

Chapter 2

Narrative Time

Now that we've sketched the basic outline of our story and built some common ground to stand on, it's time to start the main treatment and start looking at some concrete examples of how laws and descriptors are more complicated than they may appear at first glance. In the way of a small recap, so far we have stated that the instantaneous past, which we could also call the freeze-frame version of the past, is physically located at some distance far away from us. The increasingly precise, or the increasingly instantaneous, present is located at the center of each act of measurement, and *we*, or you could say everything else, lie somewhere in between.

Next, let's imagine that we are in a freeze frame picture of the universe, like we just took a giant snapshot and now we can make the most precise, perfect, instantaneous measurements imaginable. Within the context of this ultimately precise universe we are going to see that drawing the difference between two specific scenarios, namely one in which we have *witnessed* something insanely precise, as opposed to a scenario where we have *engineered* conditions such that we can guarantee this event will have happened, is sometimes hard to tell apart, especially when the thing you're observing is very far away. The distinction relies on the difference between exact *deterministic* calculations, and non-exact *probabilistic* calculations, where there is always a case¹ where the deterministic calculation must be abandoned for a probabilistic calculation when increasing the need for precision in your description.

Now remember that inside this giant snapshot, everything that is separated by some distance is *also separated in time*. Everything that is far away from you in this giant photograph happened a little before the frame was frozen, because you were moving in reference to the things when you took the picture. This means that if you travel a certain distance at the moment that the photo is taken, then everything in the photo is spread out across time as well, correct?

¹Particularly in the extreme case of the infinitely instantaneous.

If we're going to continue to maintain our narrative vision of how the universe works, namely one that started with a loud pop, we will need to note that there is a subtle difference between what things *are*, and what things *may have been previously*, which is particularly important in the context we're considering now. The following chapter is going to utilize this distinction, in the frozen universe thought experiment, to intentionally rupture the normal way we think about the present state of things, and make the case that there is a valid way of describing the *now-ness*² of fundamental particles entirely in terms of what *they probably were before*, much like distinguishing what a certain word means now by discussing the etymology of that word as opposed to the most recent incarnation of its meaning. In other words, we are going to build a case for instantaneous relative time being restructured as a narrative—particularly in the context of the universe and small particles.

2.1 Atoms at a Distance

So if the universe has a story, and that story includes everything in it, and stories have beginnings and endings, then that would mean that everything within it should also have a beginning, and an ending, correct? In other words, if there exists some narrative version of the history of the universe, the narrative we generally think of as starting at the big bang and culminating in now, doesn't this require that matter, in a very real sense, should have some place where we could assign as the "birthplace" of that particle? Conversely, if a particular particle could be found that *didn't* have a definite causal beginning, would this denote that some aspect of the universe *also* didn't have a definite beginning?

For example, let's consider the case where a particular piece of matter is currently in the process of interconverting from one form to another. Let's say for the sake of argument that our chosen piece of matter is inside the sun, and is currently being compressed such that it will soon be a different kind of matter—say a couple hydrogen atoms that will fuse to make a helium atom (Fig. 2.1). There are rules about how and when this can happen, one of which is that it will take some specific amount of time to achieve, some finite interval. In keeping with our first chapter, this means that, technically, if you want to see the hydrogen become helium, or in other words see it at both the beginning and end of its transformation, the distance it is away from you *will also change during that interval*. It gets complicated if we need to keep all this distance/age stuff straight, but suffice to say that if something happens in a finite amount of time, then there exists a corresponding *space* that it must also span, especially if we are looking at it while it is very far away from us. In other words the light from the beginning of the transformation will be a little farther away from us than the light at the end of the transformation.

²Even if it requires some version of spooky action at a distance.

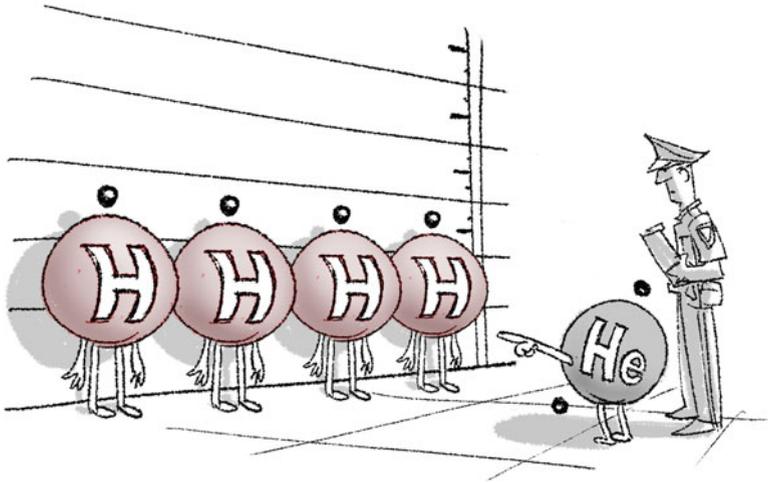


Fig. 2.1 The rogue hydrogen atom is finally identified

Generally, we can safely ignore these kinds of effects, especially if we're considering things down here near us where they are small. If however, we want to be exact and derive an exact, errorless description of our complete universe, paying especially close attention to all the *causal determinations*, complete with a narrative story with a beginning and end for each particle, we must also consider the way that matter converts from one thing to another, and even more annoyingly, the space in which this time interval exists. Additionally, this particle, while it interconverts, is probably moving relative to you. There are many ways that we can slice up how we might observe it, or imagine predicting an observation of it in the instant before or after our freeze frame which the interconversion might take, but you should see that we're not really looking for a single nice sphere frozen in space, we're looking for a kind of fuzzy smear, a pathway over which position isn't well defined. Notice, however, that the fact that there are multiple avenues it might take to get to the same outcome is not trivial. We could call this pathway degeneracy. If there are too many possible pathways this may start to get in the way of developing a precise description correct?

In fact, if we continue to think deeply about these and other relativity related phenomena, we start to note that the majority of the rules governing these interconversion events, namely the rules laid out in physics and chemistry, are generally taken as a given, where the stretching of normal space is only a consequence of moving too fast or being too light. Regarding precise calculations of events in a frozen universe, however, we must concede that relativity is ever-present. If we can find a way to re-introduce these principles as fundamental properties of observation as opposed to consequences of velocity we will be able to more deeply understand what the universe looks like in any given moment.

Let's look at it again. Given a perfectly frozen universe, the picture is actually a little more complicated than how I painted it before. In reality we would need to either *find* a situation where we know that a hydrogen atom is moving towards another hydrogen atom with the right velocity and angle of collision, and that the electrons on the surface of the hydrogen atoms must be in the correct orientation so that the correct chemical transition states appear, and the whole thing is quite complicated. Suffice to say, however, that we're going to have to know something about the velocity of each hydrogen, which is, unfortunately, *not* an instantaneous quantity. Given that we're in a freeze frame version of the universe, we're going to have a very difficult time deriving any such velocity,³ unless we relax our requirement that the universe be frozen. So we let it move just a little, resulting in our previously mentioned smear of a trajectory which will then allow us to measure a velocity and decide if it's going to convert into a helium or not. This is all nice and good, but if it moves a little then it's also moved relative to you unless you're in the same reference frame, and then the other hydrogen atom should be in a different place than you—and if they're both moving the same speed as you then they can't possibly be moving towards each other! As such there *must* exist some amount of space that the atoms move relative to you in order to make a measurement, and this space corresponds to a finite amount of time, which also corresponds to some space that you also moved during the time the universe was unfrozen, and if it's very far away on the horizon that means what we're looking for doesn't have a definite position anymore!

Think about that for a second. What was before a well defined position becomes not just a line in 3D space over some time interval, but depending on how your reference frame is changing as well, it could be a small 3D *surface*. And what's even more complicated is that your reference frame may not be moving in a simple way compared to the way the atoms are moving. What if instead of a simple continuous motion between reference frames they are vibrating in a complicated way? Now suddenly the "positions" that we need our atoms to be in are not only smeared out in space, the paths they might have traveled will start to overlap in complicated ways, and if there are multiple ways that hydrogen atoms might squish together to convert, the required shapes can start to look like a big fuzzy mess (see Fig. 2.2).

Additionally, consider the fact that as we *unrelax* our previous caveat, or in other words slow the universe back down to a single freeze frame again, the certainty we had that our chosen hydrogen combination will successfully interconvert to a helium drops off as our current moment becomes more instantaneous again! This is the heart of relativity, but we're not done yet, because the main point is that this is an example of when deterministic calculations start to break down once we accept that we are always constrained to observe the universe, and all the stuff that's in it, and all the stuff that's ever happened in it, from inside of it, and the effects of causal

³Either mathematically, or via simple observation and measurement.

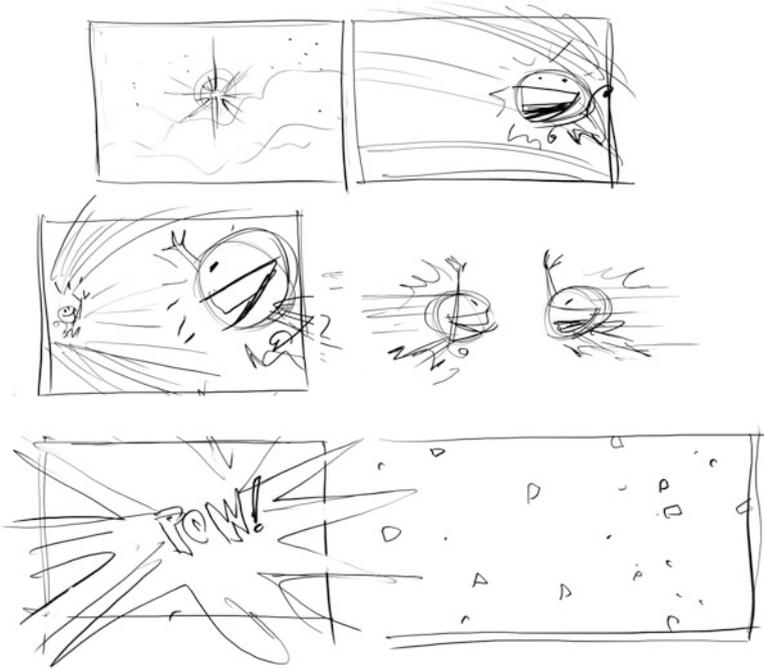


Fig. 2.2 Two atoms collide in a distant star

determination dropping off become more apparent the further out towards the edge we get.⁴

In other words there will always be issues with mapping an instantaneous measurement to another instantaneous event with reference to it, and this becomes more exacerbated the further things are away. To see this, let's add another layer of requirement. Now let's say we need to find *another* pair of hydrogen atoms which are also in the process of interconverting, and we want them to interconvert at *precisely the same moment*. It is impossible unless you are able to define a common reference frame, which is very difficult to say the least.

The take home message is this: even if it seems convenient to assume that the universe is all happening concurrently in a passive way, isolating and understanding how each event happens (which is necessary to engineer such events in the future) is very complicated and relies heavily on innate synchronization. The farther away from you such an event is, the less it is likely to be happening in a nice and neat

⁴Also, note that this starts to look *exactly* like quantum mechanics if you allow for lots of branches in your possible causally determinate moments between measurements, which is what the freezing and unfreezing parts correspond to. We're gonna come back to this and many other examples, but if you're seeing this, you're seeing the heart of how modern scientists are reforming their views of how things work.

deterministic way, or in other words, the harder it will be to say *after the fact* that you know precisely which hydrogen atoms were responsible for creating the new helium atom. In this sense quantum mechanics, coupled with relativity at distant scales, starts to look like more of an investigation into possible versions of the past that could have led to the present situation (see Fig. 2.1), than a more simplistic application of deterministic rules.

Quantum Galaxies

Let's take another example to drive this home. It can be seductively easy to dismiss the effects above, especially if deep down we just consider every chemical transition to be more or less instantaneous, even if that imbues them with a kind of magic we try to get away from in the sciences. Instead, let's consider something more classical, in fact something so decidedly non-quantum that it can't possibly be confused with a quantum object—say the formation of a galaxy. Not a general theoretical galaxy, but a specific galaxy, because we think it might soon give birth to a certain kind of star that hasn't formed yet, but there are really specific scenarios in which that kind of star forms, so I want to watch this specific galaxy and gather enough information about it to decide whether it is going to form this particular kind of star (see Fig. 2.3).

Let's slow down and make sure this comes across correctly. I don't want to know about some galaxy some other place that might be somewhat like this one, I want 100% certainty that *this* galaxy right here under my telescope will have this specific kind of star when I get there. A probabilistic framework will not work for me, I need to be 100% sure before I spend all the money and time to get ready to go there.

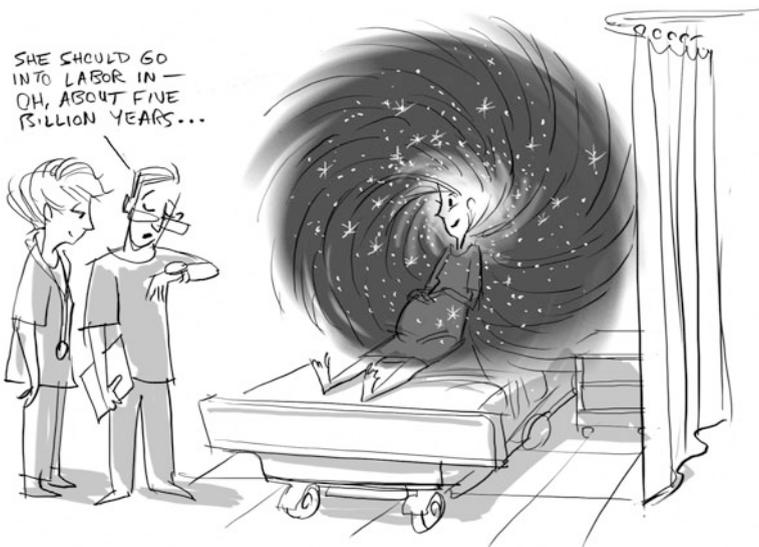


Fig. 2.3 The galaxy waiting to give birth

What if I can't wait until I directly observe the formation of the star via my telescope because if I do it will have burnt out by the time I get there? What can I do? I can gather precise real-time information about what's going on in the galaxy I have my telescope trained on, watching for the signs of the start formation and then run an exact deterministic calculation of the thing to be sure. How long do I need to observe it? What if I didn't start observing soon enough? Is there any way to calculate it out exactly?

No matter the distance that any galaxy is away from us, we can only observe it in real time. Even if we're looking further back in time to find a *different* galaxy that is similar, remember that I can't use that to guarantee that *this* galaxy, the one that I've been watching, will form the star in the same way, beyond a separate probability measurement. As such we cannot observe anything faster than real time, but we can simultaneously observe lots of events which are separated as different intervals in space and therefore in various stages of formation. This will never give us an exact deterministic calculation of the galaxy formation, however. In other words, things which are far away and wrapped in some deterministic set of criteria are therefore less and less local in terms of causal descriptions the further away they are. Isn't this starting to sound a lot like quantum mechanics? Note, however, that the only thing we need for this effect to arise is the fuzzy descriptor for what is our causal constraint—we're not sure how much time we'll need to observe a specific event in order to ensure an exact result. This is the same thing for fundamental atoms which are just as far away from us in terms of time and the dynamics as the galaxies are away from us in space.

All of this cleans up nicely, however, if we abandon the idea that the universe is fundamentally deterministic, and instead realize that it is fundamentally *probabilistic*, where the deterministic version is more of a special case.

The Atom of Theseus

So what were the conditions we needed in order to make our fuzzy quantum-like observables pop up from a completely classical object? Distance, time, and fuzzy definitions of what things are. You might return to the earlier protest from Chap. 1, namely that definitions of atoms are not the same as definitions of galaxies, or stars, which are big complex systems. Atoms, you might say are very precise, so none of this actually applies right?

In order to move forward, we're going to have to rework our idea of what atoms are. Let's start by considering the ship of Theseus. In a nutshell Plutarch posed a question a long time ago about whether a boat with all of its fundamental components replaced remains the same boat or not. One might reasonably assume that the essential *boat-ness* remains intact, assuming all the new parts are identical to those they replaced, but it can hardly be said that the boat itself remains intact, or that it is the same boat. One of the difficulties in setting up a precise narrative history of the universe since the big bang and thinking that it should be precisely deterministic

is that when it comes down to it, the atoms themselves are just as complex a system as the sun. They have life-spans, they are born and they die, and what's more is that they can swap parts when they interact with each other, sometimes jettisoning or absorbing other constituents.

In other words, if we had an infinite amount of time to wait and watch, we would realize that assigning intrinsic attributes to the atom is as difficult as assigning intrinsic attributes to something fuzzy and intersubjective, like a boat rebuilt with new parts, something that often happens to things like corporations or universities. Let's say, for instance, that I want to describe the amount of money that a specific university has, but I want to describe it as an intrinsic attribute, not a specific moment in time. I could say that it is *well off*, and you would understand what I mean. You wouldn't, however, then assume that they have an exact amount of money that isn't changing and corresponds precisely to the term *well off*. If, instead, we are interested in an instantaneous measure, the notion of the company being *well off* is no longer useful, especially if the university doesn't remain well defined with time. If the university has gone through many iterations through the years, say they had several names and invested their capital in different places, then a precise description of how much money they have becomes a constructed item as opposed to something we can passively observe. Pretty soon we're looking at a long spread sheet with footnotes, caveats, and fuzzy descriptors, where the length of the spreadsheet has to correspond in some symbolic way to the length of the lifetime of the institution itself, which also might not be a well defined item. It makes it even more difficult if later we find out that this particular university was the child of several smaller schools, or that it split into two different schools at some point.

As we saw before, fuzzy definitions like the intersubjective notions of a corporation or a university change on some timescale. So what happens if the lifetime of the attribute is on the same order as the timescale of the thing measuring it? This is what leads to quantum like indeterminacy, without any quantum mechanical axioms! So if we can argue that there's a version of describing an atom that is just as fuzzy as our definitions of corporations or planets, or galaxies, then we should also expect to see these strange indeterminacies. As it turns out, moving from an intrinsic definition of an atom to a fuzzy and hard to pin down definition of an atom is as simple as swapping its current existence with the narrative story of its lifetime, or imagining it as one of Theseus' ships.⁵ A hydrogen could have always had the same three quarks, or it may have lost a quark for a while and then later gained a different quark again. Is it still the same hydrogen?

In fact, it becomes suspiciously important to note that even distinguishing between two fundamentally similar particles, say a hydrogen from another hydrogen, is prohibited when performing a calculation in quantum mechanics, and this is often used as a crucial aspect of how we perform such calculations. In a sense it is a fundamental requirement of quantum mechanics that *all* quantum mechanical

⁵Actually, there are several versions of this thought experiment. I could as easily have called it John Locke's sock, or George Washington's axe, or Jeannot's knife etc.

objects are no longer their original iterations. They have *all* been fundamentally obfuscated in terms of definition, and this obfuscation happened pretty early on in the universe.

In short, we cannot assign the simplistic picture where everything has a beginning and an end, and therefore a causal inference frame intertwined with it, to a universe that we are observing from the inside. As long as the universe is older than any observations of it, we cannot complete a precise causally deterministic description of it, because we cannot describe things which we haven't been observing since the beginning of time. We can only observe things in real time starting from the moment we start to know what to look for, and this ends up being a very real and important limit to how precise knowledge can be assigned to given scenarios, especially in quantum mechanics and cosmology. Oftentimes, the best we can do is assign probabilities based on inference calculations, noting that I can't say which electrons started out in which molecules.

Cracking a Marble

Let's take, for another example, the act of cracking a marble. To clarify, it's not that we want to describe general features of marble cracks, but instead to predict *precisely*, whether a given marble—not a generalized marble, but this marble sitting here in front of me—will crack when I do this or this specific action. This is what the precise engineered view of causal determinism requires. Can it be done? Can I decide that this marble will crack with 100% determinism?

Let's try it. One of the first things that comes to mind is that it depends largely on what the marble is made of. Maybe if we had a perfect mapping of where the atoms lie inside of it, with 100% accuracy, that would help us determine where the weakest point in the marble is. Conversely, there's a non-trivial and relatively complicated way that some set of applied forces would possibly converge into some geometric pattern, inside the marble, and this might be important in guessing where the marble will crack. So on one side, we can try to think of the point, or set of points where there is a preexisting crack or maybe some place where marble atoms didn't quite fill in a symmetrical way when the marble was made, and on the other side we have a set of laws describing how forces will propagate through the medium. If we had a perfect description of either of these things it would be useful, but in practice neither of the two are possible in all but a few special cases. The practical solution is to find some intersection of both approaches, which limit the probability that each will produce the correct result. These limited results can bring the resulting prediction to very high precision—if I know that both there is a weak point in the marble resulting from a defect while making it *and* I know that applying forces will focus them directly onto that spot, I can be pretty sure the marble will crack! This is the equivalent of folding a piece of paper and licking it before you go to tear it, ensure that a weak spot is preexisting, then apply the force along that preexisting weak spot in order to ensure a clean tear.

Note, however, that we failed to define a fundamentally causal description. The same approach won't necessarily work for some *other* marble, and it won't work for some other set of applied forces either, and we can always envision tuning our forces a little closer to the weak spot with more precision. No matter how confident we are, we're still not 100% sure it is going to work. The best we can do, and this image is going to come back to us later, is wait until *after* the thing cracked and then determine that it was our forces that did it.

Part of this is because the two simplistic images I provided above are not quite right. The idea that we could generate a map of the positions of all the atoms in order to start our prediction has some subtleties to consider. Say we were able to zoom in as far as possible on the marble with the best microscope available, to get to higher and higher resolution images of where the defects are. First, the atoms will not be sitting in one place, they'll be moving in complicated ways. Secondly, it's not a straightforward procedure to assign positions to the atoms themselves, and deciding how well each marble atom is holding on to its neighbor marble atom will require that we know the precise position (or wave function anyway) of the electrons, which is far from simple, and beyond the reach of the most powerful supercomputers in existence for anything more than a few dozen atoms at a time. There are simplifications we could make that would allow us to approximate the issue for a generalized set of marble-like atoms, but again doing it for *our specific* marble is largely impossible using existing technologies.

And that's just for determining the state of the marble before we've even tried to apply any forces to it! When we consider that it hasn't started cracking yet, the issue becomes even *more* complicated the moment we start applying forces and predicting how those forces will interact with the marble, and how some part of the marble will need to lose its cohesiveness and break up. In other words, during the cracking event, we're going to need some way to define what constitutes marble-like atoms in some way, and what is no longer considered marble-like (i.e., looks more crack-like) and identify those features, and how they interconvert, in real time.

Are you seeing the immense technical difficulties at play here? What's more, there really doesn't exist a good way to draw the line as to where there are atoms acting alone and where there is classical marble, and this is true whether you're a chemist, a particle physicist, or a mathematician, even if these three might disagree on what to call the lack of boundary.⁶ So maybe what we're looking for, instead of a clean boundary, is a sort of gradual decrease in marble-ness and a gradual increase in not-marble-ness as we get closer and closer to being able to accurately describe the place that we expect the crack to first form.

⁶In case you think I'm exaggerating here, just be informed that there are very well respected physical chemists happily carrying the torch for arguing that the classical description of electric fields and their effects on atomic movements should hold all the way down to the nano-scales, especially in certain biological systems, and it is a matter of ongoing debate whether mathematics is capable of treating phenomena like this which reach across several space scales in small amounts of time.

But how would we do that? Is it possible to do without knowing that a crack is forming somewhere in the first place? Remember, we wanted to determine *exactly* not just where and when, but also *if* the crack would form. In other words, there are very good reasons that people studying macroscopic phenomenon such as cracks have a very difficult time theorizing about what those cracks should look like in terms of an axiomatic description involving atoms alone. All of them will concede that in order to tackle this problem, they take the initiation of the crack *at some point at some place* in the marble as a given, which is different from stating that *it definitely will crack*. A complicated process cannot be described entirely deterministically unless massively complicated initial conditions are supplied, like the fact that the crack already started somewhere in the marble, or we know all the positions of the atoms instantaneously.

It is true, however, that using a simplified model, i.e., one which assumes a clean causal event with a well defined cause of separation, can often be the most *useful* way to approach a problem, even if the model itself is akin to straight lines or perfect spheres. They are definitely useful as idealized shapes at large distances, but when we zoom in close enough we'll be hard pressed to find those individual attributes in any realistic system.

And that is the key. Engineer's can and do tackle these sorts of problems with great accuracy all the time, but they do so in probability space from very far away. They concede that they can't tell you exactly when or where the crack will start but that if you apply some amount of force for some amount of time, you'll see a broken marble, and that's pretty much all we need for everyday applications. The important point to take away is that by jumping in and out of probability space we can use idealized versions of our problems to make educated guesses at where and when things will happen. However, even if we can get those guesses up to very high accuracy, *we still don't have an exact precise understanding of what is happening*, even for something as common as cracking a marble. It's a lot like our thought experiment from the beginning of Chap. 1, where we noticed that there would be pieces missing from our view of the galaxy, even if we can make educated guesses as to what the whole thing should look like. Except now hopefully you see how the same issue applies to things which are very small, as well as very large.

2.2 Probability All the Way Down

Yet again you might reasonably ask what's the harm? What's point to all that marble-cracking stuff? Recall our nice and neat hierarchical pyramid from Chap. 1? The one where chemistry *reduces* to physics? What if, completely independent from the laws of chemistry and physics, some biological organism organized the atoms within in our marble in a way that allowed for it to crack in a specifically designed way? Where does that situation fall out of chemistry or physics? Sure the laws still apply, and there are certainly physical and chemical laws that can be used to describe the situation, but do the theories predict, based on fundamental axiom alone, that such a thing will exist in a specific place?

Basically, the issue we're running into here—namely that the mathematics have to be continually supplemented by initial conditions that are best treated in probability space, is one that has no bottom; it must be continually revisited no matter how far down (or up) the rabbit hole we decide to ascend. In practice, we can overcome these things because there's some degree of forgiveness in accuracy between each level. For example, in order to calculate the strength of an atomic bond, first we assume that for *an ideal version* of our two bonded atoms, there are a bunch of possible electronic configurations allowed to fit in between. There are an infinite number places the electron can be, even if the orbitals act as a sort of guide for the probability of the position of the electron at any given time, and the deterministic calculation becomes prohibitively expensive to carry out. You can simplify all that complication, however, by allowing the electron to move around with some predetermined probability (i.e. supply it with initial conditions), and then assign an *average* position to the electron which is what we'll use to calculate the strength of our bond. Note how it only works if we're interested in things which operate at long time intervals—like viewing it on temporal horizon as opposed to watching the electron jiggle from moment to moment.

So this is both the difficulty and the nice thing about how our universe works. Initial conditions are not guaranteed to be correct for your specific system unless you are directly observing the thing in question, always opening the possibility that you're a little wrong in your calculation. On the other hand, however, the chances of that happening are small if you know how to pick those initial conditions well—which allows us to move smoothly from level to level of inquiry. Note, however, that this requires that we be able to make independent measurements *at each scale*, which enables us to move between them, and there's no reason couched in the theory that any given observation may not have to be supplemented with more direct observation if you want more precision.

For example, what happens if we decide we don't need this process, that we're going to define something entirely in terms of things smaller or bigger than that thing? What results is a sort of categorical explosion of needed knowledge about each level of description, especially if you want to describe something even remotely complicated such as cracking our marble from earlier. If, instead, we assign reasonable initial conditions based on separate probability measurements, we can actually say something about the nature of those things at different scales, and note that this is akin to moving from the neat linear hierarchy of rules to a messier, albeit more accurate sets of rules that act independently at each scale and sometimes have intersections, as opposed to being contained within one another.

To be a bit more prickly however, it is interesting to note that all these things are common practice, often subconsciously, for our collective ontology. For instance, what kind of images are suggested by the values of commonly applied initial conditions? Even if we are tempted to use them as real physical objects, they don't represent actual physical objects—you would never be able to find an electronic configuration that corresponds directly to the average value we use for bond strength calculations, even if it is mathematically accurate! Much like using the existence of the rainbow to calculate the position of distant rain, we can say something about our surroundings without knowing precise position of the rainbow itself!

Let's put it another way. Isn't it true that many of the initial conditions we use in mathematical calculations end up being interchangeable with what we think things *are* in the popular conscience? A common example includes the perfectly useful view that everything is made up of atoms, each of which behaves quasi-independent of its existence in part of a larger macroscopic object. This is not the only useful mathematical view of how things are composed however, even if it may be the easiest for us to grasp today. Basically, we like to think of what things are made of because it allows us to easily imagine how to fix something were it to break—which usually requires taking the thing apart and then changing something and putting it back together again. This is an entirely modern view of how things work and it's really a baby in terms of its age. There are lots of perfectly legitimate ways of thinking about things which do not do this.

This is akin, returning to our example of the university from the previous section, to investigating the instantaneous amount of money a university has had over the course of its lifetime, averaging that amount, accounting for inflation, noting that that average amount is higher than the average amount that other universities have, and *then* referring to it as well off. Before we were pointing out that it isn't precisely true—now we're pointing out that even though it's not, it can be very useful and so we often do it subconsciously. This is okay as long as we don't go a step further and assume that it being generally true means you can assume an exact dollar amount and attach it to the school. You can use the precise description to assign an average, but you cannot recover the precise instantaneous measurement from the average.

Even if, however, we realize that some large portion of our ruptured hierarchy is necessarily missing big patches of information that we supplement subconsciously with idealized educated guesses, this shouldn't mean that there's anything fundamentally amiss with our tidy theory of a deterministic universe, right? We just need to make bigger and better and more precise observations and run up a very long laundry list of various initial conditions, and *then* our universe will be fundamentally deterministic right?

2.3 Tangling Our Hierarchies

In essence, this argument corresponds to a reductionist framework, which is often implied as the unilateral end-all theory of how stuff works. Basically it goes like this, if the measurements I'm using are not precise enough to describe the phenomena that I'm interested in (i.e., there are multiple solutions to the problem) what I need to do is drop down one level of inquiry and break up the current system into smaller units of observation. This is very much akin to realizing that knowing that a corporation is *well off* gives me very little in terms of whether I think they are going to buy some other company. I need to break up my average (whatever *well off* corresponds to) and go back and measure how much money precisely they have now and have had in the past in order to make my estimate about whether they're going to buy. Hence, we are *reducing* the measurement into smaller bits.

Here's what we need to keep in mind. Some things reduce in terms of composition—i.e. the instantaneous object breaks down into smaller and smaller bits, whereas some *also* reduce in time. In this framework we can say that things which reduce in composition but not in time are said to be, for lack of a better word, local, whereas things which reduce in both time *and* space we'll call field-like.⁷ Things which are field-like are emergent in the way that the property only emerges if you watch things evolve in time as well as space.

For example, consider the tornado.

In one sense, you might think this is the poster child for reductive approaches. The tornado is clearly only made up of dirt, air, and water. What more is there to know about it? Imagine, however, that for whatever reason I have never actually seen a tornado, but I've heard about these crazy things and I am in awe of how much power they seem to have over those who have seen them. So I decide I'm going to dissect the next one that comes along, and come to understand it deeply, so that I can extract the essence of *tornado-ness*, and distill out these fundamental tornado-ness units, which I will then manipulate for my own use. I wait patiently until one shows up at my door, I get all my measurement tools, then I go out and start pulling the thing apart. At first I'm excited, there's so much stuff to measure! I discover dirt, water, air. . . .more dirt, more water, more air. . . . wait a minute, there has to be more to it than this. There's dirt and water and air all over the place when a tornado *isn't* here, this gives me no advantage, no good definition of *tornado-ness* that I can use to distill down into bit's of more concentrated tornado.

What's the deal? It's actually pretty simple—the essence of a tornado is not what it is made of, not in its fundamental constituents, not what it reduces to directly in space—but the actual value of the measurements, relative to each other, at different times. Its essence is found in reciprocal, hierarchical terms like *velocity*, *acceleration*, and *curl*. This is an example of when precise spatially reductionist definitions don't really work; taking an average, even a moving average of the air water and dirt positions will hardly give us back the *umph* of tornado-ness. The essence of the tornado is emergent, across time *and* space.

So, now, here's where things get weird, but hopefully it comes as a reward for making it all the way through this chapter. There are good ways to describe things like tornados or waves precisely in a mathematical context. Without going into details because the math is pretty intimidating, let's just say that in order to treat these precisely, we calculate what we call a wave, or something akin to a tornado,

⁷Just a note, however, even if this is how I'm using the term local in this book, the term non-local is reserved for some subtle things in physics and we have to be careful about when and where we use it. Generally, it's reserved for events which are proven to be neither correlated nor anti-correlated with events that should have caused those things, which has led to the popular notion that non-local things are "faster-than-light". I have some issues with this interpretation, mostly because the majority of us don't have a deep enough notion of light to evaluate a claim like that. For this reason I'm going to mostly stay away from the local vs non-local terminology in this text, but the way I'm defining field-like properties has to do with assigning labels to things which happen across time and space as opposed to just space.

but in probability space. It only works if you can measure all the air and dirt and water within the tornado simultaneously, and you measure all of it with reference to all of the rest of it across several time windows. We don't look at the total average, we drop down to a level somewhere in between where we're taking an average of a window small enough that it's still giving us useful information, then calculate the dynamics of those averages as if the averages themselves were a deterministic set of objects! We say, well look, if the average here is moving and it interacts with this other moving average, we can calculate how those velocities interact with each other, and the end result is a very complicated equation that describes how waves move around, without ever being able to say anything precise about the positions of individual pieces of air, dirt, or water! In my field we use this trick to derive fancy equations that basically tell you how to watch waves propagate through big groups of atoms, in order to pull out all sorts of neat measurements about that particular group of atoms.

Notice what happened though—we took our probability framework, and plugged it back into our deterministic framework and got something useful back out! But we said that's not allowed! We can't go backwards like that! In reality, however, we aren't going backwards at all, we're going out a step further in terms of abandoning exactly causal deterministic descriptions of each atom, but we've built a descriptor that is causal and precise and deterministic *in probability space*—i.e., we're no longer describing anything causal at all, except in the sense that probabilities can interact causally with each other! It's a neat trick right?

But all of this isn't really surprising per se, because we know that things like waves and tornados exist, even if it's hard to pin down a precise location to them, in the same way it was hard to pin down a precise decision for when to take off to visit a galaxy, or deciding that two hydrogen atoms will successfully convert into a helium atom while observing them from super far distances. These things are field-like, but mostly because the template we use to identify them is imprecise.

So what about something like a fundamental particle?

This is where things start to get *really* weird. If you apply the same methodology to atoms—namely not how they move in large systems, but instead look at predicting precisely when and where we will observe one, the *atom is the tornado*. Mathematically, or in other words in engineering kinds of approaches, if I put together a bunch of fuzzy imprecise definitions for when and where the atom will be, I can describe it very well based on the approach mentioned above, watching probability waves knock about and interact with themselves.

But aren't electrons both waves *and* particles? Yes. But I find that it's generally not explained correctly. It works like this. If you measure a particle, it was a particle. If you even detect it at all, then it was a particle in the normal sense of how particles work, like a tiny grain of sand that hit a screen and left a dent. A particle like that.

If you try to guess where the particle *is*, however, you will measure waves. In other words, if you measure the particle over and over and start adding up the probability of finding it in a certain place, you will uncover a wave! The particle itself is never both, it's just that we cannot predict things about it at any given time or space interval until *after* you successfully measured it.

Is this starting to sound like the discussion of our marble crack? How we couldn't really set up the math in a way that could predict the exact position of the marble, but we could definitely trace it out after the fact? Additionally, just because if we repeated the marble cracking experiments and eventually found that we could uncover something neat about the intrinsic properties of the marble, something that might even tell us about the narrative history of making that marble, we'll never be able to predict the exact location of a future crack beyond probability, and if you add up all the competing probabilities and map them out in the marble, you're bound to get something that looks like a wave!

What does this mean? First of all, it means that the existence of an electron, or a proton, or whatever, is not *only* determined in terms of things smaller than it, in the way we're used to thinking about things. It is *also* determined by things larger than it!

This is kind of like having your favorite camera and asking two very distinct questions about it. One question, the classical reductionist question, would be to ask if it can take a certain picture *now*. The answer is related to which parts are inside the camera currently and whether they can handle the situation you are asking about. The solution can be achieved by reducing the camera into its fundamental constituents which are then combined in an engineering kind of description to decide—yes, the parts will function normally in these conditions, or no, they won't. Moving to a field-like description would be like asking if the camera *could ever* take that picture. The solution doesn't reduce only in space, namely the fundamental parts it contains currently, but also to a funny sort of time-dependence, where you could ask, "is it possible to track down the necessary parts, and if so, could I integrate them into this camera without the camera turning into a fundamentally different camera?" Notice how I can't say anything about when precisely it will take place, only that it could, and the probability of it happening goes up the closer the necessary parts are to the camera. Or, conversely, what if I said that the picture had *already* been taken, and now I'm asking if it could have been taken with *this* camera? We get the same result! The answer is a field-like response, i.e., it is smeared out in a quantum kind of way depending on lots of intersecting causal pathways that are necessarily obfuscated.

When we measure wave-particle duality, this is what we're measuring. There was a particle, could it have been here? Or here? Or maybe over here? The answer is yes for multiple positions, and no for multiple positions, and if you add up where all those positions are or aren't they fill the space in exactly the same way that waves propagate through mediums. But you can only say that *after* you've found a particle a bunch of times, and this tells you nothing exact or deterministic about where it's going to be the next time you find it. It's not a wave of particles, it's a wave of probability, and the probability tells you about where the particle *could have been measured, were the attempt made*.

In order to drive this all the way home and spell out the consequences, however, we are going to need to tackle a bunch of other concepts first. We're going to want to come back to it however, so let's give it a name and call it the *head swivel*. Instead of continuing to lean on a nice reductionist framework, where we usually drop down to

a smaller set of fundamental subunits in order to get more precision, we now realize we have to adopt a slightly different view of how reality is set up. We instead try to understand the behavior of atoms by treating them as indistinguishable from the forces that sink down into them, combining mysteriously and doing an unexpected dance, where the shapes of that dance correspond to how electrons and protons move around and interact with each other.

In other words, if you really want to understand quantum mechanics, you're going to have to change the way you think about how causality operates at small, fast scales. Instead of looking for the causal nature of atoms by breaking them down into their constituents, you're *also* going to have to look over your shoulder, finding the source of certain unknowns up behind you somewhere. Only by doing that will you be able to pin down the place where the event was actually caused, and even then it's not going to feel like the same kind of calculation you are used to. Imagine you have an object in your hands, and when you pull or push on it, part of the ceiling up above your head *also* moves. And it continues to do so every time you push or pull, even if the relationship between the kind of move happening in the ceiling and the kind of move you impart on the object is not at all obvious.⁸

Again, we'll come back to all this. As we continue down the path, however, note that by the end of the discussion we'll have developed ways to talk about atoms as both capable of clumping together into classical stuff, and also be classical stuff that breaks down into atoms, and we'll be looking for ways to talk about that process as it accounts for *all* the properties we see in atoms. Only when we can carefully articulate clear descriptors at these scales and how they are related can we talk confidently about what atoms *are* in a meaningful way, and we have to remember that what we're describing will be field-like, in the same way that the tornado is field-like.

⁸And later you realize that even though you aren't *causing* the correlation to happen, it will always happen anyway because it turns out that no matter how clever you are, you will not be able to devise a way of pulling or pushing on the object that *doesn't* correlate with the ceiling also moving. That is what the universe requires in order to push or pull this particular object, but the reasons are only apparent in the end limits of observations, like a horizon or a rainbow.



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