

# It's All Relative

In the search for quantum gravity, Olaf Dreyer is doing something completely different. Measurement problem, meet internal relativity and space-stuff-time.

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**News**

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Back in the day, the concept of “space-time” had some scientific street cred.

It was one of those edgy-but-true ideas that science fiction writers could pull out to prove their scientific chops. Physics students could stay up all night philosophizing over space-time in their dorm rooms. And, if worked properly into cocktail party conversation, space-time could lend a person a sort of brainy mystique.



**AND NOW FOR SOMETHING COMPLETELY DIFFERENT**  
**Olaf Dreyer**

But, according to Olaf Dreyer, a physicist currently working at the Massachusetts Institute of Technology, the notion of space-time is passé. Matter isn't just a passenger riding along the grid of space-time; matter itself is intrinsic to the fabric of the universe.

Which means that the next time you want to impress your friends with your cosmological expertise, you'll have to talk about “space-stuff-time.”

## All The World's a Stage

“I was always interested in the most fundamental questions in physics,” says Dreyer. “At first I thought that this would lead me to studying particle physics, but I soon realized that no really fundamental understanding of nature can be obtained if one excludes gravity.”

Physicists have long known that the equations that spell out gravity – Ein-

stein's General Relativity – break down in the teeny domain of quantum mechanics' atoms and sub-atomic particles. Now, with the help of an US\$80,000 research grant from The Foundational Questions Institute, Dreyer is developing a new approach to “quantum gravity” that could unite these clashing theories.

“It is very ambitious work, very high risk/high payoff,” says Lee Smolin, an FQXi Member and quantum gravity researcher at the Perimeter Institute for Theoretical Physics in Waterloo, Canada. “Dr. Dreyer's work is in the best tradition of foundational physics.”

Dreyer starts with a redefinition of the geometrical architecture of physics. Classically, objects can move “on” the geometry of space, but space itself is static. (Think of chess pieces gliding across a stationary chessboard.)

Einstein's General Relativity complicated the situation by adding a fourth dimension – time – to the formerly three-dimensional coordinate system, and suggested that “space-time” actually responds to the objects within it, warping and stretching to produce what we observe as gravity. (Now imagine the chessboard is made of spandex: as the pieces move, they distort the stretchy fabric.)

But even in Einstein's dynamic world, geometry is only a “stage” on which the motion of matter plays out. As Dreyer sees it, the stage and the player (matter) are actually inseparable: You can't define one without the other: hence “space-stuff-time.” (Think “chess piece” straining inside “chessboard” – *Alice in Wonderland* meets *Aliens*.)

But if you remove the background framework, how can you define distance and time?

## Internally Relative

Dreyer says that you start by describing the system using only its internally avail-

able parts.

Imagine that two friends are stuck in a room with no clocks, no rulers, and no native sense of time or distance. Without a background structure to describe the environment, they must do so “internally”—meaning, Dreyer says, “They have to use what is available to them to build clocks and rulers.”

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- Olaf Dreyer

Pre-relativity thinker Hendrik Lorentz provided a good thought experiment. Set a charged particle in motion. This whips up an electromagnetic field that depends on the direction and speed of the particle. Now let an electron loose in that field. The electron's motion will have all the hallmarks of special relativity—length contraction, time dilation—even though nothing in the setup was relativistic. It is important here that neither time nor distance was measured against any background structure. So special relativity emerges naturally from the system and the principle of “internal relativity,” says Dreyer.

But what about gravity? Dreyer conjectures that Einstein's equations of General Relativity also hold true in internal relativity. For example, Einstein's

equivalence principle, which states that acceleration due to gravity is indistinguishable from acceleration from any other cause (say, the acceleration of an elevator as it starts to climb, Einstein's favorite example), follows naturally from internal relativity.

### A Few Random Thoughts

Dreyer is also aiming to unite the workaday physics of classical mechanics with the mind-bending paradoxes of quantum theory.

"I was brought up in the 'shut up and calculate' tradition of quantum mechanics," says Dreyer. "Only after spending some time at the Perimeter Institute did I realize that there are actually really interesting things to be learned and that one can make some headway by just doing something completely different."

In Dreyer's case, "doing something completely different" starts with a fresh look at what physicists call the "measurement problem."

Classical physics holds that objects behave in fundamentally predictable ways. A baseball flying through left field, a yo-yo bobbing up and down, a marble rolling down a ramp: As long as we have all the information about the objects in each of these systems, we can predict their outcome perfectly every time.

But in the quantum realm, the best you can do is place odds on the outcome of any particular experiment. Physicists have spent decades puzzling over how the macroscopic certainty of classical physics follows from the probabilistic ambiguity of quantum mechanics.

"Large numbers of particles," that is, macroscopic bodies, "can have collective properties that single particles cannot have," explains Dreyer. "Our problem is that we understand the world using these collective properties," but in quantum mechanics, "we now encounter particles that do not seem to have these properties."

Yet, Dreyer points out, even classical mechanics reflects an element of randomness. Consider that Physics 101 standby, the pendulum. Given just the right push, it should freeze suspended in mid-air, 180° from its resting position. In reality, that never happens: The initial nudge always has just a little more, or just a little less, power than the pendulum needs to stay balanced at that "criti-

cal point," and so the pendulum swings back to its starting place.

Dreyer suggests that the same sort of "chaos" arises when the microscopic particles of the quantum world meet up with measuring tools – or as Dreyer calls them, "randomizing devices" – in the lab. Imagine that a particle is teetering between two quantum states as it enters the randomizing device. Any infinitesimal energy deflection in the lab environment will shunt the particle to one state or the other. To the scientist running the experiment, the result seems due to some random whim, but in reality, says Dreyer, the appearance of randomness arises from our incomplete knowledge of the system.



**CHESSBOARD** Space-Stuff-Time?

"This is the first new idea I have heard about the measurement problem in quantum mechanics in a long time," says Smolin.

Smolin continues. "For a long time I've been convinced that the lack of solution of the measurement problem meant that quantum mechanics was wrong and needed replacement with a hidden variables theory. Reading Dr. Dreyer's paper on the measurement problem made me reassess my view. It happens very seldom that reading a paper changes my mind about something."

Will Dreyer's approach to quantum gravity stand the test of time?

"I don't know if he is right," says Smolin, "but his work shows he is that rare kind of person capable of coming up with solutions to these kinds of problems."

### Internal Relativity and the Worst Prediction in Theoretical Physics

Dreyer's internal relativity may shed some light on another cosmological quandary: The quantum mechanical prediction that a "vacuum energy" should be warping our universe beyond recognition.

Vacuum energy is quantum mechanics' "sound of silence"—a bare hiss of energy that would remain even if every last photon were plucked out of the universe. This "pure quantum magic," Dreyer says "has big consequences."

In General Relativity, matter and energy cause space-time to curve. But, "if you add all [of the vacuum energy] up you find that the curvature is so large that you should not be able to see the end of your nose," says Dreyer. "People have called this the worst prediction of theoretical physics." In fact, the vacuum energy predicted by quantum mechanics is 123 orders of magnitude (or ten followed by 123 zeroes) away from the actual value observed by astronomers.

But internal relativity turns this argument on its head. In internal relativity, says Dreyer, "it is the photons that *make* the space-time. So the argument immediately stops working and the problem goes away."

"Dr. Dreyer's proposal is one of the few original ideas I've heard about this in many years," says Lee Smolin, of the Perimeter Institute for Theoretical Physics in Canada. "If true, it would certainly affect cosmology. For example, it could affect models of inflation in the early universe."