THE SCI-FI WRITER'S GUIDE TO QUANTUM PHYSICS

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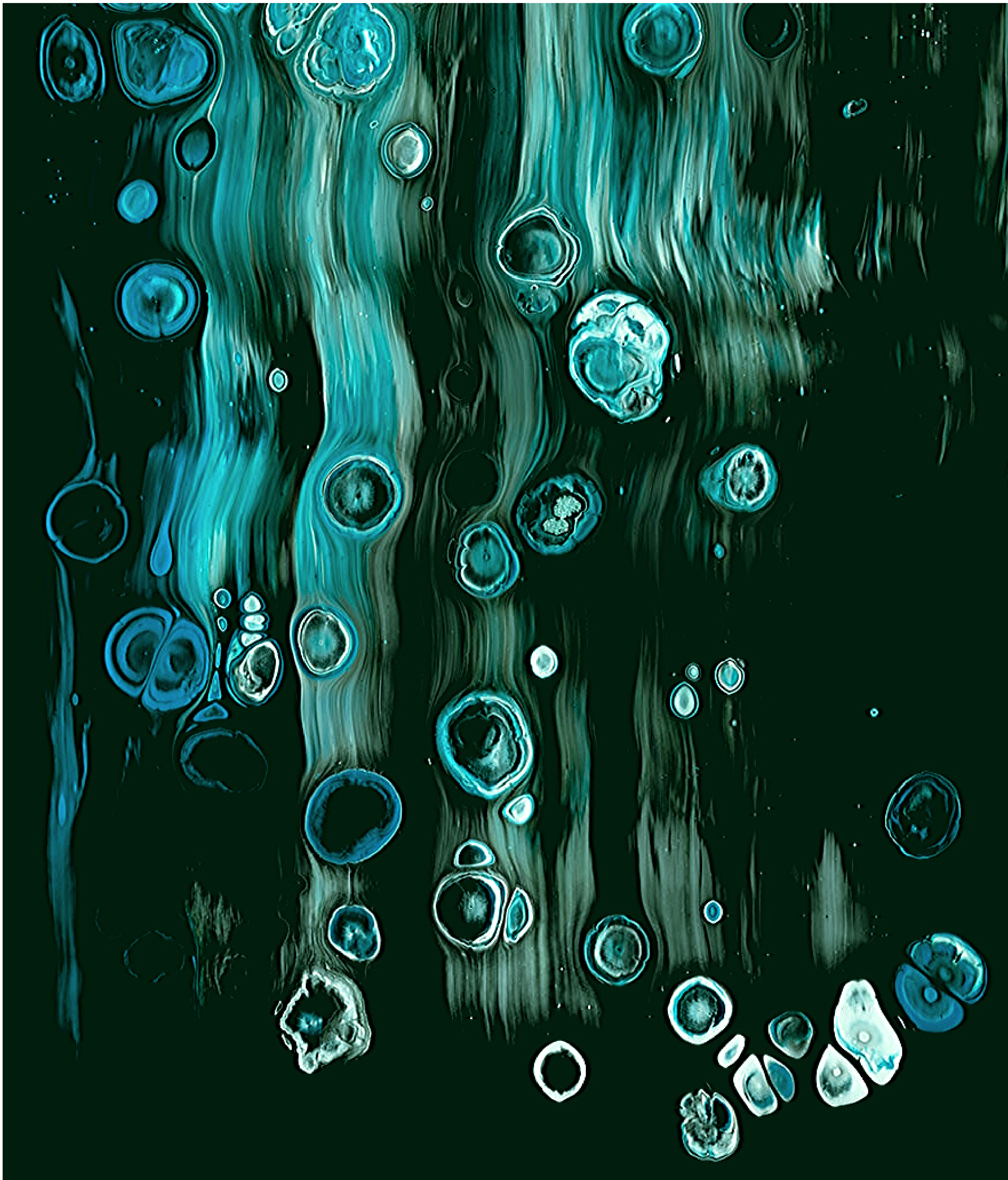

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The Sci-Fi Writer's Guide to Quantum Physics

Hello science fiction writers! Whether you're writing a screenplay, looking for an idea for your next short story, or simply hoping to add a little quantum *oomph* to your novel, this is the perfect place for you!

This guide is meant to be the tip of the iceberg, a quick cheat sheet of sorts for you to glance at when you want to learn or remember a concept in quantum physics. It covers the most commonly used terms in popular culture, and is not meant to be a comprehensive guide to the whole subject.

The goal is to allow you to start from a factual origin in order to extrapolate to 'believable unbelievability', the way a lot of fantastic science fiction does, from the *Marvel Cinematic Universe* to *The Wheel of Time* to *Doctor Who*. As the Dalai Lama once said, "Know the rules well, so you can break them effectively."

Included is a handful of potentially useful quantum phenomena, how they may be explored in fiction, and some fictional writing prompts to get your creative juices flowing. Happy writing!

What is Quantum Physics?

Quantum physics is the physics that governs the super small. Think subatomic small. Tossing a ball to a friend follows classical physics: your friend can easily predict where the ball will land depending on its trajectory and how fast you threw it, and will likely catch it. (Unless your friend has terrible hand-eye coordination. But that's a different matter altogether.) If you and your friend were to shrink down to the size of atoms, and you 'chucked' an electron, the story would be very different because at that level, the laws of quantum physics take over, and quantum physics is a theory of probabilities. Your friend may not 'catch' the electron, because there will be a possibility of the electron 'landing' at any point of the surrounding region. Each point will have some sort of probability associated with it. Perhaps something like: there's a 2% chance the electron will land where your friend is, a 5% chance that it will land to your friend's right, 3% chance that it will land to your friend's left. And so on. This brings us to the uncertainty principle.

The Uncertainty Principle

Since quantum physics is a probability theory, there's a level of uncertainty involved. Pairs of observables (characteristics you can measure/observe) exist that have a sort of "trade-off" between them, and are called 'incompatible'. What qualifies two observables to become an incompatible pair is beyond the scope of this guide, but suffice it to say that if you know complete information about one, you cannot know anything about the second: simultaneously measuring both with 100% precision is impossible.

One such incompatible pair of observables consists of position and momentum. Let's revisit the tossing an electron example: if you know for sure how fast the electron moves, then you cannot at all know where the electron is. The more you know about its momentum, the less you know about its position. A simplistic analogy may be drawn with trying to determine where a basketball is by blindly throwing tennis balls around a court. When a tennis ball finally strikes the basketball, your joy at having found it would be short lived because the basketball would have moved once struck! You've determined the position, but now do not know in which direction nor how fast the basketball moves.

Interpretation in Fiction

You can have a lot of fun playing with creating incompatible observables that may either be tangible or abstract. Perhaps a device that temporarily provides someone with extra strength also temporarily depletes intelligence, in a universe where strength and intelligence are incompatible. Perhaps a protagonist has to make the excruciating choice of whether to locate her mother, in a strange world where finding out an exact position prevents someone from physically going there. An example of such a trade-off can be found in Brandon Sanderson's *Mistborn* series, in which certain people have the ability to store senses like sight into metal rings. The process of storing the sense, however, renders it temporarily weakened. While the magic system isn't necessarily quantum, it loosely follows the rules of physics.

Writing Prompt

We are living in a simulation, and the source code is masked by the uncertainty principle in quantum physics.

Superposition

In the classical world, a ball is either moving or at rest, a film is either playing or paused, and a cat is either alive or dead. Combinations of the two are not possible. There are definitive states that each object can take. However, quantum particles can be in a number of states at once. This is called *superposition.* Superposition is pretty fragile, because even a slight disturbance in a particle's environment can disrupt its state.

The fundamental computing unit for classical computers is the bit, and it can take only one of two values called 'basis states': 0 or 1. That is, everything you do on your digital devices can be broken down into 0's and 1's. A *quantum bit* or *qubit* can not only be in one of the two states, 0 or 1, but a probabilistic superposition of the two. Once it is measured, it becomes a 0 or a 1. Now, by 'probabilistic superposition' I mean that has a certain probability associated with becoming a 0 and a certain probability associated with becoming a 1 after you perform a measurement on it, say, a 50-50 superposition, or a 60-40 superposition. A 50-50 superposition would mean that each outcome is equally likely.

Any single operation on the qubit is equivalent to that operation acting on a 0 and acting separately on a 1. On a classical computer, this would take two separate steps, but on a quantum computer it would take only one -- basically, you're getting a two for the price of one deal!

Interpretation in Fiction

The Schrödinger's Cat thought experiment is probably the most referred to in popular culture as an illustration of superposition, and it works if the cat were a quantum particle -- otherwise it opens a whole can of worms. The 2013 film *Coherence* involves a comet that reveals a huge superposition of multiple realities, and the characters discuss Schrödinger's Cat:

"There's a cat in a box that has, like, a 50/50 chance of living because there's a vial of poison that's also in the box. So, regular physics would say that it's one or the other. That the cat is either alive or dead. But Brian would argue that quantum physics says that both realities exist simultaneously. It's only when you open the box that they collapse into a single event."

While this explanation is not entirely complete (the vial is actually connected to a radioactive element, and the state of the cat is basically entangled with the state of the element), it's sufficient for a sci-fi story! (This also ties in with the Many-Worlds Interpretation, discussed ahead.)

Quantum superposition in fiction needn't solely be explored on such a large scale, that is, as a superposition of realities. You can play with objects or even people being in a superposition.

Perhaps tea is both hot and cold until a character touches it. Or there's a vehicle that is a car, a plane, a boat, and a submarine, and a character uses a dial to adjust the probabilities so that the superposition goes from 25-25-25-25 car-plane-boat-sub to something like: 0-100-0-0 when she needs to fly. A hilarious example of playing with probabilities, is the infamous Infinite Improbability Drive in Douglas Adams' *The Hitchhiker's Guide to the Galaxy.*

From the 2005 film adaptation: *"As the Infinite Improbability Drive reaches infinite improbability, it passes through every conceivable point in every conceivable universe almost simultaneously. In other words, you're never sure where you'll end up, or even what species you'll be when you get there. It's therefore important to dress accordingly."*

Writing Prompt

Some people are born with the unique superpower of *superposition:* they can be in a superposition of a number of states, and mentally adjust the probabilities associated with each possibility.

The Wave Function

Quantum physics is a theory of probabilities, and all information about the probabilities associated with each possible outcome is contained in a *wave function*. The state of a quantum particle or quantum system is mathematically described by this wave function. This is what gives particles their wave nature. At a particular point in space and time, the value of a wave function tells us how likely we are to find the particle there.

One interesting quantum phenomenon is that of *quantum tunneling*, which is impossible in the classical context. A ball in a box stays inside the box unless someone physically removes it; it can't pass through the walls. However, quantum particles *can* pass through energy barriers if their wave functions extend beyond the barriers, that is, there's a non-zero probability that the particle will be found outside the box.

Interpretation in Fiction

Quantum tunneling is visually super cool in science fiction, because it technically allows people to walk through walls! Examples of fictional technology that make use of tunneling are the phase-shifting devices used by the Tollan people in the *Stargate* universe, and the suit worn by the villain Ghost in the 2018 film *Ant Man and the Wasp.* You can play with this concept by having characters tamper with a person's wave function, and hence, probabilities. Perhaps an enemy who wants to prevent the protagonist from walking through the wall of a facility can engulf the facility with a force field that effectively reduces the probability of the protagonist being inside the facility to zero.

Writing Prompt

Quantum tunneling devices exist that not only allow people to walk through walls and other barriers, but through the Earth itself.

Entanglement & Non-locality

Quantum particles can influence one another if they are entangled, that is, tampering with one immediately affects the second without the second ever having been touched. More precisely, the state of each particle cannot be independently described. Entangled pairs of particles can be generated in a number of ways, such as both having been generated by the same source, or by sharing a history, perhaps being part of a single particle before it split or decayed. In much the way superposition is fragile, so is entanglement; a simple fluctuation in a particle's environment can break the entanglement.

If two qubits are entangled, then they can be entangled such that they both take on the same value when measured (i.e., 00 and 11) or they take on opposite values when measured (i.e., 01 and 10).

A system of two or more parts is said to be *non-local* if each of the parts can affect one another if they aren't in each others' locale. Non-locality is often mistaken for entanglement in popular culture, but two particles that are entangled are not necessarily non-local. If they are non-local, they can be separated by even light-years, and still instantaneously affect one another. If they are simply entangled, moving them apart from one another may destroy the entanglement.

Note that in quantum physics, entanglement and non-locality are not always related, but for the purpose of science fiction, you can consider entangled particles to either be non-local or not.

Interpretation in Fiction

A great example of entanglement is the connection between Ant Man and the Wasp in the 2018 film *Ant Man and the Wasp.* The entanglement is unknowingly established when Ant Man shrinks down to the quantum realm, because the Wasp is already there. This allows her to take control of his mind towards the end of the film.

How would entanglement *without* non-locality look? The human - dæmon connection in Philip Pullman's *His Dark Materials* trilogy is a good example. In an alternate world, human souls reside outside of their bodies in animal form called dæmons. Humans need to be close to their dæmons, and if the two are forcefully separated by a certain distance, then the connection is severed, which may lead to death. If the human survives, there's no light or emotion left.

When incorporating entanglement and non-locality in a story, you can ask yourself: what causes entanglement in this universe? What are the things that can break this entanglement? Are all entangled particles non-local?

Writing Prompts

- Let's say souls are quantum particles, and soulmates are entangled souls. What happens to one affects the other. If the souls are non-local, then what happens to a person instantaneously affects their soulmate even if they are on another world.
- A quantum communication device that works over long distances can work because of non-local entangled particles.

The Many-Worlds Interpretation

When a qubit, say, is measured, we know it becomes a 0 or a 1. But we do not know just *how* it becomes one of the two. There are a number of interpretations of quantum physics that theorize how this happens. One is the Many-Worlds Interpretation (MWI), which says that every possible outcome is obtained, each in its own reality. So if you measure a 0 here, then an alternate you in a parallel universe measures a 1. This is not the most commonly used interpretation of quantum physics, but a number of prominent physicists do believe in it. It is, however, definitely the most appealing one for science fiction!

Interpretation in Fiction

There are many ways the theory of multiple universes can be creatively explored in fiction. *Rick and Morty* explores bizarre alternate realities, where a character's alternate self may not even be human. The 2013 film *Coherence* explores alternate realities that are almost identical. Robert Jordan's *The Wheel of Time* speaks of parallel universes being less tangible to us the further in similarity they are from our own universe. There are mentions in *Doctor Who* about other universes that follow different laws of physics. *Avengers: Endgame (2019)* talks about accidentally creating an alternate reality if an Infinity Stone is removed from its original timeline. That is, a change in the past can lead to a whole new timeline that branches off from the main one. The *Back to the Future* film series similarly explores alternate realities due to modified histories.

Writing Prompt

An alternate you has a better life, and you want to switch!

Teleportation

Quantum teleportation is absolutely real, but it isn't, unfortunately, the type made popular by *Star Trek*. In quantum physics, you can only teleport quantum states and not actual physical objects. But it's the states that matter. For instance, Alice might have an electron in an arbitrary state that we don't know about, and Bob, in a distant lab, might need that electron. Alice can teleport the state of her electron in such a way that the state of an electron at Bob's end is changed to the required state. The state of Alice's electron is destroyed in the process, so at the end, Bob is the only one with the important electron.

Interpretation in Fiction

The depiction in the *Star Trek* universe of people essentially being broken up into tiny particles and beamed to a new location isn't inaccurate; if teleportation were real, then in order to teleport, each state of every particle in a person's body would need to be teleported. The states would need to be transmitted over a secure quantum channel, and the 're-materialization' would essentially mean providing the states to latent particles waiting at the receiving end.

Writing Prompt

A new, exact replica of you is created every time you teleport, and the old one is destroyed.

Applications of Quantum Computing

When classical computers were first invented, no one could predict all of the amazing things they'd be used for. Similarly, there are likely hundreds of uses of quantum computers that we haven't even begun to contemplate. However, quantum computing already has useful avenues that scientists are currently exploring. The goal is to be able to do things that classical computers cannot do very well or at all, not replace classical computers. Let's take a look at some of its applications (there are, of course, innumerably more!).

Optimization

One of the things classical computers can't do very well is tackle large scale optimization problems. If you have 3 books, then there are 6 different ways you can arrange them on the shelf — that is, 3! (read "three factorial") possible arrangements. If you have 5 books, then you have 120 potential combinations. Bump that number up to 8 and you have 40,320 different arrangements, and if you move to 10 books then you have a whopping 3,628,800 unique combinations. Suppose you have to find a single optimal arrangement out of the many possibilities. If you're anything like me, you have *dozens* of books at home. You see the problem? Classical computers, even the best available supercomputers, struggle to analyze exponentially large scenarios like these. What could take a classical computer years to analyze may take a quantum computer mere minutes, and it is hoped that quantum computers will help with optimization problems such as traffic control and financial portfolios.

Simulations

Quantum computers have applications in fields like chemistry and materials science due to potentially being able to simulate things classical computers cannot. Accurately simulating a molecule, for instance, requires taking into account every single electron-electron repulsion/attraction. For complex molecules, even supercomputers struggle because every time a new electron is introduced, the problem becomes exponentially large, in a manner similar to the book arrangements described above. Since molecules are governed by the laws of quantum physics, it seems intuitive that computing technology that runs on those very laws can accurately simulate them in a way that classical computers cannot. This can lead to the discovery of better drugs in the pharma industry, and new materials.

Cryptography

The widely used RSA cryptosystem is based on how difficult it is to factorize large numbers. However, quantum computers can potentially factorize large numbers in a very short span of time — the algorithm for this already exists. Its implementation is as yet to come, but quantum cryptography is an ever increasing field in which more secure alternatives are being explored for the day when systems like RSA can be easily broken.

Interpretation in Fiction

Many science fiction storytellers focus on foundational concepts in quantum physics, but as you can see from the taste of applications given, quantum computing can potentially contribute colorful flavoring to a fictional world. Futuristic stories in particular would be more accurate if they involved some sort of quantum computing based technology!

Writing Prompt

- Self driving cars navigate based on quantum algorithms in a world that no longer has traffic jams.
- A new quantum pharma company renders all others redundant because of the accelerated development of brilliant drugs due to simulations on quantum computers.
- Every government wants to get their hands on the world's best hacker, who has disrupted security systems around the planet due to her proclivity for quantum cryptography.

More to Explore

Articles
The Economist: Proof emerges that a quantum computer can outperform a classical one (2019)
BigThink: Scientists achieve teleportation breakthrough (2019)
Science Daily: Physicists 'teleport' logic operation between separated ions (2019)
ThoughtCo: Understanding the "Schrödinger's Cat" Thought Experiment (2019)
ThoughtCo: What Physicists Mean by Parallel Universes (2018)
Scientific American: How Close Are We—Really—to Building a Quantum Computer? (2018)
How Stuff Works: How Quantum Suicide Works
Quantum Computing Report: The Best Applications for Quantum Computing

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B. Greene. "The Elegant Universe." W. W. Norton & Company. (1999)
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Videos
Domain of Science: Quantum Supremacy Explained (2018)
Coding Tech: A Beginner's Guide to Quantum Computing by Dr. Talia Gershon (2017)
Scientific American: Is our universe a hologram? (2014)
TED Talk: Brian Greene: Is our universe the only universe? (2012)
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Papers
M. Campagna, et. al. "Quantum Safe Cryptography and Security, An introduction, benefits, enablers and challenges." ETSI White Paper. (2015)
M. Tegmark "Many Worlds in Context by Max Tegmark." Arxiv Pre-print. (2010)

Resources
Hyperphysics: The Uncertainty Principle, Tunneling
IBM's Virtual Textbook: Learn Quantum Computation using Qiskit
Fandom.Com Wikis
Udemy: QC101 Quantum Computing & Quantum Physics for Beginners
Brian Greene's Website
Film Inquiry: Fantasy Science Archive

About the Author

Radha Pyari Sandhir is a quantum physicist, writer, scientific consultant, and cat mom based in India, whose personal goals are to demystify science, and say hello to every cat she meets. Catch her column Fantasy Science on Film Inquiry, or find her on Twitter @RadhaPyari.

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