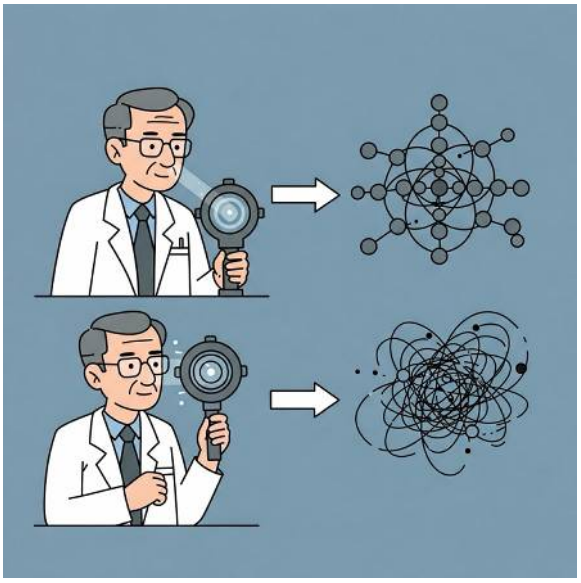
How does measuring affect the arrow of time?

Jacob Werner



Since the dawn of civilization, man has wondered about the nature of time. Nearly all of us have wished to be able to stop time or go back in time, and as a curious physics student, I became particularly interested in understanding the nature of why time flows forward. As a first-year master's student at the University of Tokyo, I have dedicated my research to this question, and I am very grateful for the decisions that I took to reach this point.

Physicists long ago discovered that some processes in the world only go in one direction. For example, food on the ground decays, people die, heat flows from hot to cold; the list goes on and on. It turns out that all of these processes are deeply related to a concept which scientists have called entropy. Entropy gives a way to measure the degree to which a process can only flow in one direction. We say that entropy measures the arrow of time, or in other words, it measures the irreversibility of a process. Processes which produce a lot of entropy are highly irreversible, while those that produce no entropy are in equilibrium, a state of balance where processes can flow in either direction. I study this property of entropy for processes taking place at very small scales, which physicists call the quantum scale, a realm where much still remains

unexplained. I'm interested in how entropy behaves for these quantum systems, and I am particularly interested in how measuring these systems affects the entropy.

You're probably wondering how measuring can have an effect on entropy. For example, when you run an experiment, whether or not you watch the experiment doesn't affect what will happen. A ball will roll downhill and not uphill regardless of whether you are looking. However, everything behaves very differently at the quantum scale, and if I measure a quantum experiment, the system will behave very differently than if I don't. Many other very weird things happen in the quantum realm. For example, are you sitting or standing right now? I don't know what your answer is, but it definitely isn't both. However, in the quantum realm, particles can be in multiple states at once. A particle can be both here and there, can be going in this direction and that direction, or be in that state and this state, all at the same time. When I started learning about quantum physics, all of these concepts felt very unintuitive and weird (they still do), but I was intrigued and knew I had to learn more.

Being at the University of Tokyo, I have the freedom to do research into any topic I want, and I have guidance and assistance from the people in my lab whenever I get stuck. I loved studying physics for my undergraduate, and the more I learn, the more I want to keep learning. After my master's, I plan to get a PhD and then begin a lifelong career in physics, where I can spend every day learning more and more about how the world works. I know that as a middle schooler, you probably haven't decided what you want to do when you grow up, and that's perfectly ok. My biggest advice to you would be to learn what you are interested in, and don't ever think that because a topic seems hard, you can't learn it. From years of studying physics, the main thing I have learned is that I can learn anything, if I ask the right questions, be patient, and learn from experts.

In my bachelor's at the University of Cambridge, I often would start a class and be completely confused. I would tell myself that this class would be the one that I wouldn't be able to ever understand. However, after a few weeks, the ideas were becoming clearer, my confusion

was going away, and I was able to see that really it wasn't so bad. It takes time though. Don't expect to be able to learn all of physics, you never will. Even in my narrow field of quantum entropy production, I am constantly learning new things, and I always will be. Become comfortable with not knowing things, and more importantly, be comfortable with asking questions. Don't ever be afraid of asking a stupid question, that's the best way to learn.

Learning does take work though; the information isn't just going to magically appear in your head. You have to do the work to put it there. Sometimes when I learn something, my brain hurts because I am thinking so hard. This is good though! Don't be discouraged, this means that your brain is creating new connections, and the next time you learn that content will be easier. This is how we grow. You have a bright future ahead of you, all you have to do is learn what interests you, and the rest will fall into place.

Acknowledgements:

I generated my image using Google Gemini AI. It depicts a scientist making measurements on quantum system, and the system responds differently based on how he measured it.

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