in an electrical socket, causing overheating and then a fire
                                battery cable corrosion in Chuck Yeager's X-1 that almost killed him.

Second, annoyances (or worse) due to concentrated energy in the object being present or flowing by it, but *not* inherent or part of its nature:
        Tires that blow out              hydraulic brake systems that leak suddenly under pressure
                audio speakers that are fed high wattage signals      230 volts into a 115 V house circuit
                        winds in the air.....from gales to hurricanes, from windstorms to tornadoes.
        A car going 80 around a 30 mph curve, a 747 hitting a mountain, an Indy car into the wall.

Q: Yeh. Yeh. I get the point. Or points. Know too much about car crashes. New to me, before we began to talk, was to hear that burnable stuff, like wood and paper and cloth in my room (along with the oxygen of the air) is basically a bunch of concentrated energy chemicals. But I don't have sparks or candles around to give them an activation energy kick and cause a fire. Breaking things is more of a problem to me. Is there energy locked inside a skateboard or a ski that wrecks it (and me) because it tends to diffuse or spread out?
A: Good comment and good question. It's great that you now understand *why* certain things can react with oxygen and *why* a spark or low flame sets off a spontaneous reaction. You also know now that all of these kinds of problems from fires to plane and car crashes to lightning to tornadoes and fires are related by the second law of thermodynamics: concentrated energy tends to spread out. (A fast-moving car is a "really really big" bundle of concentrated kinetic energy.)

    Your question about breakage is just as important because that kind of incident or accident happens to us more often than "Murphy problems" of fire that is due to energy concentrated inside the substance of the object and oxygen.

    Breaking things involves concentrated energy that is initially *outside* the thing that gets broken. It's the second law working in the environment of the object -- energy flowing around or through it for some reason or other and hitting it with enough energy and of the right kind to tear it apart. (Right kind? Right amount? Heat won't make a concrete bridge shatter into fragments in thirty seconds, but a strong earthquake will.) Chemists never talk about breaking things because they don't consider that to be a chemical process. The chemical nature of a ski that gets broken, for example, isn't changed. It's just two skis so far as the chemicals in it are concerned. (Try to tell that to the skier!) Technically, the chemical composition of the two pieces of ski is almost the same so chemists call a fracture a physical process.

    However, in a micro sense it is a chemical process because in any break chemical bonds are ruptured all along the line of the break as well as complexly broken and reformed near that break line. It's just that the number of bonds altered is extremely small compared to all the others in the ski that are not affected and therefore a chemist would never be able to measure any composition change. Also, where and when the break will occur depends on so many factors that aren't what chemists call fundamental, such as: how the object was made, its shape, its ratio of surface area to volume, the strains and defects present in it, whether it is brittle or ductile and even the rate of application of energy to it.

    But we can plot the effect of a load (mechanical force) being applied to a solid object until it breaks. (Let's choose something that is especially valuable or useful.) In the diagram at the right, the line A represents the external load on it (the "mechanical force", that is, the effect of energy striking the object); B shows the internal energy of the object; and C is a rough estimate of the "human desirability" of the object (what it is worth).  All the lines (A, B, and C) are initially horizontal to indicate their respective reference states before the application of any external force or load. As the load on a particular spot on the object is steadily increased, the internal energy of the object (line B) increases regularly with the greater and greater load (line A) bearing on it. If the external load acting on the solid is increased until fracture occurs, Line B immediately falls to the starting internal energy value (except for transient heat and the quickly dispersed kinetic energy in any flying fragments).

The difference between the high point of Line B and its original (and final) energy level is labeled in the diagram above as EACT SOLID. This is *partly*like an Ea , an energy of activation in chemistry. An Ea is the amount of energy required to start substances reacting. Then they continue to react spontaneously because of the considerably greater amount of energy evolved during the reaction. In contrast, an EACT SOLID is both the energy required to start a fracture and virtually the same amount of kinetic energy given out by the two separated pieces of solid.

    Line C drops radically after the break, a rough indication of the far lesser value to us of the two broken pieces as compared to the original object. (Market economics, i.e., the value/price of the object before and after the break, best describes what line C represents.)

    That diagram above is for a single break of a solid object. In a hurricane, wind energy is successively applied to the two fragments of the first break so that houses become scattered parts; boards often are torn into splinters. In the terrible 1995 Kobe earthquake, even concrete structures were torn apart and many portions of them reduced to rubble. At each successive step, the qualitative diagram applies -- additional load is supplied to fracture parts of the original and then those parts are again broken.

    Oops. Splintered boards. Rubble. I'm afraid I have to talk about it.

Q: That's gibberish. About IT? About what?
A: About ENTROPY! Scientifically, qualitatively, entropy is simple -- entropy change is just a way of measuring exactly what we have been talking about, how much change occurs at a specific temperature when energy spreads out according to the second law.

     But that word entropy has been so erroneously defined and so misused by so many people that I'm sorry that I got trapped into talking about it when were thinking about what a city looks like after a huge earthquake! That mess of broken buildings and busted bridges would be foolishly called "an example of entropy increase" by many people who aren't scientists -- and even by some chemistry teachers.

Q: What's wrong with that? My chem text says that "Entropy is disorder" and a mess is disorder, isn't it?
A: Your text may be excellent in other topics, but it's just plain dumb wrong where it says that! Entropy only involves **energy** and its spreading out (and temperature), not appearance or neat patterns. Even when considering molecules precisely arranged in a crystal, any question about entropy must be like "What is the energy distribution here? How is the crystal vibrating and the molecules moving fast but almost staying in one place," not "How orderly is this pattern?" Energy, energy, energy!

Entropy is **not** "disorder". No way. No how. That's an old 1890s idea that was obsolete after statistical and quantum mechanics became fully developed in chemistry. However, it hasn't yet been eliminated from a few textbooks. They may be good in other parts but they simply don't tell you the straight stuff about entropy if they use that old obsolete definition with "disorder".

Q: Hey! You can't just say a text is wrong and expect me to believe you! You'd better give me solid evidence that "entropy is not disorder" if my chem book says it is.
A: Of course. Your text is out of date because most new editions of college/university general chemistry textbooks have deleted "entropy is disorder" and adopted my approach.

Click on [entropysite.oxy.edu](http://entropysite.oxy.edu/) to ‘what’s new’ and scroll down to May 2009 to see the list of new editions that have thrown out “disorder” and now define entropy in terms of energy dispersal. (Your professor can check <http://entropysite.oxy.edu/cracked_crutch.html>. This is the article that helped convince textbook authors to delete “disorder”. Also for your professor, the article at <http://entropysite.oxy.edu/entropy_is_simple/index.html> describes the bases for interpreting entropy as energy dispersal and an improved approach to microstates.)

Q: OK. What IS entropy, really?
A: It's simple basically because you know about the second law -- that energy spreads out and disperses rather than staying concentrated, i.e., localized in one place. Entropy just measures what happens in that kind of process of energy dispersing. And that's why your text says that entropy is always increasing in the world -- it's because spontaneous reactions/events are what are always “happening” and they happen because then energy spreads out! (Actually, we should always say "entropy **change**" because we're measuring the difference in energy distribution "after" some happening versus the "before".)

More precisely: Entropy (change) in chemistry measures either by

1) how **much** molecular motional energy has been spread out in a reversible process divided by the constant absolute temperature, T

                      S = q(rev)/T

[ q is the amount of energy (motional energy, thermal energy, "heat") that is dispersed to a system at T from the surroundings at a very very slightly higher temperature than T, or vice versa, from the system at a tiny bit higher temp than the surroundings at T. Because the temperature differences are so small, this gradual dispersal of motional energy ("heat") in either direction is essentially reversible. This is the case in phase changes, at the melting point or the boiling point. (As some more advanced texts state, when you heat a system - i.e., increasing the "how much" motional energy is in a system - by calculus you can find the S change)];

or (2) how **spread out** the original molecular motional energy (i.e. no *change*in q) of a system becomes (e.g, when an ideal gas spontaneously expands into a vacuum and increases in volume or when different ideal gases or liquids mix. (No change in temperature in the processes.)

Entropy change doesn't measure "disorder"! (What are the dimensions of "disorder"? Malarkeys per minute or some such nonsense? The scientific dimensions of entropy change are joules/Kelvin.) Entropy change in chemistry measures the spreading of molecular motional ENERGY. (For more details of that kind of energy of molecules moving ["translating"] and rotating and vibrating, see <http://2ndlaw.oxy.edu/entropy.html>. Your professor could check the site for instructors at <http://entropysite.oxy.edu/entropy_isnot_disorder.html>)

Q: If entropy measures how much energy has been dispersed in a bunch of chemicals, and that's q, why bother with dividing by T?
A: Because you don't really have entropy (or entropy change) if you don't include that absolute temperature, T. With entropy properly defined that way you have immense power in understanding how important is any energy change to that "bunch of chemicals". Entropy change, S, doesn't merely measure energy spreading out, it shows us exactly *how****important****to a system is the dispersion of a given amount of energy in that system or substance at a particular temperature*.

How's this for an analogy: If a quiet library represents a low temperature system (relatively small number for T), and you yelled "HEY, YOU!" there, everybody would jump and the librarian would turn purple. However, in a football game at touchdown time (like a high temperature system, very large number for T), if you yelled "HEY, YOU!" just as loudly, nobody would notice it. The effect of the "energy spread out in your yelling" is a lot different in a library than in a stadium!

The scientific application is this: an amount of energy dispersed, say a q of 10 joules, from the surroundings (that are just infinitesimally warmer than 100 K) to a cold 100 K system would certainly be important (q/T = 10 J/100 K= 0.1 J/K) while the same amount of 10 joules spread out from different surroundings (just infinitesimally warmer than 1000 K) to a 1000 K system would be relatively trivial. (q/T = 10 J/1000 K = 0.01 J/K)

Now, you **know**that a hot pan will cool down if the room is cooler than the pan -- we started with that -- it's our lifetime experience -- it's what we called the second law and we interpreted it as energy spreading out if it can. But is there any quantitative way that we can show that the second law "works"? Yes! That's where the power of entropy comes in! Entropy measures energy's spreading out; the larger the entropy increase, the greater the spreading out and the more probable is the event. Just look at that preceding paragraph: If a 1000 K and a 100 K system are in contact and 10 joules of motional energy were allowed to flow from one to the other, which direction would the energy flow? Only if energy flowed from the 1000 K system to the 100 K system would there be **any** entropy increase -- (the calculation that you will learn from your text and class is not as simple as the arithmetic for the reversible transfer in the preceding paragraph, but the *direction* of the process is adequately indicated by that easy arithmetic.).

So entropy increases when "heat" (transfer of energy) spontaneously flows from something hot to something colder. (Same as "entropy change is positive in sign.")

Q: So that's all?? Just hot pans cooling down again? And that one little q(rev)/T is entropy change?
A: ALL? HOLD IT now!! That's just like your question "Is that all?" when we first talked about the second law. And then we went on to see the amazing implications of the second law -- that it's the greatest generality in all of science -- that it's incredibly important for your understanding of how the world works -- that it's the greatest good and baddest bad for your own being alive. Ya can't have anything more important than that! Exactly parallel, entropy is of enormous importance in ANY serious understanding of chemistry and chemistry is central to everything in this universe.

The words and meaning of "entropy" and "second law" are so closely related (entropy being the quantitative measure of the qualitative law) that they are often used interchangeably. Never never forget that entropy MUST always be connected with ENERGY in general, and specifically with ENERGY that is being or has been dispersed.

[Entropy is more fully discussed in <http://2ndlaw.oxy.edu/entropy.html> . In the Appendix to the site you are now reading (accessible from the Last Page) are given some details of processes in which q is zero --i.e., the original ENERGY of the system is unchanged but it is *more spread out over more volume*; thus entropy increases. Those processes include a gas expanding into a vacuum, or two or more ideal gases or liquids mixing. An ideal solute dissolving in a solvent also involves no change in original ENERGY but the entropy of the solution increases because an added solute allows that energy to be more spread out.]

Q: You sure are yelling LOUD and long about energy being connected to entropy!
A: Absolutely!! THAT'S the big mistake that popular writers and even some teachers make about entropy. They've heard that antique erroneous statement about "entropy is disorder" so often that they too say that anything you can see in the world as mixed-up or messy is an example of an entropy increase. Nonsense. Total nonsense. You have to focus on how much and how widely is **energy** dispersed in their examples. When and how and what kind of **energy** got spread out has to be the first question in any example they talk about or we think about. Here, look at some horrible actual quotes.

      In a textbook, there is a picture of Einstein's desk taken the day he died. Like most desks where scientists have been working hard, it looks messy. But the textbook says "Desktops illustrate the principle that there is a spontaneous tendency toward disorder in the universe..." Wow! Stay away from desktops -- you don't ever want to get caught by the scary spontaneous tendency that happens there! Here's a quote and a photo that really deceives a reader by the first four words that I've italicized: "*If left to themselves*, the books and papers on the top of my desk always tend to the most mixed-up, disordered possible state." (And that was written by a scientist!) Wasn't he ever near that desk of his? Some mysterious alien force from outer space did it? Another, from a book about entropy that sold over a million copies: "Anyone who has ever had to take care of a house, or work in an office, knows that if things are left unattended, they soon become more and more disorderly..." Unattended means that nobody is around, doesn't it? Isn't that writer implying that things all by themselves cause this disorderliness, rather than people? (He should be told that King Tutankhamen's tomb was left unattended -- really unattended -- for 3274 years and its arrangement of things was found to be seemingly unchanged, though dusty, when the tomb was finally opened in 1922.)

     You get the point. The messy *appearance* of a bunch of visible objects (and even the neat molecular order in an x-rayed crystal) have nothing to do with entropy. The only questions are "what is the energy process that made the objects that way? In what way was energy dispersed and how much energy change at what T occurred? In the usual dumb examples like those quotes in the paragraph above, it is in the *ATP of the muscles of the people* who pushed the papers/books/clothes/pizza plates around where energy has been dispersed and so only there has the entropy increased.

Q: Why be so critical? Those writers just failed to say that they or somebody else was messing things up. What's this got to do with entropy?
A: That's not a minor omission! It's like a guy outside a bank telling you (as police were running toward you two), "Look at all this money that the nice bank teller shoved at me" and JUST FAILED TO SAY, "I had a gun pointed at him." Don't you think the gun had something to do with the money-shoving?

    As I said a minute ago, reading statements like these in books gives many people who aren't as sophisticated as you a strange idea about entropy: it's a mysterious force that makes ordinary things jump around and is at work to mix up the world. That's total balderdash…. Every one of those authors was writing about the second law of thermodynamics and entropy

    BUT "they left out the gun"!

     That's most frequent error of scientific as well as popular writers -- even texts "leave out the gun" when they start talking about the ordinary world getting mixed up and "going toward disorder". It's people who mess up desks and dorm rooms (and much of the environment), it's hurricanes and tornadoes that tear houses and trees to pieces and scatter the bits; it's earthquakes that can even fracture a concrete freeway and topple a whole building. What's common to all those examples? Energy getting spread out, of course. Energy of ATP in human muscles, energy of air flow in hurricanes, energy of earth movement in earthquakes. As a result of those kinds of processes, solid things get scattered all over and mixed up. The objects do NOT, *by themselves*, become disordered or random. There isn't any "tendency of objects to become disorganized" in nature any more than bank tellers have a "tendency to give money to robbers" -- without a gun. *Energy flow of many kinds is the driving force, the gun, for the world's macro objects becoming disorderly*.

    The reason so many authors make this mistake of saying "things are tending toward disorder" is their over-extending the basic behavior of *internally energetic*, *mobile* molecules and atoms all the way to totally immobile macro objects. We have already seen that those *microparticles* at 1000 miles an hour clearly tend to be as random and disorderly as they can be. But if they are "boxed" in static *macro* *objects*, whether in the stones of an Egyptian pyramid, or in the cardboards of a card deck in Los Vegas, or in the clothes and books and papers in a dorm room, they can't magically move those whole "boxes" they're in! Solid things, whether cards, stones or clothes, will stay exactly in the place that they are, at any moment in time, unless some adequate\* energy flow *from outside* them forces them to move a little or a lot.

     If the initial arrangement of things was in some pattern or orderly, when the things are forced to move they will be pushed to different places and become more disordered. *Things don't have any tendency in themselves toward macro disorder; the energy flow that moves them is the cause of disorder.* That's no indication that nature "doesn't like order". It's just that statistically there are many more billions (or quadrillions) of arrangements that are what we call "disorderly" than there are of the few dozens or hundreds that we call neatly patterned. A technical statement would be:

Whenever an adequate\* amount of energy flows through a system of objects, it tends to scatter them. (The energy flow, if adequate\*, can break bonds and disperse the resulting object parts.) They will be strewn to random, statistically probable locations consistent with all applicable factors of the objects and their flight paths or those for their fragments. In this process the concentrated energy in the energy flow becomes spread out or dispersed in imparting kinetic energy to the objects; *its entropy is increased by such spreading out*. Unless the original objects (or an appreciable part of them) are ground into a fine powder, their energy and *their entropy contents are essentially unchanged* a short while after the process of movement and scattering has stopped. (This time period allows any temporary heating effects to come to equilibrium with the local atmosphere after the energy flow ceases.)

\*"Adequate" here means coupled (of the type and frequency that can interact with the object, necessary) and large enough to disrupt the existing arrangement of the object in its locale (sufficient).

    Maybe the most dramatic example possible is what happens in a violent windstorm. After a tornado or a hurricane has devastated a town, the shattered houses and scattered wreckage are tragic sights. In seconds powerful winds have made random the most treasured and complex patterns that individuals have carefully created over many years. Ironically, the entropy change is not in all the shocking visible devastation. It is not in the destruction of our human patterns, not in *their* change from orderly things to disorderly things. The thermodynamic entropy change is invisible in the sense that it is in *the dispersal of energy from the concentrated energy source* -- the awesome whirling winds that have just passed have spread out some of their kinetic energy in spatially moving objects (an entropy increase in the winds) along with a lesser decrease (energetically) in temperature due to making the previously relatively calm air of the town more turbulent and it is slightly warmer.

Q: I get it. It's "adequate" energy flow that hits things and shoves them around to look disorderly -- things don't do anything like that by themselves. But wait a minute In some class or other I heard the prof say "everything is going downhill to maximum entropy, to chaos and disorder"
A: Some profs say weird things! That's a century-old misstatement that may sound profound but actually is just plain ignorant. It's like he took your class to a horse show but let you look only at the rear ends of the horses. Let's look at the rest of the horse instead.

     You know all about the second law, how it says that spontaneous reactions "go downhill" -- meaning that they all spread out energy, and so entropy is always increasing. (Because entropy measures how much energy disperses at a specific temperature, T.) So in all such processes, sometimes the energy spreading out is "adequate" to push things around a little or a huge amount. Maybe we think that's undesirable disorder, or maybe it's obviously disastrous destruction.

     Stop there a minute! Tornadoes and hurricanes in the US *are* often horrendous -- their powerful energy flow certainly causes chaotic wreckage, especially in towns or cities. What's the source of that energy flow? It's energy from the sun hitting different kinds of the earth's surface, including oceans (where water is evaporated, rises to high altitudes and forms clouds). Because of the earth's varied surfaces, that solar energy heats the air near them differently, so the rising air moves at different rates. Energy dispersing; entropy increasing. We feel that as slight breezes or even strong winds blowing here and there. Is that bad? (That's somewhat "disorderly" but not really "chaos" or there wouldn't be any meteorologists and TV weather people!) Occasionally in the US, powerful colder winds from northern regions collide with equally fast-moving warmer moist air from the south and for a few hours tornadoes are formed here and there. Not good at all.

     But compare the number of those undesirable events with the uncountable days of normal flow of moist air with clouds that bring rain to different regions of the US! Those many many days of rain all over the continent (and all continents) -- caused by "adequate" solar energy pushing millions of tons of water from the oceans up in the air -- is absolutely essential for plant life. Are growing plants -- from wheat and corn to flowers and trees -- undesirable "chaos and disorder"? And that's just one facet of the *good* that the sun does -- sending to the earth only a billionth of the huge quantities of its energy it disperses per second -- even though, thereby, causing an enormous increase in entropy *in the sun* as well as a tiny fraction of that entropy increase on the earth. However, we must always be aware that the most sensational downhill spreading out of solar energy (entropy increase) is the small fraction that is coupled with the uphill process of photosynthesis. Our whole lives -- almost all life totally depends on that capture of solar energy as it disperses.

[[There is more readable information about energy coupling in biochem toward the end of<http://2ndlaw.oxy.edu/obstructions.html> and by clicking on "Photosynthesis" near the end of the [http://entropysimple.oxy.edu](http://entropysimple.oxy.edu/) introductory page.]]

And that "uphill"aspect of the second law -- coupled with activation energies that protect systems from going back "downhill" energetically -- is what most professors who are not in science simply don't realize.

Q: Hey! I get it -- that's the end of the horse that they don't know about because they don't know chemistry: "The second law is our "greatest good"! You said all that back on page five.
A: Sure did. Glad you realize that big idea from science.

      Think what a wonderfully different place the earth is today, compared to what it was a billion years ago when it was truly chaotic and disorderly. "Everything going to hell in a handbasket", some profs say? Activation energies hold the handles of that "handbasket" so everything *doesn't* go to hell in so many instances! Today, full of amazing "uphill" plant life and "uphill" life of all sorts plus all the beneficial human-created order in small and large things, the earth is a remarkably better place than as the hot hunk of matter it began.

     A major reason that our present physical world is deteriorating, of course, is human over-reproduction and overconsumption that results in the degradation of our environment. But those problems aren't due to some inexorable mysterious force or the Silent Sinister Subtle Scheme of entropy! It is we who are causing them.

It is true that the sun is decreasing in mass as thousands of tons per second are changed into truly huge amounts of energy. The sun is "going downhill" but it will take more than four billion years to get to that hill's bottom. That's a pretty long time off. I'm a lot more worried about the next fifty or hundred, aren't you?

Q: Sure. The next two. I have a feel for entropy. But why did you go into such a big song and dance with that jagged diagram a while ago just for busting a surfboard, skateboard, snowboard or ski??
A: Add "or for a car fender, jet engine blade, freeway bridge, leg bone, spine, or skull"!! Doesn't that mean you?! That diagram covers breaking an enormous span of solid things that really are important to us. So, it is a pretty big deal for our understanding bad things that can happen in our lives. 
See that arrow, the EACT SOLID on the diagram? That represents a function which is equivalent to the Eathat starts chemical changes, chemical reactions like burning cellulose and rusting iron. The EACT SOLID is the activation energy that has to be applied to any solid object to start a physical change., its fracture. So, the powerful new idea we have here is that both for chemical changes like fires AND for physical changes like breaking things, there is a minimum amount of energy, an activation energy, that is required to initiate the process.

     With that new idea we can broaden our previous statement about activation energies in chemical reactions being obstacles or hindrances to chemical change. (As we've said, all of the organic compounds in our bodies could immediately catch fire in the oxygen of air if there weren't such obstructions to the second law as Ea.) Energies of activation in solids, EACT SOLID, similarly prevent solid objects from being broken readily. ("Wear" in solids is breaking off clumps of atoms so the EACT SOLID is very very important in thinking about tires or gears or bearings or anything wearing out. When things don't *wear out* very fast, it means that inherently they have relatively high activation energies against fracture occurring.)

(Actually of course, as we talked about before, it is the resistance of chemical bonds to being broken that is reflected in the energies of activation. Thus, Ea and EACT SOLID are indicative or derivative functions -- i.e., they are due to a number of factors involving chemical bonds but they can be used as shorthand or symbols for resistance to change.)

Q: So what?
A: So everything! Here comes the big payoff: How knowing about the second law and activation energies can make a big difference in our understanding bad things that happen to us.

   People from the beginning of history have worried about material things going wrong in their lives. About why bones break, why shiny copper jewelry (valuable in antiquity) turns green, why tools wear out, why rivers of mud rush down the hills and wreck the village, why people get sick, why they die. Fate and karma and spiteful gods have been just a few of the infinity of inaccurate solutions to the threatening problem of seemingly erratic nature. "Why me?" has probably been a human feeling before the invention of language. It is common today in any catastrophe. Is it justified?

    You now know the basic cause of every material/physical event that we think is bad: It is the second law or, more accurately, what the second law describes: the behavior of energy in our real world. All the structures that we prize -- from our own bones to our artifacts like chairs or houses, skyscrapers, bridges or jet planes -- are subject to being broken or destroyed by adequate energy flow moving from being concentrated to becoming spread out and diffused. The distressing results of forceful impacts on bones and cars and buildings are simply manifestations of this tendency of concentrated energy.

(Quakes and violent winds are temporary and coincidental accumulations from less concentrated energy sources).

     Further, you know now that all the chemical catastrophes that hit us are similarly caused because the substances involved in the disaster obey the second law. Whether forest fire, or Hindenburg fire-explosion, or dangerous corrosion of a car part, blocking of brain patterns by Alzheimer's factors, or bacteria that interfere with a critical feedback system in the body -- these are just examples of concentrated energy spreading out contrary to our human preferences.

     As one of our major goals, we humans want order and organization of many different varieties. An equally important goal is our desire (not realizing the potential dangers) for oxidizable substances like wood or iron to use in our artifacts and like gasoline for always-safe power source in our machines. Neither goal is consistent with the second law. Yet we are surprised when, against our naive wishes, the predictions of the law actually come about. Murphy's Law (speaking only of matter-related events) that things always go wrong fits an emotional human need when we are frustrated; it’s a joke because it is such a gigantic exaggeration.

    However, we may subconsciously let its humor make us concentrate on things going wrong and blind us to the most amazing fact in our second-law world:**Usually things do NOT go wrong**. There are three major reasons that they don't: First, constant human care and caution in protecting against second law predictions. (Two mundane examples: planning and actions that reduce the possibility of fire in industry and the home, painstaking design for safety and the continued careful inspection of airplanes.) Second, the existence of activation energies that obstruct and block chemical processes or fracture of materials from occurring spontaneously (i.e., “blocking” the second law from milliseconds to millennia). Third, the literally incredible organization in living things: All the complex energy-processing systems -- from simple amebas to humans, from primitive grasses to complex plants --live and procreate because they are protected from failure by an enormous variety of feedback mechanisms.

(It is often the failure of only one activation energy out of billions, or one feedback loop out of thousands, that makes Murphy's Law seem valid. Fancifully, Eas and feedback cycles act as our ‘protectors’. Thus they could be called Maxwell's Angels (in contrast to that humanly-unhelpful “Maxwell’s demon”.)

     A fractured leg in a ski accident, a spark in the fuel tank of TWA Flight 800, a broken timing gear in a Corvette, a fire in a fraternity house started by a forgotten cigarette, a California freeway collapse in an earthquake, a fall from a horse that results in a broken spine and quadriplegia -- all these are examples of activation energies being exceeded, whether in chemical reactions or physical fractures. Together with the thousands of illnesses that can destroy our functioning as whole persons, they constitute "things going wrong" in people's lives.

     But activation energies that obstruct undesirable chemical and physical events almost always protect us and our prized objects even from disastrous change that the second law predicts. Bodily feedback systems almost always protect us from bacterial attacks and malfunctionintg human biochemistry.

*Almost*always*.*

     Shouldn't "Why *me*?" be our near-constant question of wonder and delight at being alive and being able to move and think and create -- in a second-law world that favors dispersed energy and inert sand? Knowledge of the second law makes unrealistic the human cry of "Why me?" that is so frequent at times of tragedy.

     At such times, the only rational response is "Why *not* me?", even though then it is emotionally quite unacceptable.

*[*[*Links*](http://secondlaw.oxy.edu/ten.html#links)*and*[*References*](http://secondlaw.oxy.edu/ten.html#refs)*follow below]*

**Addendum: The Importance of Chemical Kinetics**

     *"Time's Arrow", our psychological sense of time*

Philosophers and novelists and their readers have been disserved by hearing statements of the second law (that events and physical matter move in the direction of energy dispersion) without the essential codicil from chemistry that the law is continually blocked by activation energies.

    Chemical kinetics (chemical dynamics) is the area of chemistry that focuses on activation energies and the rates of chemical reactions.

     Physicist Arthur Eddington's maxim about the second law is an incomplete view of the way the world works without a chemist's correction : --

(AE, 1925)            The second law of thermodynamics is time's arrow
(FLL, 1996)    **but chemical kinetics is time's variable clock.**

Or (FLL, 1998):    **Chemical kinetics firmly restrains time's arrow
                                   in the taut bow of thermodynamics
                                        for milliseconds to millennia.**

As a result of my suggestion, Professor Keith J. Laidler in his "To Light Such A Candle" (Oxford, 1998) says it profoundly at the end of his chapter on thermodynamics:

                               **The universe as we know it is therefore as much controlled
                                     by the laws of chemical dynamics
                                         as by the laws of thermodynamics.**

**Links**

* [http://http://shakespeare2ndlaw.oxy.edu](http://shakespeare2ndlaw.oxy.edu/), a site primarily for students or adults in the humanities and arts. A summary of what C. P. Snow *should*have said about the second law and activation energies to his audiences when he mentioned thermodynamics. Some of the ideas in secondlaw site, but omitting entropy.
* [http://entropysimple.oxy.edu](http://entropysimple.oxy.edu/), a more complete description of the second law and its implications for the ecology (weather patterns, photosynthesis, etc.) of the earth as well as the benefits of the second law for humans. Less informal than secondlaw site. Primarily for adults interested in the subject rather than students taking chemistry courses.
* [http://2ndlaw.oxy.edu](http://2ndlaw.oxy.edu/) has five parts.

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|      The first, "Entropy and the second law of thermodynamics" gives a superior introduction to entropy from the standpoint of molecular behavior ("molecular thermodynamics") and quantized microstates, but does not introduce math or quantum mechanics. |
|      The second, "The second law of thermodynamics is a tendency" is almost a repetition of material from secondlaw site. |
|      The third, "Obstructions to the second law make life possible" develops the concept of activation energies as does secondlaw site but goes further in showing the relationship of endothermic reactions to energy input, including some material on substances found in space: how they could arise. |
|      The fourth, "The second law of thermodyamics and evolution", responds to many questions sent to secondlaw site by individuals who did not realize that the second law energetically *favors* the formation of more complex compounds from the simple elements. |
|      The fifth, "Entropy and Gibbs free energy", is only for chemistry students, whereas all preceding material was for science and for non-science majors. The page really should be named "The Gibbs equation is ALL entropy!" – just to surprise chem students who have to work with it.)  |

* [http://entropysite.oxy.edu](http://entropysite.oxy.edu/) is primarily for chemistry instructors

**References**

Please send your favorites to entropy.lambert@gmail.com for future versions.

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