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18. The arrow of time

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"*In which we learn why, unique among Nature's Laws, entropy gives the direction of time—reinforcing what poets have been telling us, forever, it seems.*"

Nature's entropy law aims time's arrow—feathers in the past, barb in the future. All 10 of the other 11 laws of classical physics (and it seems *all* the rules we've uncovered so far about modern physics [1]) would happily allow time to go backwards or forwards—spontaneously changing messy rooms to tidy rooms. But invoking her entropy law, Nature says no! She decrees that anything that would decrease the entropy of the universe is *verboten*.

But to our delight—and good fortune—increasing universal entropy does *not* require that local entropy increase. If we can export entropy as fast or faster than it's produced, we can enjoy the excitement of entropy producing activities *without* local entropy growth. That's our saving grace. It keeps us alive, brings us our joys.

Surprise is the core of humour. When we experience the unexpected, it can sometimes be hilarious—like a movie run backwards. Today it's a rather tired way to get a laugh, but when movies were novel it was a sure source of guffaws. Early moviegoers had lived long enough to know what to expect from Nature's laws, but they hadn't yet learned they could expect *anything* from unconstrained Hollywood fantasy.

When I introduce embryo engineers to the ideas of entropy, entropy production and the arrow of time, I often speak of movies. When we want to decide if a process will produce a little (or a lot) of entropy, it's useful to imagine a movie of the process running *backwards*. If backwards stills seem realistic—like a backwards movie of a pendulum swinging—the process produces little entropy. Conversely, if backwards appears preposterous—like a backwards movie of an egg thrown at a brick wall—the process is strongly entropic.

Processes that produce zero entropy are *reversible*. Processes producing entropy are *irreversible*. Sometimes, when little entropy is produced—like an exquisitely balanced pendulum swinging in a vacuum—engineers often *assume* the process is reversible. Assuming reversibility makes calculations a lot easier—something students want to know for exams.

During World War II, the Allies repeatedly showed a film clip of Hitler performing a jig outside the railway car where he'd accepted the surrender of France on June 22, 1941 at Compiègne. Hitler's jig was supposed to demonstrate his silly nature. But even at the time, many people in the allied nations suspected the film had simply been run backwards, then forwards, then backwards a few times. In B-grade advertisements, we sometimes watch cats perform a jig as they approach (what we're told is) the cat's favourite food. Same trick as with Hitler.

Sometimes the idea of backwards movies don't evoke laughter, rather they are painful reminders that "we can't go home again". How many times have we watched the film of a motorcade wending past the Texas Book Depository on November 22, 1963—wishing we were not about to have confirmed, again, what has been confirmed over and over. Do we not wish we could simply run Zapruder's home video backwards and claim the backwards version to be reality? Nature says no. I cringe in the saying, but the entropy of the whole brains is less than the entropy of splattered brains.

And now, after September 11, 2001, we have another example, this time too close, too painful to abstractly dissect as merely another illustration of massive entropy production. A terrorist attack is an explosive reminder of the tie between entropy production, irreversibility and the arrow of time.

Let's climb out from this darkness.

Water jumps off the lawn and travels back up the hose. Now we're back to funny because it astonishes—in a harmless, silly way. Real water in a real world doesn't jump from the

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[1] No aspect of modern physics conflicts with the entropy law. Moreover, as we said when discussing the 11 laws of classical physics, it's important to distinguish between laws that govern the behaviour of all material without reference to a specific material—like the 11 laws of classical physics—and rules that are material-specific, which we called "constitutive relations". The overarching principles of relativity and quantum mechanics are in the former category. The special behaviour of sub-atomic particles falls into the latter. Still, for someone curious about perhaps the most curious of phenomena related to time direction, I suggest looking at the unique, rare and strange case of long-lived *kaons*.

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lawn back into the hose because, in the jumping, it would violate Nature's entropy law. Why? Because there are many more *micro*states associated with the water on the lawn than with the water in the hose. The entropy of water on the lawn is greater than the entropy of water in the hose.

Pretend we had zero life experience—but *somehow* had still learned that any real process produces entropy. Then, if we wanted to know if some imagined event is possible, we could calculate the entropy at the beginning and end of the imagined event. If calculations showed the entropy of the universe would increase, we'd know the process was possible. But if the calculations showed it decreased, the process just can't happen.

My brand-new daughter Lee wobble-stood in her playpen on the front lawn, both hands grasping the crossbar as she surveyed her new world. Quietly, I sat watching. A rather stupid fly landed on the crossbar within a few inches of her nose. Lee slowly released her right hand from the crossbar. Wobbling increased. Her index finger moved forward to push the fly. Suddenly, the fly departed. Lee's head snapped down to see where it had fallen—no doubt a reflex from pushing unwanted toast from her highchair. But then an expression of wonder *and* amusement crossed her face as she realized this thing had fallen *up*. She was beginning to learn something new; when living things exploit Nature's laws, they don't always behave like bits of toast.

Most of us have been marinated in life experience. Lee was just at the beginning of her marinating when she nudged the fly. We don't need a course in thermodynamics to know that while the movie "Back to the Future" might work in some parallel universe, it won't work in ours. For most processes we might imagine, we simply *know* if they're possible or not. We don't need to go through the trouble of entropy calculations.

But sometimes it's not so easy, like when dreaming up new technologies. Too often inventors invent things that will never work the way the inventors claim, because their claim would violate Nature's entropy law. Of course, they often still get a patent. Understanding the entropy law is seldom a patent attorney's long suite. Besides (as I'm often reminded), theirs is not to check if the invention will work. Theirs is simply to determine if it's been patented before and, if not, to protect it against some damn fool who might want to patent it in the future.

I'm consistently amazed by investors, entrepreneurs and dreamers who become so enmeshed, so promotional, so *enthralled* by technical schemes that, in fact, are doomed by Nature's laws. Repeatedly witnessing this murder of capital, talent and human spirit, was the reason I determined we must pursue our odyssey in search of exergy—as difficult as I knew some of that journey would be.

We'll talk about the difference between Nature's laws and civilization's laws in a later article. [2]

[2] D.S. Scott, "Bits and Pieces" a future article in this series, Int. J. Hydrogen Energy.

Humpty Dumpty splattered over the ground has higher entropy than Humpty sitting on the wall. Spilled milk has more entropy than bottled milk. A cadaver has more entropy than somebody hopping round a dance floor—or giving a brilliant lecture. So entropy—time's arrow—tells us that cadavers won't be giving brilliant lectures, that Humpty won't be jumping back on the wall, and that the milk on the floor will not *spontaneously* jump back into the bottle.

I added the word spontaneously for the spilled milk—but not for the cadaver. So nuances remain. We can remove entropy from spilled milk. We can use our brains, to direct our hands, to hold a squeegee and carefully gather the milk to put it back in the bottle. Of course, using your brain, your hands and doing the squeegeeing all produce entropy—a lot more entropy than you'll remove from the spilled milk as you get it back into the bottle. The *total* entropy of the universe will have increased. So if you don't want to cry over spilled milk, but rather just want to squeegee it back into the bottle, the entropy law will remain inviolate. It's tougher to get a brilliant lecture from a cadaver.

The everyday consequences of the entropy law are so obvious they've been the staple motif of poets, philosophers and novelists, forever, it seems. Since entropy's manifestations are everywhere, we might have expected Nature's entropy law to be much easier to discover than, say, Her conservation laws of mass, momentum or energy. But entropy seems to have been the toughest to find. And the toughest to explain.

Now two brief diversions:

- Western cultures have always considered time linear. In contrast, many Eastern cultures have considered it cyclic. Nature's entropy law confirms it's linear. I wonder if this may be one reason the core ideas of entropy were developed in western cultures. [3]
- "Order out of chaos", is the engaging, profound phrase that Ilya Prigogine used to describe his study of phenomena for which he was awarded a Nobel Prize. Unfortunately, some who hear titles but don't read books took it to mean the entropy law can be violated. Not so. Order from chaos results because low entropy streams are fed to the original chaos. [4]

The entropy law may tell you why "you can't go home again". Yet, as we're about to discover in "*Leitmotiv* of Living Planets", it also keeps our world brilliantly alive.

Earlier societies deified sunlight as our planet's life-giving energy stream—kneeled before the Sun God.

[3] An equation-free but non-trivial history of the development of these ideas is covered in the book called, not surprisingly, The Arrow of Time, by Peter Coveney and Roger Highfield, Flamingo, 1991.

[4] Prigogine, Ilya (with Stengers), Order out of Chaos, Heinemann, London, 1984.

In our own way, we do too. If you have ever felt the warmth creep into your bones as the sun cracks above the horizon after standing the dawn watch on a small sailboat in mid-ocean, you will understand.

Yet the infrared energy Earth pitches out to the universe is at least as important as the incoming sunlight. Perhaps more so. For it pours into the universe all the entropy produced by our planet's exuberant lifestyle.