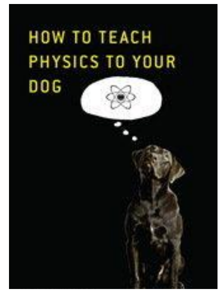

Excerpt

Introduction

Why Talk to Your Dog about Physics?
An Introduction to Quantum Physics

The Mohawk-Hudson Humane Society has set up a little path through the woods near their facility outside Troy, so you can take a walk with a dog you're thinking of adopting. There's a bench on the side of the path in a small clearing, and I sit down to look at the dog I've taken out.

She sits down next to the bench, and pokes my hand with her nose, so I scratch behind her ears. My wife and I have looked at a bunch of dogs together, but Kate had to work, so I've been dispatched to pick out a dog by myself. This one seems like a good fit.

She's a year-old mixed-breed dog, German shepherd and something else. She's got the classic shepherd black and tan coloring, but she's small for a shepherd, and has floppy ears. The tag on her kennel door gave her name as "Princess," but that doesn't seem appropriate.

"What do you think, girl?" I ask. "What should we call you?"

"Call me Emmy!" she says.

"Why's that?"

"Because it's my name, silly."

Being called "silly" by a dog is a little surprising, but I guess she has a point. "Okay, I can't argue with that. So, do you want to come live with us?"

"Well, that depends," she says. "What's the critter situation like?"

"Beg pardon?"

"I like to chase things. Will there be critters for me to chase?"

"Well, yeah. We've got a good-sized yard, and there are lots of birds and squirrels, and the occasional rabbit."

"Ooooh! I like bunnies!" She wags her tail happily. "How about walks? Will I get walks?"

"Of course."

"And treats? I like treats."

"You'll get treats if you're a good dog."

She looks faintly offended. "I am a very good dog. You will give me treats. What do you do for a living?"

"What? Who's evaluating who, here?"

"I need to know if you deserve a dog as good as me." The name "Princess" may have been more apt than I thought. "What do you do for a living?"

"Well, my wife, Kate, is a lawyer, and I'm a professor of physics at Union College, over in Schenectady. I teach and do research in atomic physics and quantum optics."

"Quantum what?"

"Quantum optics. Broadly defined, it's the study of the interaction between light and atoms in situations where you have to describe one or both of them using quantum physics."

"That sounds complicated."

"It is, but it's fascinating stuff. Quantum physics has all sorts of weird and wonderful properties. Particles behave like waves, and waves behave like particles. Particle properties are indeterminate until you measure them. Empty space is full of 'virtual particles' popping in and out of existence. It's really cool."

"Hmmm." She looks thoughtful, then says, "One last test."

"What's that?"

"Rub my belly." She flops over on her back, and I reach down to rub her belly. After a minute of that, she stands up, shakes herself off, and says "Okay, you're pretty good. Let's go home."

We head back to the kennel to fill out the adoption paperwork. As we're walking, she says, "Quantum physics, huh? I'll have to learn something about that."

"Well, I'd be happy to explain it to you sometime."

Like most dog owners, I spend a lot of time talking to my dog. Most of our conversations are fairly typical -- don't eat that, don't climb on the furniture, let's go for a walk. Some of our conversations, though, are about quantum physics.

Why do I talk to my dog about quantum physics? Well, it's what I do for a living: I'm a college physics professor. As a result, I spend a lot of time thinking about quantum physics.

What is quantum physics? Quantum physics is one part of "modern physics," meaning physics based on laws discovered after about 1900. Laws and principles of physics that were developed before about 1900 are considered "classical" physics.

Classical physics is the physics of everyday objects -- tennis balls and squeaky toys, stoves and ice cubes, magnets and electrical wiring. Classical laws of motion govern the motion of anything large enough to see with the naked eye. Classical thermodynamics explains the physics of heating and cooling objects, and the operation of engines and refrigerators. Classical electromagnetism explains the behavior of lightbulbs, radios, and magnets.

Modern physics describes the stranger world that we see when we go beyond the everyday. This world was first revealed in experiments done in the late 1800s and early 1900s, which cannot be explained with classical laws of physics. New fields with different rules needed to be developed.

Modern physics is divided into two parts, each representing a radical departure from classical rules. One part, relativity, deals with objects that move very fast, or are in the presence of strong gravitational forces. Albert Einstein introduced relativity in 1905, and it's a fascinating subject in its own right, but beyond the scope of this book.

The other part of modern physics is what I talk to my dog about. Quantum physics or quantum mechanics* is the name given to the part of modern physics dealing with light and things that are very small -- molecules, single atoms, subatomic particles. Max Planck coined the word "quantum" in 1900, and Einstein won the Nobel Prize for presenting the first quantum theory of light. The full theory of quantum mechanics was developed over the next thirty years or so.

The people who made the theory, from early pioneers like Planck and Niels Bohr, who made the first quantum model of the hydrogen atom, to later visionaries like Richard Feynman and Julian Schwinger, who each independently worked out what we now call "quantum electrodynamics" (QED), are rightly regarded as titans of physics. Some elements of quantum theory have even escaped the realm of physics and captured the popular imagination, like Werner Heisenberg's uncertainty principle, Erwin Schrödinger's cat paradox, and the parallel universes of Hugh Everett's many-worlds interpretation.

Modern life would be impossible without quantum mechanics. Without an understanding of the quantum nature of the electron, it would be impossible to make the semiconductor chips that run our computers. Without an understanding of the quantum nature of light and atoms, it would be impossible to make the lasers we use to send messages over fiber-optic communication lines.

Quantum theory's effect on science goes beyond the merely practical -- it forces physicists to grapple with issues of philosophy. Quantum physics places limits on what we can know about the universe and the properties of objects in it. Quantum mechanics even changes our understanding of what it means to make a measurement. It requires a complete rethinking of the nature of reality at the most fundamental level.

Quantum mechanics describes an utterly bizarre world, where nothing is certain and objects don't have definite properties until you measure them. It's a world where distant objects are connected in strange ways, where there are entire universes with different histories right next to our own, and where "virtual particles" pop in and out of existence in otherwise empty space.

Quantum physics may sound like the stuff of fantasy fiction, but it's science. The world described in quantum theory is our world, at a microscopic scale.* The strange effects predicted by quantum physics are real, with real consequences and applications. Quantum theory has been tested to an incredible level of precision, making it the most accurately tested theory in the history of scientific theories. Even its strangest predictions have been verified experimentally (as we'll see in chapters 7, 8, and 9).

So, quantum physics is neat stuff. But what does it have to do with dogs?

Dogs come to quantum physics in a better position than most humans. They approach the world with fewer preconceptions than humans, and always expect the unexpected. A dog can walk down the same street every day for a year, and it will be a new experience every day. Every rock, every bush, every tree will be sniffed as if it had never been sniffed before.

If dog treats appeared out of empty space in the middle of a kitchen, a human would freak out, but a dog would take it in stride. Indeed, for most dogs, the spontaneous generation of treats would be vindication -- they always expect treats to appear at any moment, for no obvious reason.

Quantum mechanics seems baffling and troubling to humans because it confounds our commonsense expectations about how the world works. Dogs are a much more receptive audience. The everyday world is a strange and marvelous place to a dog, and the predictions of quantum theory are no stranger or more marvelous than, say, the operation of a doorknob.

Discussing quantum physics with my dog is useful because it helps me see how to discuss quantum mechanics with humans. Part of learning quantum mechanics is learning to think like a dog. If you can look at the world the way a dog does, as an endless source of surprise and wonder, then quantum mechanics will seem a lot more approachable.

This book reproduces a series of conversations with my dog about quantum physics. Each conversation is followed by a detailed discussion of the physics involved, aimed at interested human readers. The topics range from ideas many people have heard of, like particle-wave duality (chapter 1) and the uncertainty principle (chapter 2), to the more advanced ideas of virtual particles and QED (chapter 9). These explanations include discussion of both the weird predictions of the theory (both practical and philosophical), and the experiments that demonstrate these predictions. They're selected for what dogs find most interesting and also illustrate the parts that humans find surprising.

"I don't know. I think it needs...more."

"More what?"

"More me. You don't talk about the fact that I'm an exceptionally smart dog."

"Well, okay -- "

"And exceptionally cute, too."

"Sure, but -- "

"And don't forget good. I'm way better than those other dogs."

"What other dogs?"

"Dogs who aren't me."

"Look, this is really a book about physics, not a book about you."

"Well, it ought to be more about me, that's all I'm saying."

"It's not, and you'll just have to live with that."

"Okay, fine. You need my help with the physics stuff, though."

"What do you mean?"

"Well, sometimes you leave some stuff out, and don't answer all of my questions. You shouldn't do that."

"Like what? Give me an example."

"Ummm...I can't think of one now. If you read it to me, though, I'll point them out, and help fix them."

"Okay, that sounds fair. Here's what we'll do. We'll go over the book together, and if there are places where you think I've left stuff out, we can talk about them, and I'll put your comments in the book."

"Talk about them like we're doing now?"

"Yeah, like we're doing now."

"And you'll put the conversation in the book?"

"Yes, I will."

"In that case, we should talk about how I'm the very best, and I'm cute, and I should get more treats, and -- "

"Okay, that's about enough of that."

"For now."

Behind the Book

Five Reasons Every Dog Should Love Quantum Physics

Quantum physics may seem so arcane that even humans don't need to understand it, let alone dogs. A surprising number of everyday things have their origins in quantum physics, though, making quantum physics crucial for the happy life of a modern dog. Here are five things that wouldn't be possible without quantum physics:

1) **Computers**: Modern computers are based on silicon chips containing billions of tiny transistors. The transistors are made by adding tiny amounts of gallium or arsenic to the silicon in different parts of the chip. The amount added is extremely small—less than one atom in 10,000—but it's enough to change the quantum behavior of the electrons in the different regions, making a transistor. Without quantum physics, it would be impossible to make the computers we use for writing books, playing games, or looking at silly pictures of cats on the Internet.

2) **Lasers**: Lasers use a quantum phenomenon called "stimulated emission," first predicted by Einstein in 1917, to amplify light at very specific frequencies. This produces a source of light with a single frequency which behaves as a single wave—all the light waves produced by different atoms are perfectly in synch. Without quantum physics, it would be impossible to build the lasers that are found in the DVD players that we use to watch movies, the fiber-optic telecommunications systems that carry email and phone calls, and the price scanners that supermarkets use to determine the price of dog biscuits.

3) **GPS Navigation**: The Global Positioning System consists of a collection of satellites orbiting the Earth, each broadcasting a radio signal giving its position and the time. A GPS receiver determines its distance from three different satellites by measuring the time required for the signals to reach the receiver. This determines the position of the receiver on the Earth to within a few meters, provided you know the time within a few nanoseconds (light travels about one foot in one nanosecond). To get this accuracy, the satellites contain atomic clocks, which measure time from the energy difference between two quantum states. Without quantum physics, it would be impossible to build the GPS system that humans need to keep from getting lost because their noses aren't good enough to sniff out the way home.

4) **Magnetic Resonance Imaging**: The MRI scanners used by doctors and hospitals work by driving the nuclei of hydrogen atoms back and forth between two quantum states and measuring the radio waves produced. By measuring the amount of radio waves from different parts of the body, they can distinguish between different types of tissues, and make detailed images showing the arrangement of muscles and tendons and ligaments. Without quantum physics, it would be impossible to make the MRI scanners that doctors use to diagnose health problems and help humans heal up so they can take good dogs for walks.

5) **Sunlight**: The Sun generates vast amounts of energy by fusing two hydrogen atoms together to make helium, and some of that energy travels to the Earth in the form of visible light. But the hydrogen atoms repel each other because their nuclei are both positively charged, and even in the Sun the atoms don't have enough energy to overcome that repulsion. We have sunlight anyway because a quantum phenomenon known as "tunneling" allows the nuclei to get close enough to fuse even though they don't have enough energy. Without quantum physics, it would not be possible for

a dog to spend a lovely afternoon basking in the sun and keeping an eye out for squirrels trying to infiltrate the yard.