Causality is Fundamental, not Math Ontology

Roger Schlafly

Jan. 21, 2018

Abstract:

The concept of causality has been derided by philosophers as being not truly fundamental, and the search for fundamental physics usually leads to the quantum state function, spacetime, string theory, or some other mathematical object. I argue that causality is more fundamental, and that the arguments against it are mistaken.

Submitted to the FQXi.org 2017 Essay Contest answering: “What is fundamental?”

Author Bio: Roger Schlafly has a BSE from Princeton U, and a PhD in Mathematics from U California Berkeley, under I. Singer. He blogs at DarkBuzz.com.

Introduction

The search for fundamental physics usually focuses on mathematical objects. They might be strings in ten dimensions, wave functions, or space-time. Physics is called an exact science, and fundamental physics is supposed to be exactly equal to mathematical formulas, to all orders of precision.

I believe that this view is mistaken. Infinite precision and exactness only make sense in mathematics, not physics. Science is about predicting and explaining observations, and collecting data is always subject to error and approximation.

Instead, the fundamental entities of physics are concepts like energy, time, entropy, and causality. Much of physics can be considered just an attempt to understand the behavior of energy.

Energy is widely accepted as fundamental, so little needs to be said. But it is commonly assumed that mathematically exact formulas are fundamental, while causality is not. I argue that his is backwards, and causality is fundamental.

The argument against causality being fundamental

Philosophers and others sometimes argue that causality is not fundamental, or that causality plays no role in fundamental physics. The following chain of reasoning is typical:

* The equations of fundamental physics have a time reversal symmetry.

* Microscopic physics obeys those equations, and hence has no arrow of time.

* Entropy has an arrow of time, but that is classical physics, and hence not fundamental.

* Without a fundamental arrow of time, there is no way to say one thing causes another.

This reasoning is just wrong on every level.

Equations of physics are not time symmetric

Some equations of physics do have time reversal asymmetries. The heat equation is an extreme example, as heat dissipates as you go forward in time, and the equations are not necessarily even solvable going backward in time.

Equations define entropy, and it only increases with time.

The standard model of elementary particle physics has a time asymmetry associated with neutrinos and CP violation.

The ordinary scalar Schrödinger equation has the property that time reversal is like complex conjugation, so there appears to be a time reversal symmetry. Likewise, most wave equations formally have a time reversal symmetry. But this is only a formal mathematical symmetry of the equations.

The physically realistic solutions to those wave equations do not have a time reversal symmetry. The solutions are obtained by solving an initial value problem, and propagating the solution forward in time. Waves propagate from a source, and not to a source.

Microscopic physics has an arrow of time

It is obvious that macroscopic physics has an arrow of time, as you might break an egg but never the reverse. The same is true about microscopic physics.

A free neutron will decay into a proton, electron, and neutrino. You will never see the reverse. The double-slit experiment can only be run forwards in time. Again, you cannot see the reverse. Every quantum mechanical observation is irreversible.

Entropy is fundamental

Entropy increases with time, and this "second law" is arguably the most fundamental law in all of physics. It applies to classical and quantum mechanics.

The argument is sometimes made that the increase in entropy is just an empirical observation, or a statistical quirk, or something else that somehow makes it not fundamental. The argument is mistaken.

There is an anecdote about a famous physicist who would regularly attend theoretical seminars with outlandish proposals for revising the laws of physics. Sometimes they would reject energy conservation, or quantum mechanics, or spacetime, or anything else, and the physicists would patiently listen. But if the proposal violated the second law, then it had no chance. A world without the second law is just inconceivable.

Causality does not require an arrow of time

A medical paper might have data showing that smoking causing lung cancer, but it does not need an arrow of time to reach the conclusion. There would be causality even if all the laws of physics were time symmetric.

The simplest smoking-cancer studies would just show a correlation between smoking and lung cancer. Those would leave the possibilities that smoking caused lung cancer, or that lung cancer retro-caused smoking, or that both had some common cause.

A controlled study can say more about causality. If 2000 volunteers agree to take some pills, and half are randomly given a new drug and the other half placebos, then statistical differences between the two halves can be attributed to a causal effect from the drug.

The causal effects are always later in time, of course, but the arrow of time does not have to be assumed. The medical study could also look for group differences earlier in time also. Conceivably, a study could find that a new drug causes men to have already gone bald before taking the drug!

Such a retro-causal conclusion would be absurd, of course. The world does not work that way. Any such finding would be attributed to a statistical fluke, or to defective randomization, or to research errors.

It is because causality is so fundamental that we so easily reject the future causing the past. The point here is that we could find evidence of future events causing past events, if that were really possible. Any such finding of retro-causality would require a major rethinking of all of science, if accepted.

Stochastic systems can be causal

Causality is so fundamental to the scientific outlook that many scientists find it hard to imagine physical theories that are not totally deterministic. They think that the entire universe should be determined by the first second of the big bang. The usual textbook quantum mechanics is not so deterministic, but many physicists are unhappy about that, and find it hard to believe that a truly fundamental theory would not be deterministic.

In fact, causality has very little to do with determinism. When we say “A causes B”, we don’t mean that A makes B 100% certain. We commonly say that smoking causes lung cancer, even though most smokers do not get lung cancer. We mean that smoking substantially increases the risk of lung cancer.

Putting an atom into an excited state causes an emission, even though it might be impossible to predict the precise nature of that emission. The change has a causal effect on the atomic state, even if not all aspects of the emission are predictable.

The point here is that causality applies equally to stochastic and deterministic systems. Causality is fundamental, whether you believe in determinism or not.

History

Historically, the search for fundamental physics has focused on finding magic equations that explain nature. Again and again, formulas were found that worked far better than anyone could have expected.

Here are some examples. Kepler use ellipses to model planetary orbits, when ellipses just happened to be convenient geometrical figures that were nearly circular. Soon telescopes were invented, and ellipses worked amazingly well.

The inverse square law was devised for planetary orbits also, but later found to work for electric charges on a vastly different distance scale.

Maxwell's equations were discovered from 19th century experiments, but soon found to have an exactness and precision that is far beyond those original experiments.

In the 20th century, discoveries of relativity and quantum mechanics led many to believe that mathematics was the ultimate reality. While both theories were driven by experimental discoveries, everyone quickly latched onto the mathematics of the new theories as great breakthroughs in fundamental physics.

These examples have proven the value of mathematics in explaining the world, but they also give us a false confidence about what is fundamental. Yes, the world has mathematical patterns and math is essential to making precise predictions, but that just makes make an excellent tool.

Conclusion

Causality is fundamentally at the heart of what science is all about. It is essential to explaining and predicting the natural world. The physics of how something causes something else is much more fundamental than any particular equation used.

References

Dark Buzz. http://www.darkbuzz.com

Nature has no faithful mathematical representation, Roger Schlafly, FQXi 2012 essay contest. http://fqxi.org/community/forum/topic/1283