Which way was the ball thrown?

Intro to thermodynamics

Intro to "Time's Arrow"/ "Reversibility" / "Thermodynamics"

"We may regard the present state of the universe as the effect of its past and the cause of its future. An intellect which at any given moment knew all of the forces that animate nature and the mutual positions of the beings that compose it, if this intellect were vast enough to submit the data to analysis, could condense into a single formula the movement of the greatest bodies of the universe and that of the lightest atom; for such an intellect nothing could be uncertain and the future just like the past would be present before its eyes."

-- Marquis Pierre Simon de Laplace

Symmetry and Physics

Newton & co. codified what they learned about nature in some equations ("laws").

The equations have certain *symmetries*.

If you replace every position with *minus* that position, like flipping your graph paper upside down and calling +x "-x" and East "West," the equations are the same.

Nature must have the same symmetry: no law of physics cares whether you go left or right, and if I watch a movie of you doing one or the other, I can't tell if I'm watching it in a movie.

(Then why are most humans right-handed, why are we made of left-handed amino acids, why do we metabolize right-handed sugars? *good questions...)*

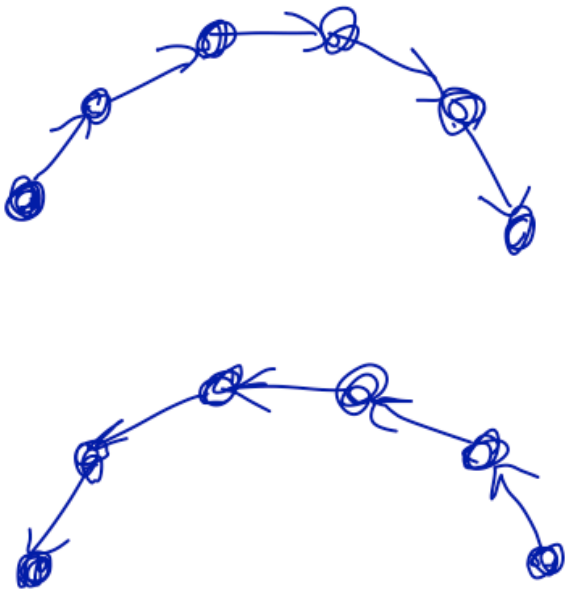
Symmetry and Physics

If you replace every "t" with "-t", the equations are also the same. If those equations were all there was to the world, how could forward in time be so different from backwards??

Does this mean there *must* be new laws?

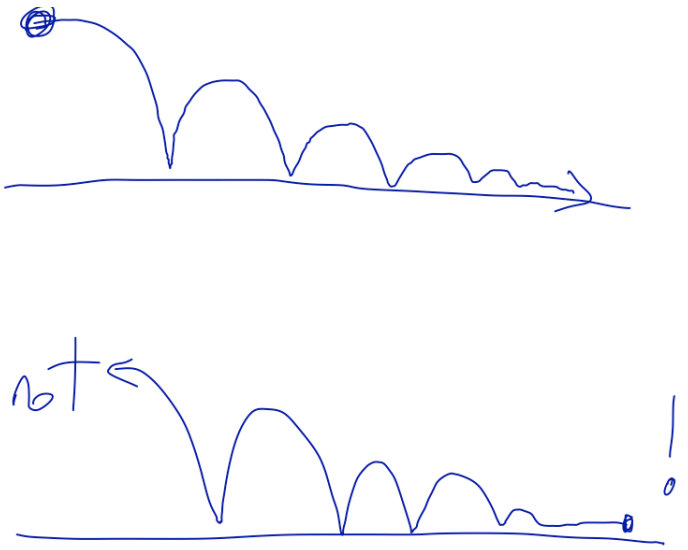
(NB: replacing every t with -t includes all the "implicit" times, like the one buried in a velocity of "+5 meters / second"...)

Watching a tennis ball in flight

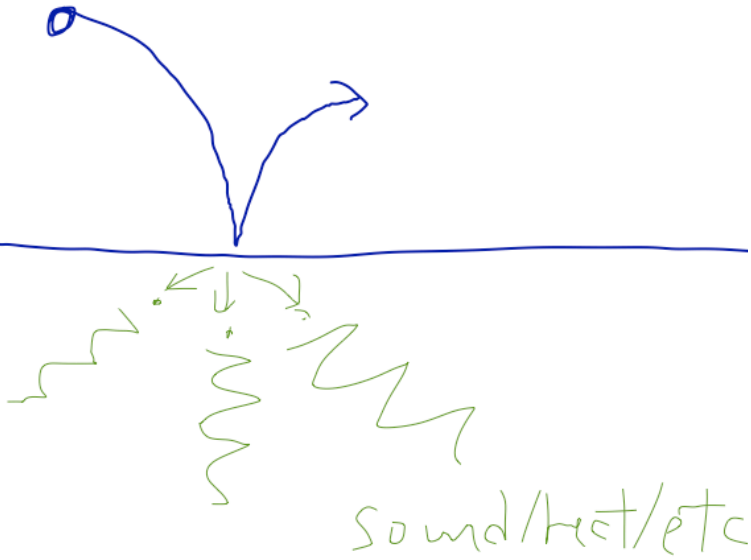


Why does the world seem irreversible?

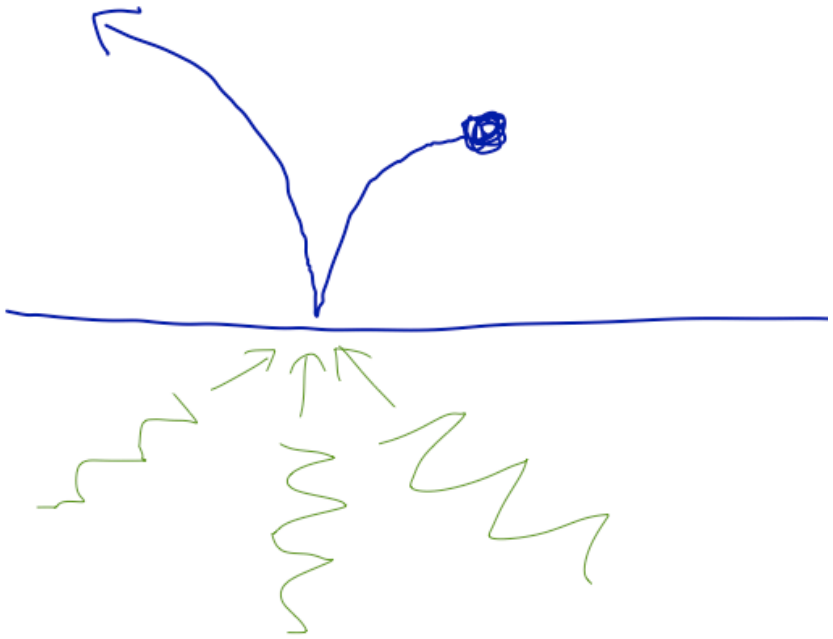
Perhaps because energy decreases with time (water flows downhill, etc.)?



Not quite; energy is conserved.



Why doesn't all the sound and heat ever come back to push balls off the floor?



Microscopically reversible laws nevertheless yield macroscopic irreversibility...

Connected with heat or "dissipation" -- energy can leak out into many (infinitely many?) degrees of freedom, but is *unlikely* to conspire to come back together.

Probability, not law?

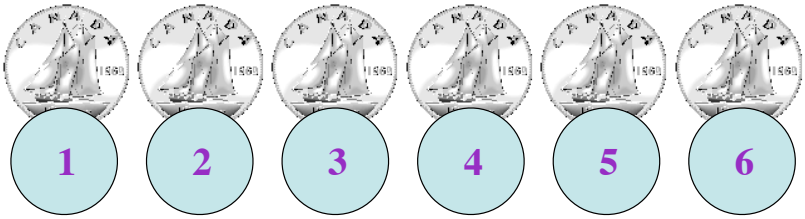
"Statistical thermodynamics."

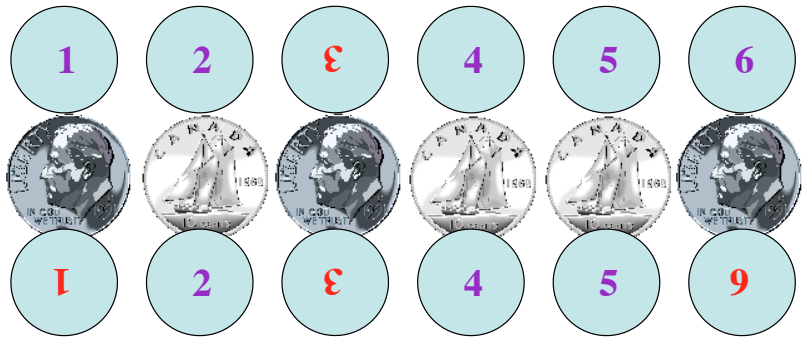
Probability

A:

B:

Probability





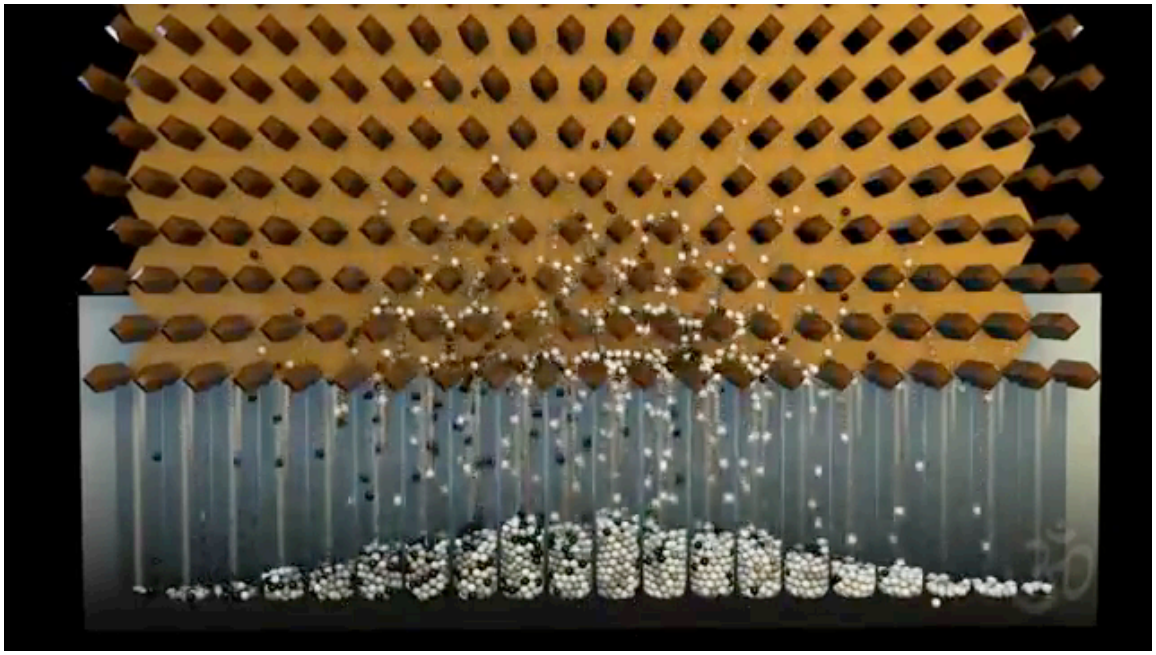
Probability

Only one way to get 6 tails

***Six* ways to get 5 tails & 1 head.**

... and so on ...

Quincunx: Pascal's Triangle



Entropy

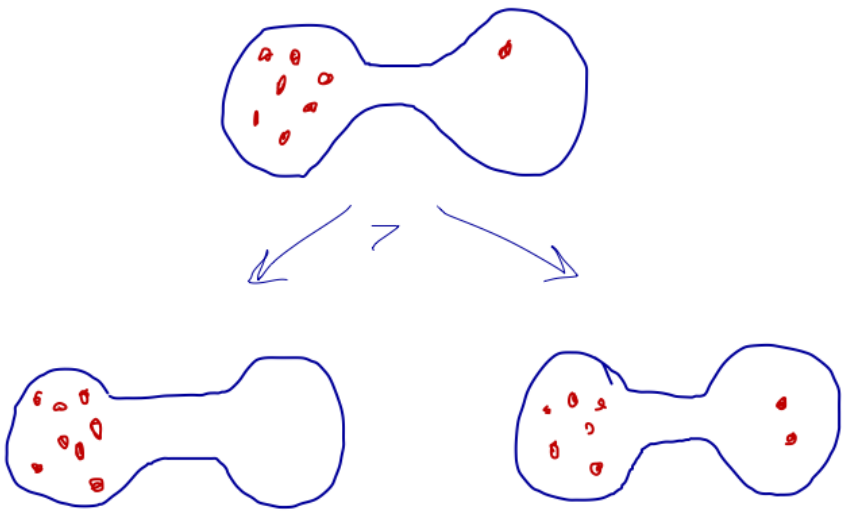
Roughly speaking, entropy is "disorder" (randomness).

The second law of thermodynamics states that
***Total* entropy never decreases.**

All 6 coins being tails represents "order."
The coins being equally likely to be heads or tails represents disorder.

Things get more disordered simply because there *are more states* that have high disorder than states that have low disorder.

The air molecules in the room being spread roughly evenly around represents *disorder*.
The air molecules all deciding to congregate near the ceiling, suffocating us, would be a high degree of order.



(Julio's applet)

http://www.uark.edu/misc/julio/kinth/distri.html

Entropy

Like air molecules, energy is more likely to be distributed "evenly"; heat flows from hot objects to cold ones, and never the reverse.

It's not that energy goes *down*; it's that energy gets *spread out*.

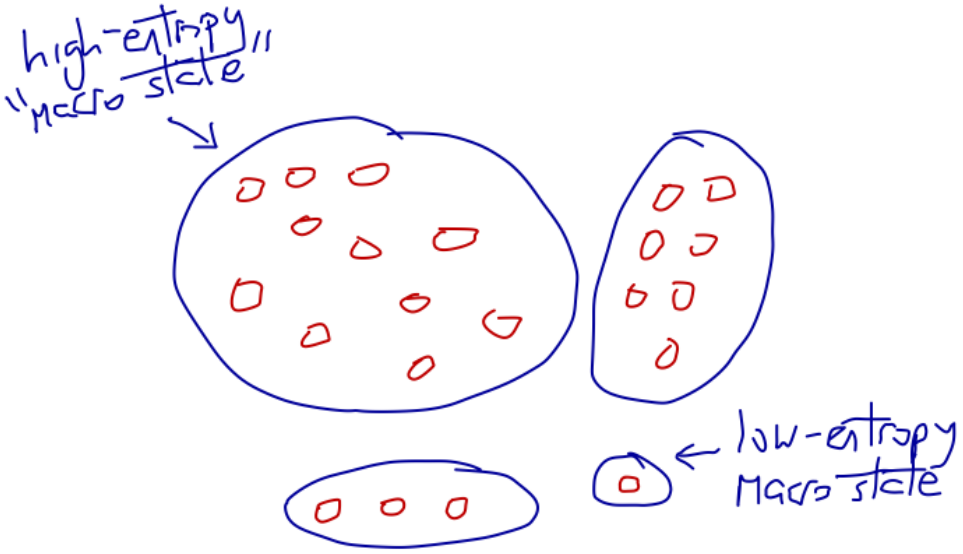
When the ball bounces, there are millions and millions of different ways the floor could vibrate; but only one way for those vibrations to go in reverse and launch a ball off the floor...

An abstract picture of laws of physics

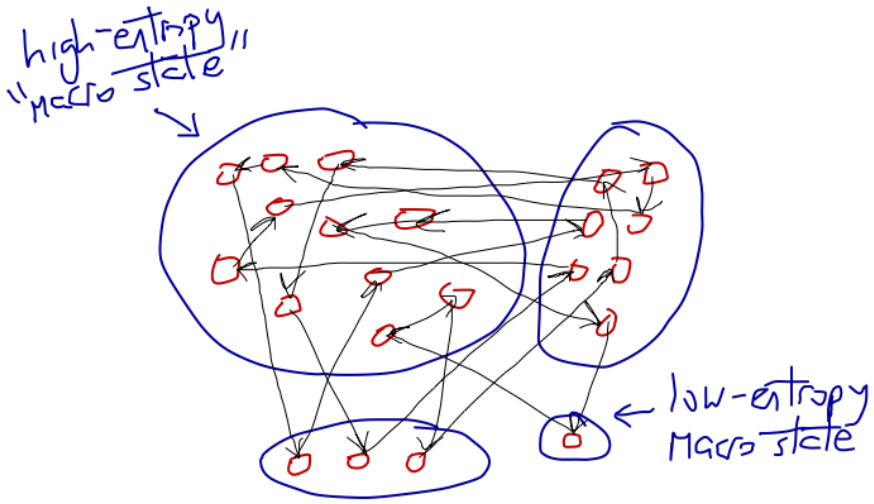
reversibility

ALL THE STATES OUR SYSTEM COULD BE IN:

"LAWS OF MOTION":

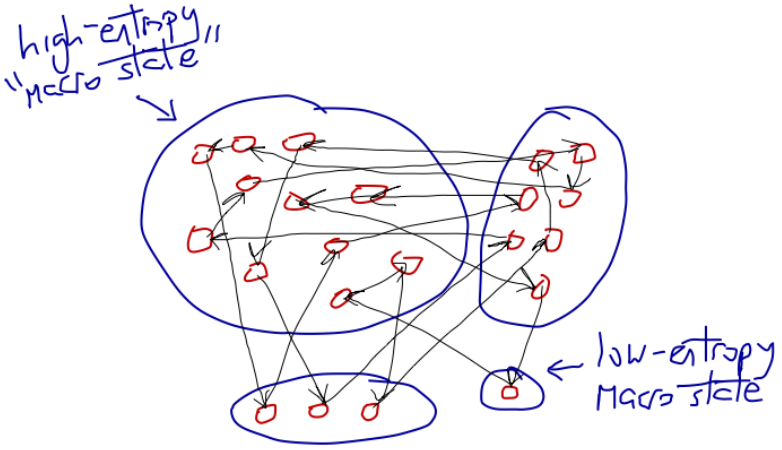


Laws of Physics are just arrows...



Obviously, no matter where I start (and even though the arrows go both ways), *eventually* I'm more likely to be in the high-entropy "macro state" than in the low-entropy one.

Is this really a solution?



If I follow the arrows backwards to figure out where the system was in the past... no matter where I start, I should eventually end up (most likely to be) in the highest-entropy state.

So if I look *back* in time, I should also expect to see entropy increase?

Boltzmann:

"That in nature the transition from a probable to an improbable state does not take place as often as the converse, can be explained by assuming a very improbable initial state of the entire universe surrounding us.

“This is a reasonable assumption to make, since it enables us to explain the facts of experience, and one should not expect to be able to deduce it from anything more fundamental"

The founders of thermodynamics

"Ludwig Boltzmann, who spent much of his life studying statistical mechanics, died in 1906, by his own hand.
Paul Ehrenfest, carrying on the work, died similarly in 1933.
Now it is our turn to study statistical mechanics.
Perhaps it will be wise to approach the subject cautiously.”
--- David Goodstein, in *States of Matter*

It turns out that entropy almost *always* increases in such pictures -- as long as you haven't reached the "maximum" entropy state!

But -- if we reached the maximum, would time's arrow reverse? Or perhaps the expanding universe means we never reach the max?

Maybe the universe did just start out with very low entropy (at the big bang, everything was in the same place); then entropy would have nowhere to go but up.

And what if the universe had begun in the *equally* unlikely state which was set up just right so that in 15 billion years everything would coalesce into one tiny low-entropy point?

Would we see time going backwards? Or would our notion of time also work the other way around?

(Why do we remember the past and not the future?)

After all this time trying to figure out why the laws seemed symmetric when everyday life doesn't...

It turns out the laws *aren't* quite symmetric!

(and now we're even *more* surprised.)