Helgoland

What's in it for me? A look at the latest in quantum physics.

It's the summer of 1925, allergy season, and Werner Heisenberg can't stop sneezing. To alleviate his hay fever, the 23-year old physicist escapes to Helgoland, a small rocky island in the North Sea. Here, finally able to breathe freely, he begins to think deeply about atoms. His insights will revolutionize physics and our understanding of reality. Drawing on the expert storytelling of physicist Carlo Rovelli, these blinks tell the fascinating story behind the development of quantum mechanics. Along the way, you'll discover what Heisenberg's theories tell us about the strange and counterintuitive realm of subatomic particles and how his insights revealed questions that are still baffling scientists today. In these blinks, you'll learn

how hay fever led to the discovery of quantum mechanics; when an object isn't really an object; and why multiverses are unnecessary.

Heisenberg kicked off a new, complex field of study called quantum physics.

The early twentieth century is an exciting time to be a young, ambitious physicist. Niels Bohr, a Danish physicist, has recently identified an odd phenomenon. He's observed that, when heated, atoms emit light in certain specific frequencies. These patterns imply that electrons, the small subatomic particles that whizz around the atom's nucleus, only orbit at certain specific distances. The question on Heisenberg's mind is why? Why should electrons stay confined to certain orbits? And why should they leap between orbits in specific quantifiable ways? Essentially, he wants to understand the mechanics of quantum leaps.

The key message here is: Heisenberg kicked off a new, complex field of study called quantum physics. The problem was this: scientists at the time couldn't explain the orbits of electrons or the quantum leaps between these orbits. To describe the movement of particles, classical physics relied on discrete numbers for variables like position, velocity, and energy. But, for electrons, it was difficult to determine these variables. Scientists could only observe how these variables changed as electrons jumped between orbits. To skirt this mystery, Heisenberg focused on what was actually observable, that is, the frequency and amplitude of light emitted during these leaps. He reworked the classical physical laws and replaced each separate variable with a table or matrix representing all the possible changes which could occur. The math was extremely complicated, but the outcome perfectly matched what Bohr had observed. Meanwhile, Erwin Schrödinger, another physicist, took a different approach. He considered electrons not as simple particles that orbited a nucleus, but as electromagnetic waves that propagated around it. Using the simpler math of wave equations, he was also able to accurately match Bohr's observations. But, there was a snag. Waves are diffuse, but when observed by a detector, electrons are clearly distinct points, or particles. How to reconcile these seemingly incompatible models that, nonetheless, give the same results? A third thinker, Max Born, had the answer. He argued that while Heisenberg's matrix calculations explained the outcomes of observing electrons, Schrödinger's wave calculations provided the probability of making those observations. It seemed that in this new quantum physics, electrons somehow existed as waves until seen by an outside observer. Then, they collapse into a point. This gave rise to a new, vexing question: why?

Superpositions pose difficult questions about the nature of reality.

There's a classic thought experiment which illustrates the confounding world of quantum physics. It involves a cat in a box with a very curious device. When triggered, it releases a powerful sedative to lull the animal to sleep. Now, let's say the device is only triggered by a certain quantum phenomenon, like the decay of an atom. Moreover, let's say

Schrödinger’s equations give a one in two probability of this phenomenon occurring at any given point. So, until we open the box, we don’t know if the phenomenon has occurred. The cat is somehow both asleep and awake. This is called a quantum superposition, and it occurs when two contradictory properties are, in a sense, both present. It’s a notoriously difficult concept to wrap your head around, and for decades, physicists and philosophers alike struggled to explain exactly how it works. The key message here is: Superpositions pose difficult questions about the nature of reality. This thought experiment, known as Schrödinger’s cat, illustrates a central mystery of quantum physics. While superpositions seem improbable, scientists have demonstrated that they actually occur. For instance, a single photon of light can act as if it’s taken two completely separate paths! There are competing explanations, sometimes described as interpretations, for this strange reality. One interpretation is the many worlds theory. In this model, the idea of the cat being both asleep and awake is taken literally. That is, since the probability of the trigger occurring is one in two, both occur, just in different timelines. You, as the observer, also exist in each of these timelines. In fact, because there’s an infinite number of quantum events, there’s actually an infinite number of timelines or worlds. A competing interpretation, the hidden variables theory, avoids infinite worlds by separating Schrödinger’s wave from the quantum particle itself. In this idea, the probability predicted by Schrödinger exists in a real way we don’t yet understand, even as the observable physical reality only takes one form. So, the probable asleep cat exists in our world, even if we only see an awake one. Yet, a third interpretation, called quantum Bayesianism or QBism, is wholly different. According to this theory, superpositions and Schrödinger’s probabilities are just information, and incomplete information at that. When observers open the box and see the cat, they get more information. In this way, the observer makes reality through observation piece by piece. Though, this leaves the question: who, exactly, is this observer?

The relational interpretation presents a world where everything is in flux.

In the layman's view of quantum mechanics, quantum superpositions exist until an observer comes along and sees what's actually happening. So, an electron whizzes around in an indeterminate cloud of probability until a scientist arrives with an electron detector and, through observation, identifies its real location. But what makes the scientist so special? Is there something about her that gives her a privileged status of observer? Is it her lab coat, her advanced technical equipment, or her very existence as a sentient being capable of sight, thought, and consciousness? Actually, it's none of these things. In the relational interpretation of quantum theory, observation isn't about seeing in the traditional sense. Really, any type of interaction is an observation. The key message here is: The relational interpretation presents a world where everything is in flux. When it comes to quantum theory, the word observation is a bit of a misnomer. It implies a separation between the natural world of physics and a special subject, usually a human, who somehow observes this world from outside it. But the relational interpretation of quantum physics destroys this distinction. In this model, any and every single entity in the universe is both observed and an observer. You see, the universe is filled with an astounding array of things, from photons, or light particles, and rainbows to cats, clocks, and galaxies. None of these things, sometimes called physical systems, exist in isolation. They're in constant interaction. And, in fact, it's these various interactions which give physical systems their properties. If something had no interactions, it wouldn't exist in any meaningful sense. In this way, all physical properties, sometimes called information, are relational. That is, they're in flux, coming and going depending on the circumstances. In some sense, we already know this to be true. A property like speed only emerges through the relation of two objects. If you're walking on a boat, your speed is different when measured in relation to the deck of the boat or the surface of the water. Imagining the world as an endless network of relations creating properties doesn't sound radical, but it is. Let's return to Schrödinger's cat. While in the box, the cat is asleep or awake depending on its relation to the trigger, but to you, outside, it's neither. Both of these are true because different relations produce different realities. It just depends on which relational event, or frame of reference, is being considered.

The relational model demystifies the process of quantum

entanglement.

Imagine two photons, both existing in a quantum superposition where they're both red and blue. Like Schrödinger's cat, we can't determine the definitive state of either until we make an observation. But, as each photon has two options, each color has a 50 percent chance of manifesting when observed. Let's send one of these photons to Vienna and the other to Beijing. If we take a peek at the Vienna photon, it'll manifest as either red or blue. For this example, let's say it's red. Now, when we observe the Beijing photon, it should match the Vienna photon about half the time. But here's where things get strange. If the Vienna photon is red, the Beijing photon will also be red, every time. This seemingly magic link is called quantum entanglement. The key message here is: The relational model demystifies the process of quantum entanglement. Quantum entanglement is one of the most bizarre phenomena in physics. When two photons are entangled, their features correlate, or match, even across distances. Of course, a pair of red gloves is also correlated across space – if you separate them, they both remain red. However, a pair of photons in red-blue superpositions are neither color until observed. So, how is one able to match the other? Well, the first photon could somehow send a signal to the second. Yet, entanglement is observed across distances where this signal would need to violate the speed of light. Or, maybe the pair decide their color before being separated. This explanation is also ruled out by a complex set of equations called Bell inequalities. So, what's really going on here? The relational model may give some clues. Remember, in this model, properties only exist in interactions. Since no entity is capable of observing both the Vienna and the Beijing photons simultaneously, each has no real properties in relation to the other. The Vienna photon's red color only exists in relation to observers in Vienna. So, to the Viennese, the Beijing photon, and in fact, everything in Beijing, remains in a quantum superposition. Until mutual observation takes place, any comparison is meaningless. Yet, these distant events can come into relation. A scientist in Vienna can call her counterpart in Beijing. This interaction, or observation, delivers the information about the Vienna photon's red color, causing the entangled photon to manifest as red. So, there's no mysterious link across distance, but instead a web of relations connecting these events and giving them their properties.

Philosophy and science are deeply intertwined with one another.

Ernst Mach is probably the most influential thinker you’ve never heard of. Both a scientist and a philosopher, his knack for counterintuitive insight and provocative thinking earned him admirers and detractors across many fields. The Russian revolutionary Vladimir Lenin wrote scathing critiques of Mach’s work. Another revolutionary, Alexander Bogdanov, fiercely defended them. The acclaimed novelist Robert Musil incorporated Mach’s thinking in his epic novel The Man without Qualities. And, Einstein and Heisenberg both credit Mach’s ideas as important influences on their own breakthroughs. So, what radical notions did Mach advocate to send such shockwaves through the worlds of politics, arts, and physics? Well, he suggested that the world consisted of sensations, an idea that has curious resonance with relational quantum theory. The key message here is: Philosophy and science are deeply intertwined with one another. Throughout the eighteenth and nineteenth centuries, science was largely dominated by a philosophical premise called mechanism. At its most basic level, mechanism argued that reality operated a bit like clockwork. The universe was a vast empty container called space and all phenomena consisted of matter rigidly interacting in this space. To Ernst, this model was useful but limiting. He considered mechanism to be too metaphysical, or abstract. Instead, he argued science should focus on what’s actually observable, that is, the sensations that occur when elements interact. If this sounds familiar, it’s because this exact idea inspired Heisenberg to investigate the actions of electrons, opening the door to quantum theory. But Mach’s notions have an even deeper reach. In his conception of reality, physical objects aren’t independent elements that mechanically interact, but rather it’s these interactions which produce the world. And observers also aren't separate from this system. They, too, only know the world through the sensations of interactions. Again, this notion seems to presage the relational interpretation of quantum physics where properties don’t exist independent of their context. This isn’t to say that Mach had a prophetic understanding of quantum mechanics. Rather, Mach’s insight shows the valuable interplay between science and philosophy. Had Heisenberg ignored Mach and rigidly adhered to the tenets of mechanism, he may never have arrived at his crucial discoveries. Likewise, contemporary philosophers can grapple with the latest scientific understandings to sharpen and refine their own ideas about reality. So, how does all this look when applied to a tricky subject like consciousness? We'll examine that in the next blink.

Considering relations and correlations can shed light on how the mind works.

Spend a few moments clicking around on the internet and you'll see quantum concepts applied or, more accurately, misapplied in innumerable inventive ways. Gurus speak of quantum spiritualism, scam doctors advertise quantum healing, and tech entrepreneurs extol all varieties of quantum nonsense. It seems that the inherent strangeness of quantum physics has a way of sparking the imagination. But can quantum theory shed light on life's big questions? Can it explain love, elucidate the origin of beauty and truth, or provide meaning to existence? Not exactly. But applying the concepts of relational quantum theory to a question like the nature of consciousness can open new paths for investigation and inquiry. The key message here is: Considering relations and correlations can shed light on how the mind works. In general, philosophy offers three main models for the human mind. There's dualism, where the mind exists as a separate, almost spiritual, entity from the body and nature. There's idealism, where the mind encompasses and accounts for all of reality. And there's naive materialism, where mental phenomena are just the outcome of brute physical processes. Relational quantum theory can offer a slightly different account of the mind. To understand it, it's helpful to think about meaning. For human cognition, meaning is extremely important. We see signs, read words, or think thoughts – these mean something because they refer to, or signify, something external in the real world. The German philosopher Franz Brentano calls this process intentionality, and it's how we communicate with each other and navigate reality. But how does intentionality arise? One answer is through relevant relative information. Relative information is a correlation that emerges when two systems relate. So, spotting a falling rock creates relative information by correlating an external object, the rock, with an interior state, your brain ascertaining its descent. This information becomes relevant because it determines your body's reaction, that is, getting out of the way. In this scenario, the information generated by the relations between exterior and interior produces intentionality: the sight of a falling rock signifies danger, and you move to avoid it. Of course, this account only describes the physical processes which take place between various systems. It says nothing about your individual experience of dodging a rock. Explaining how such a subjective experience emerges is trickier. This is called the "hard problem" of consciousness, and it remains an open subject of debate.

Studying quantum physics can help us see the world in new ways.

When you look at a cat, what do you actually see? Well, in the traditional model of sight, perception is all about absorbing information. Photons bounce off the cat's form, fur, and whiskers and enter your eyes. Your retinas process the light into a signal and send it on to your brain. Finally, your neurons interpret the signal into an image of a cute kitten. But that's not exactly correct. In actuality, your brain predicts what the eyes should see. The eyes still gather light but only pass on signals that conflict with this preexisting image. These discrepancies between what we expect and what we detect are the crucial information we use to make sense of the external world. The key message here is: Studying quantum physics can help us see the world in new ways. This second explanation of sight, where the brain plays a leading, primary role, comes from a concept called the projective consciousness model. In this theory, consciousness arises from the brain constantly refining its preconceived ideas and mental representations against data collected by our senses. In this way, our interpretation of reality is a "confirmed hallucination" that constantly updates and evolves. In some ways, science works on the very same principles. Humanity dreams up one vision for how the world works, then, through experience and experimentation, we find all the ways reality departs from and defies these models. Of course, while our brains perform this process in a fraction of a second, science does so much more slowly. The cycle of testing and refinement is a collective effort that spans generations. Our theories of quantum physics, including the relational interpretation, are but the latest outcome of this ongoing process. Currently, they give us the most accurate picture of reality according to what we can observe, map, and measure. Though, it’s a very strange picture indeed. Relational quantum physics presents a world where static, stable things do not exist. Instead of concrete entities interacting in space, all of reality is a web of interactions where events converge and dissolve in an endless froth. We don’t stand outside this churn of relations either. Even our very identity, or subjectivity, is a product of this ongoing flurry of correlations. Seeing the world this way may seem peculiar, psychedelic even, but as for now, this hallucination has been confirmed, and we should see where it takes us next.

Final summary

The key message in these blinks is that: At the dawn of the twentieth century, a cadre of young physicists, including an allergy-plagued Werner Heisenberg began dismantling the classical understanding of physics. They replaced the old deterministic and mechanical model of the universe with a quantum one defined by uncertainty and probability. The relational interpretation of quantum physics argues that this quantum reality is made up of a web of unstable relations – what is real and true can vary depending on what relations are taking place. Got feedback? We’d love to hear what you think about our content! Just drop an email to with Helgoland as the subject line and share your thoughts!