These posts are unedited.

Characteristics of Science, Part 1.

This is something I've been thinking about doing for a while, but after a post from Science Based Medicine that I shared yesterday, I decided that it's probably something I should get around to already.

It often comes up that in arguing about pseudoscientific or anti-scientific claims that people don't really know what science is or how or why it works. The SBM post from yesterday was about exactly this question with respect to "alternative" medicine and science-based medicine. But it's the same question that comes up when one argues about the Big Bang, Evolution, Climate Change, and other topics that are controversial in the eyes of the public but not in scientific circles. What is science? What makes something scientific and what makes it pseudoscientific? How is science done? Philosophers of science have been trying to answer these questions since before science even existed, since Aristotle really. Some notions have been born out as having merit, and some have been rejected; some remain current in philosophy of science, and some have been distorted so badly that they are hardly recognizable any more. Thus, talking about what makes science science is not easy. My idea, though, is to take one such notion at a time and discuss it at some length. When you put it together, I hope there will be a nice picture of what science is and what it isn't. But be aware that science is not any one of these. Feel free to debate and discuss in the comments, but I may just respond by saying, yeah, I'm coming to that in a couple days.

The first things I want to start with is the idea that science is non-ideological, or if you prefer, non-dogmatic.

This is often a problematic concept for people not familiar with science and it's often claimed that science *is* dogmatic. This charge comes most often from those who challenge the legitimacy of science, but it stems from a lack of understanding of the scientific method and the history or science, not to mention the mountain of evidence available to support certain scientific claims.

By non-ideological I mean on the one hand nonpolitical in the sense that science is not by nature Democratic or Republican, Progressive or Conservative. But I also mean this in the broader sense. Science does not begin with a preconceived notion of the world and then attempt to fit facts to that view and reject those that don't square with that belief. Rather it begins by asking questions, and rejects positions, no matter how deeply held, if they cannot be made to square with all the facts. Individual scientists are not perfect in this regard, of course, but over time, and with mutually contrasting biases pitted against each other, science is designed to come to a conclusion that best fits all the available facts. This is why the scientific consensus is so important. Science is prepared to reject even well-established theories, as was done with the very well-established Newtonian physics, in light of new data and a better theory.

Ideological biases are sometimes the best way to spot a pseudoscientific theory. Psychoanalysis is a famous example. Many psychoanalysts in practice were guilty of pseudoscience because facts that appeared to contradict Freud's theory were explained away, so much so that no evidence could be presented to alter the view of committed psychoanalysts.

We see ideological biases in creation and intelligent design. Bringing a preconception with them that god must play a role in creation, they view all data in view of this preconception. Creationists reject carbon dating in addition to evolution in order to support the idea of a young earth. Intelligent design supporters often confuse evolution with abiogenesis because we know so much less about the latter that it's easier to challenge; or they will speak of microevolution vs. macroevoltion, a distinction not made by evolutionary theorists.

Climate change deniers will say it's impossible for humans to affect the climate this way. They will make the argument that it's "arrogant" to assume that we can, as if arrogance has any bearing on climate data. Sometimes these views are rooted in a poor understanding of mathematics, and sometimes in a biblical worldview (e.g. after Noah's flood, god said he'd never destroy the Earth that way again), or in libertarian market-based accounts that simply don't like that proposed solutions to dealing with the problem might go against their laissez-faire ideologies. These preconceptions motivate people to reject certain claims of climatologists or focus on a single line of argument rather than looking at the big picture and following the facts.

The anti-vaccine movement is similarly ideologically committed. Despite countless studies showing that vaccines are largely harmless, and certainly less harmless than actually getting the disease; despite Wakefield's paper claiming a link between autism and vaccines has been retracted and the author accused of fraud, the movement continues to claim that there is still something to be afraid of, and no amount of data will to the contrary will overcome their view. Once one cause of concern has been rejected, they seek another in order to keep making their same claims: first it was mercury, then it was giving the vaccines too early.

Supporters of "alternative" medicine approach data in a similar way. They cite studies that support their view, no matter how poor the methodology, and reject results that disagree with their view even when they have better methodology and replication. Their new tactic is to claim that the placebo effect is "real" so that they can claim these approaches are effective, and thereby deliberately misconstrue what the placebo effect is: a way to account statistically for uncontrolled variables, and those people that will get better without intervention. They often talk about how "ancient" these methods are as if old things are necessarily proven. For comparison, pick any other medical topic, say surgery, and ask yourself if you'd rather use old surgical techniques from 3000 years ago.

Compare these with the story of the Big Bang. Some people supported it when Hubble first proposed it because it accorded well with their religious views of creation, but most scientists actually looked on it quite skeptically for precisely that reason. The theory was ultimately accepted despite that initial sense of discomfort because that's where the data pointed, and as the data accumulated for the theory increased, the religious accordance was set aside as not being relevant to the facts.

Well-established scientific theories, for those not aware of the data supporting them, can sometimes come across as though scientists are being dogmatic. As I mentioned before, this is often claimed against evolution and climate change. But these claims lose sight of the history of these fields, not to mention the initial scientific skepticism they have faced and overcome. If science insists on these things, it is for these reasons, not because they are dogmatically committed to evolution or climate change. If the collection of facts available to us were to change significantly, then our view of theory would change. Ideologies cannot imagine any data that will overcome their claims, and even when they do say it exists, they will move the goalposts instead of changing their minds.

A good recent example is the report of the alleged faster-than-light neutrinos. Scientists are naturally skeptical, because it appears to be a single anomaly against a mountain of support for the idea that this is just impossible. However, science is still taking the result seriously enough to attempt to replicate the outcome, and if it can be replicated it could be a window onto a whole new understanding of physics that may involve rejecting even well-established theories like relativity, at least in their present form. It's just that it's gonna take more than a single experiment to bring down a theory with otherwise airtight empirical support gathered over a century of careful science. It's not likely, but it could still happen. That is the essence of the non-ideological stance of science.

More tomorrow.

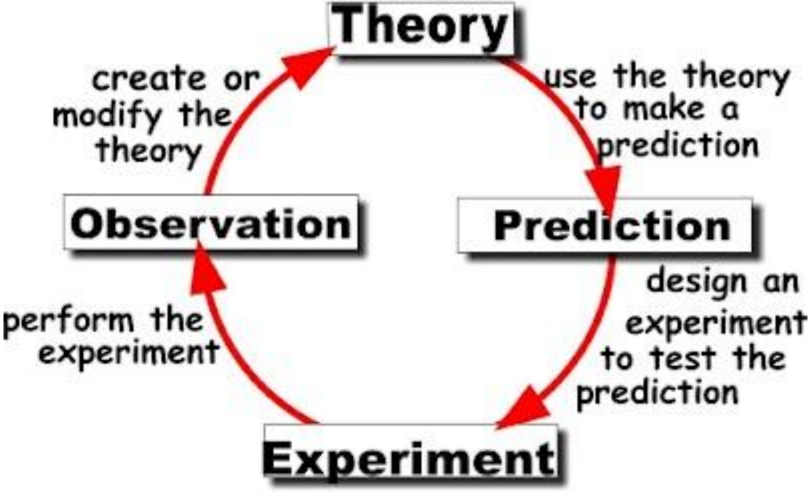
Characteristics of Science, Part 2.

In philosophy, one can pretty much divide nearly all major philosophers into two camps: the empiricists and the rationalists. This is an over-simplification to be sure, but this division goes back to Plato and the rebuttals to his philosophy by his most famous student Aristotle.

Plato was a rationalist. Critics like me tend to this about his approach as armchair philosophy. Descartes did this more literally. One sits and thinks about the world and tries to devise a scheme to explain it based on logic. The only way to challenge such positions, at least to the rationalist himself, is to find a flaw in their logic. They generally take their premises to be unquestionable.

Empiricists, on the other hand, as Aristotle did, make observations about the world and use data to come to conclusions about it. Sometimes empiricism leads to extreme skepticism of the Humean sort, where even causation is questioned, and only information about the past is possible since we can't know information about what hasn't happened yet.

The scientific method tries to take the best of both worlds by combining rational theorizing and logically consistent worldviews, and combining them with empirical support. Science thus has the advantages of both approaches. Logically consistent worldviews can still be challenged on the basis of both premises and predictions by means of gathering data that bears out or refutes the theoretical construct. Empirical data can but gathered and put into a larger framework of understanding that helps us make sense of that data and put it to use. The scientific method thus creates a kind of feedback loop. Neither rationalists or empirical approaches taken by themselves have been deemed to be that reliable (look at the dustbin of the history of philosophy to see this), but taken together, they compensate for the weaknesses of the other. It's because of this that science is not just facts, but also the theories that explain the facts. You can't have one without the other or we'd all still be arguing about monads (Leibniz) or the world of forms (Plato). Instead we have the weird world of quantum mechanics, which no one should believe in except for that we have a century of data to back it up.



Characteristics of Science, Part 3.

The next thing I want to talk about is replication. While replication is not a key feature of all sciences, it is an important one in any experimental science. The division between what is an experimental science and what is an observational science I will put off for another day, but the line is not always a clean one, so for our purposes what I mean here is any experiment done on behalf of science needs to be replicated.

What is the point of replication? Primarily, it is because we are dealing with probabilities in science, and we need a way to ascertain whether the results of our experiment are a fluke, i.e. a low probability event, or if it is a high probability event, indicating that the experiment is indicative of some larger effect that we wish to study. If we cannot replicate the results, we have no way of knowing what the causal factors might be, nor can we get a better understanding of the results by changing the conditions slightly.

We've seen the need for replication in the news recently with the announcement of the FTL neutrino data. If the result is true, it's an astonishing result, but skeptics are right to suspect that there may be an error as the probability of the result, given what we know, is quite low. To increase the probability that this is real, the original researchers checked their data and reproduced the results.

However, replication is part of the process of weeding out errors as well. Some of these potential errors cannot be weeded out by the original team. If something is wrong with their timing equipment, or some other part of their apparatus - something peculiar to them - then they may not be able to eliminate the error on their own. If the data can be replicated by another team, using different equipment, then either both teams and apparatuses are wrong in exactly the same way or the result is real. When this can be done numerous times, the probabilities will eventually swing in the direction of even highly unlikely events such as this one. While it's not as glorious as the original discovery, confirming these discoveries is an essential part of science, and one of the features that makes it so effective.

I've used an example from physics, here, but the same can be said of medicine. However, since it's much more difficult to control for all the variables, medical studies will report results with much lower probabilities, and much greater likelihood that they are in error. This is one of the reasons that years after drugs are released to the market we sometimes find that they are not as effective as was originally believed. (This is in addition to other problems with not reporting negative data, and so forth.) The principle remains the same, though. Getting a new drug or other treatment to market typically requires many levels of replication, first in the lab, then in animal studies, then in human trials, before being introduced to the general public. Sometimes the large data sets needed to gauge precisely the effectiveness of a treatment are not available until many years after the product has been available to the public.

Characteristics of Science, Part 4.

Falsification is an important concept in science first championed by Karl Popper, who wanted to "rescue" science from challenges to inductive knowledge and set science more firmly in the deductive camp. (I'll talk more about induction vs. deduction in a later post.) However, it's not to say that falsifying theories was never important before then, but it did take on added significance afterwards. Falsification is considered deductive, like mathematics, because you can *prove* in the strong sense that a theory is false, in a way that you can't prove that an inductive theory is *true*, since there may be an exception you just haven't found yet.

The idea behind falsification is this: science wants its theories to be as strong as possible, not only to explain existing data, but also to make predictions about data not yet collected. The argument goes that a theory can never be truly "verified" because it's possible to construct an alternative theory that will make the same predictions, but a theory *can* be falsified by making a prediction that turns out to be false. (More will be said about prediction in general at another time.)

Falsification is closely related to the idea of a theory being testable. For a theory to be considered "scientific" it must make some prediction that can be tested through the collection of additional data, or an analysis of existing data in a way that hasn't been done before. Theories that cannot be tested, or falsified, cannot be considered scientific. Theories can be perfectly internally consistent, but if there is no way to prove they are incorrect, they must be relegated to the realm of philosophy. Examples are the Platonic theory of forms, or Leibniz's monads: both claim that our senses are so untrustworthy that we must utterly disregard them and use only logic. No empirical evidence is capable of refuting these claims because all such evidence can be explained away as "deception".

New scientific theories, especially in physics, sometimes run into the problem of falsification. String theory is internally consistent and can explain existing phenomena, but such theories had difficulty making claiming that could be tested and either verified or that would be capable of discarding the theory on the grounds that it made a false prediction. for instance, how can we determine if there are 10 dimensions or 21? This isn't necessarily a fatal flaw, as technology may one day advance to the point where such claims can be tested, but until that is the case, they will tend to hover on the edges of science, and it will face competing theories with the same problems until we have reason to choose between them.

Proving a theory false is such a central component of the scientific enterprise that Nobel Prizes are won for proving long-held theories to be false, just as they are won for devising theories that later win solid empirical support (these can be related, but need not be). That motivation is one of the features that keeps science honest: there are often as many (or more) people trying to disprove a theory as verify it, and the rewards are greater for disproof than for verification. It's the kind of thing that makes "scientific conspiracies" such a comical notion. If a scientist could prove that climate change or evolution was wrong, they'd get not only a Nobel Prize for it, they'd also get a lot more grant money (if indeed money motivates a scientist).

Characteristics of Science, Part 5.

One of the distinctive characteristics of science is that well-developed sciences are expressed in that language of mathematics. Indeed, this feature was one of the first to set sciences off from natural philosophy.

The first efforts at mathematization were in Ptolemaic astronomy. Ptolemy produced a geometrical model of the solar system capable of reproducing and predicting the motions of the planets. There is some debate in the history of science literature as to just how seriously geocentric astronomers took this model as a reflection of how the universe actually *was* or whether it was merely instrumentalist (i.e. a useful predictor only), but probably this differed by time and place. Certainly as the model's flaws became more clear, it would have been seen as more-or-less merely instrumental. As a predictor of the qualitative behaviour we see in the sky, the Ptolemaic model was highly successful, and was only replaced with a new mathematical model when the quantitative flaws became too large to ignore.

The trend toward creating mathematical models of science was taken up in earnest by physics. With the development of calculus, mathematical models spread rapidly based on the ideas of Newton to create idealized, simple models to capture large-scale behaviours. Later on, models are revised to take into account more features, in less idealized situations. Usually this means the mathematics becomes more complicated over time.

In the last century, mathematical models have spread beyond physics and astronomy. Biological models of populations of predators and prey, and speciation events have been modeled with mathematics, not to mention the complex behaviours of neuronal firing and ion exchange through cell membranes. Social sciences rely heavily on statistics, but we are also seeing mathematical models developing to study language change, and to predict the spread of fashion trends. And of course, there is economics, the most quantitative of the social sciences.

The spread of mathematical models in the social sciences tends to be complicated by two things: 1) mathematical models need something numerical to measure, 2) models are easiest to develop if the system is simple. Social sciences are often dealing with things like fashion or social norms which are difficult to represent numerically. Human systems are also incredibly complex, much more complex than dealing with mere nuclear fusion it turns out. However, as our understanding of the qualitative nature of these systems improves, the data is finally beginning to yield features that can be successfully modeled, and such models will make it easier to find the next layer of analysis. Sophisticated computer technology and massive computing power also make it much easier to work with models of very complex systems.

So, as much as I love natural science, don't dis the social scientists, guys. They have a much harder job than you do if they want to put their fields on the same level of mathematical rigour.

Mathematization is important for science because it allows science to organize a lot of data into a concise statement about the way the world *is*, and it allows science to make predictions about what will happen in the future. This is important for making predictions that can be tested against the real world, a crucial step in the testing of theories under the scientific method. If one's predictions are not very good, it may not be possible to know if the theory is working or not.

Climate change is one of those fields that depends heavily on highly complex mathematical models, and sometimes the field is attacked specifically on these grounds. Because climate models are nonlinear dynamical systems subject to chaotic behaviour (chaotic in the mathematical sense, not the colloquial sense), climate models cannot be created now or ever that can precisely model the exact climate data of the last century-and-a-half. But climate models can model the climate very successfully over much longer stretches of time qualitatively accurately. Similarly, we cannot use such climate models to predict the weather on February 16th, 2112, but they can still make accurate qualitative predictions if the right physics goes into them. The weakness, if any exists, is that we can never have perfect information (only good or better information), and in the mathematics itself. Much of what we know about mathematics was developed specifically to solve problems in modeling physics or astronomy, but systems as complicated as climate must be handled numerically because closed-form solutions to models as complicated as those used for climate do not exist. "Skeptics" often over-blow these limitations to try to pretend that science is just guessing, and yet they are perfectly content with every other system on the planet that runs on basically nothing but the self-same mathematics.

Science without math is just armchair philosophy.

Characteristics of Science, Part 6.

One of the most useful things about science is the way that it improves thinking. And I'm not just talking here about logical skills or even problem solving, but in the way that we think about the work *semantically*. I tend to think of this process as "precisification" which is a term I borrow from the philosophy of logic. There the term is used to decrease vagueness in an interpretation of a word like red so that there are fewer cases that are questionable. We also know what red means, but we may make different judgments of how red a particular colour patch is at different times, in different contexts, whether we put it in the red category, or, let's say, the orange one. These may be predictable or semi-random, but the fact that they aren't "clearly red" is all that matters. We can increase the precision of our definition to eliminate questionable cases, say by defining red to be a range of wavelengths in angstroms. We as people may not be able to get all these cases correct, but our instruments can be used to eliminate the variability even when we cannot.

One key feature of science is the tendency to put things into categories. This is only natural, for language of any kind cannot exist in a meaningful way unless we do this consistently. Just as with our attempts to mathematize science, our categories (like our mathematical models) tend to begin in a very simplified fashion, and they encode whatever our preconceptions are about the things in those categories. However, science, in order to make meaningful statements, tries to make those definitions of the categories precise in the way described above. Not necessarily in a numerical way, though of course this is a common approach, but also just by trying to carefully define the category in a way that leaves few or no instances uncategorized. By doing so, science can begin to ask questions about the categories they've proposed, and the definitions of them. When those answers prove to be incompatible with what we thought we knew, the definitions, and sometimes the categories, can be changed to better reflect what we know. And what can sometimes happen is that the boundaries of the categories we tried to make so precise collapse entirely because the categories don't say much about the world that is interesting or useful. The world, after all, is under no obligation to be binary.

One particular instance of this in recent history (in the last decade) has been the debate over what it means to be a planet. I don't think this story is in any way settled. The definition of planet has undergone several apparent redefinitions in its history. Once, planets included the Sun and Moon because they orbited the Earth according to the geocentric model of the solar system just like the planets. Then the Sun and the Moon were removed, and the Earth added to the list of planets as bodies that orbited the Sun (together with Uranus and Neptune when they were discovered). In the mid-19th century there was a blip in the definition when the largest asteroids were first discovered, and then decades passes while they were slowly removed from the list again as the scientific consensus changed. And then came in little Pluto. But still, for 50-60 years, the definition remained vague, and with relatively little controversy. We are in the midst of another redefinition, and if you listen carefully to the arguments on both sides there isn't a clear consensus on what it should mean to be a planet. We can certainly tell the difference between a planet and a moon. And probably between a planet and a star. But what to do with objects too small to be a star that don't orbit other stars? Or what if they are "too small" and what does that mean anyway? What if their orbits are "too elliptical"? What if they are made of "too much ice" like comets? What does it mean exactly to "clear one's orbit of debris", or to be "gravitationally dominant" in its orbit? I mean, some researchers suggest that Mars is smaller than the Earth because Jupiter prevented it from collecting more material. Does that mean that Mars doesn't dominate it's own orbit? It may be in the end that numerically precise definitions will have to be put forward: a planet is an object with a mass between a and b, and a density of c to d; an orbital eccentricity of no greater than e, and an inclination with the plain of the ecliptic of no more than f. Or else we may conclude that none of these are particularly relevant, and decide that planet is a much broader category than we presently believe and sub-categories of planets are needed to talk about them in more meaningful and predictive ways. Part of the problem here is that we lack data, and we aren't doing a good job using our imaginations to test the what-if scenarios. What if we found an object the size of Mars (or Earth) in the Kuiper Belt? Is that still a "dwarf planet"? All of this, however, is part of the process of learning about the universe.

Why is this process of precisification important? Because it changes the way we think about the world. We think in terms of terminology and vocabulary. Our brains are hardwired this way. Having well-defined terms allows us to think about the world more clearly and make better inferences. When we employ vague terms, we cannot make good inferences. Google's attempt to figure out gender from the articles we read and the searches we do is a prime example. Their definitions of what "women" search for and what "men" search for are poor (probably over-determined in this case), I'm not Googling for things a woman is "supposed to" be interested in, and so even though I've told Google what gender I am, it doesn't believe me. A better understanding of men and woman by their algorithm would avoid such unnecessary mistakes, not to mention they'd do a better job marketing products to me I might actually care about. It's as though they are using a definition that has long since been discarded by science.

When we understand the world better, our terminology naturally does a better job of reflecting reality. It is through science that our understanding improves.

Characteristics of Science, Part 7.

I've been thinking about this one for a couple days now, because it's a complicated topic, and easily confused with things I don't mean. I'd like to talk about *scientific skepticism*.

It's important to distinguish scientific skepticism from philosophical skepticism and the kind of "skepticism" engaged in science denial. Let's begin by talking about what scientific skepticism isn't.

Philosophical skepticism has a long and rich history, and scientific skepticism is deeply indebted to that history; however, philosophical skepticism is not scientific skepticism, and they are related only in broad strokes. Some important figures in Philosophical Skepticism are Sextus Empiricus, and David Hume. By some views, even certain religious philosophers like Al-Ghazali have been called Skeptics. It's typical for Philosophical Skeptics to question even the existence of causation. While skeptics have much to teach us about the uncertainty of knowledge, and questioning long-accepted traditions, scientific skeptics don't generally doubt *causation* (a topic for a future post). Going down that road had led some philosophers, like Al-Ghazali, and Malebranche, to argue that god must intervene in every action to keep the world going: a position that cannot be endorsed by scientific theory.

What is scientific skepticism then? Scientific skepticism embraces doubt and uncertainty, but neither does it hold doubt up as something that is not able to be overcome as far as practical belief goes. Skepticism is pitted against evidence and statistics. Skepticism acknowledges that evidentiary support can never reduce doubt to exactly zero, it can make it quite small, at least in experimental sciences like physics. Still, the positions adopted are accepted only tentatively, and they are open to questioning, if new data is forthcoming. This is a hallmark of scientific skepticism.

The recent news stories about the apparent faster-than-light neutrinos are a perfectly good example of scientific skepticism at work. If true, FTL neutrinos would be a stunning reversal of Einstein's theory of relativity. No scientist thinks this is completely impossible - skepticism toward established views never completely goes away - but they are also doubtful of one experiment overturning all the data that is presently available that supports the current theory. Naturally, the scientific community wants to see more, because only more data will begin to persuade their perfectly justified skepticism of the new result. The fact that most amazing experiments turn out to be wrong is only born out by the recent news that the FLT neutrinos experiment might have been caused by a loose cable. Science is right not toss out Relativity after one experimental result, even if it were a reliable one. But if the result can be repeated, if the proper skeptical questions are answered and then repeated again... now that would be exciting, because there is a much better chance that what we are seeing is no illusion. We are still waiting to see what will happen with the neutrino experiment now that the cable is fixed. But that doubt, that resistance to getting carried away with emotion... that is not a weakness of science; it is a *feature*.

Climate skepticism is not this kind of scientific skepticism at all. This kind of "skepticism" is immune to data, and that's what makes it unscientific. Climate skeptics say the data just isn't there, but no data ever will be. The anti-vax movement and creationists simply move the goal-post when their old evidence standards are proven to be inadequate for maintaining their beliefs. These kinds of skeptics have chosen a belief that they seek to support, and see only the evidence that supports that belief, and are "skeptical" of all others. Good skeptics are skeptical of even their own biases. But, of course, pseudo-scientists take this to be a weakness and not something to be desired.

Characteristics of Science, Part 8.

One of the topics I find most fascinating in the history and philosophy of science is the issue of causation. This idea that things have causes is controversial, particularly in skeptical (philosophical) circles, so let's talk a bit about what we mean first.

Aristotle spoke of 4 causes: material, formal, efficient and final causes.

Final causes are mostly rejected by science because these are purposive things, i.e. the reasons someone or something does things. It supposes a will, and for non-conscious beings this is generally rejected, although Aristotle did not. The final cause for all things in the universe was ultimately the Prime Mover. You will still hear some philosophers and theologians argue about final causes, but it's not a particularly scientific notion, especially in the natural sciences.

The other three causes of Aristotle are: Formal cause invokes Aristotle's (and Plato's) notion of forms and has to do with the arrangement of the matter in a thing. The material cause is matter of which a thing is made. The efficient cause is the reason a thing changes.

Modern science is concerned almost exclusively with the equivalent of the efficient cause. What it is that triggers or causes a change in something. There is a temporal as well as material notion here. Even with causes thought of in this more narrow sense, controversy has erupted in skeptical circles as to whether we can know what causes are at all. Indeed, David Hume was just one man in a long line of skeptical philosophers that argued that if something was not logically impossible, we could only use statistics to guess at "causation". (In some sense, he was arguing that our mental conception of "cause" was a very elaborate *post hoc ergo propter hoc* fallacy.) Only logical necessity could tell us about "real" causes. The examples he used were billiard balls and the sunrise. He argued that since we can imagine the sun failing to rise, we do not understand it's true cause. If we can imagine a billiard ball doing something other than it normally does when it hits another ball, say, jump off the table instead, then all we have to go on is the statistical probability that in the future it would do what it had done in the past, but we could not be sure.

I always found Hume's arguments a bit puzzling, but he was not the first person to make them. Al-Ghazali in the 10th century made almost identical arguments about the sunrise. But I always felt that such an attitude presumed that we were looking at the world as though at a black box: we can only see the outcome, but we know nothing about how things work underlyingly. And maybe this worked in the ancient world when we knew so little about how things work. But it actually doesn't take much knowledge of the world to understand that the sun must rise tomorrow morning. The law of conversation of angular momentum and basic geometry is all that is needed. Given that much information, I literally cannot imagine a way in which the sun cannot rise, not without making one of the premises untrue.

The notion that things have a cause are essential to the development of science. For it is through the notion of causation that we can take even deviations from expectations, even unlikely ones, and say that there is a reason for that deviation. On the macroscopic level, causation is essentially to piecing together the laws of science as we know them: from relatively to chemistry to economics. Without causation, it can be hard to imagine what science would be like.

And yet, in the most fundamental physics, causation may be non-existent to some extent. In quantum mechanics things seem to fundamentally behave on a statistical level and without a specific temporal cause. When an atom decays radioactively, there is no (known) thing that happens in the instant that the atom decays. The nucleus is unstable to be sure, but what happens from the moment when it was holding itself together to the moment when it was not? What makes it decay in that moment and not another? Apparently nothing. That is the puzzle of the non-deterministic world that is quantum mechanics, and part of what some of the greatest thinkers in history, like Albert Einstein, had some problems with: where is the cause? And if there is no cause at the quantum level, does that mean that at the macroscopic level there is also no cause? But of course, in some sense, the cause is the instability of the atom. What is missing is only the temporal aspect.