I continue quoting from Alan Lightman's, "A Modern Day Yankee In A Connecticut Court and other essays on Science".

Conversations with Papa Joe

The Fourth Evening

"The next day I stayed home to prepare some lectures, but my heart wasn't in it. I spent the time reading a novel instead, sitting in Papa Joe's chair. That night the old gentleman returned as he had promised, and wasted no time in getting to the topic of conversation.

"Now, I'm not afraid of numbers, young man," he began. "A fellow in construction for forty years knows numbers." He paused. "But I don't understand about equations. And I especially don't understand why you put so much stock in them."

I got out a sheet of paper and wrote down:

$$C = 2 \pi r$$

"Papa Joe, this says that the circumference of a circle equals its radius times two, times pi, a special number close to 3.14."

"I remember that rule," my great-grandfather said.

"The real strength of equations is their logic," I said. "You start at one point, and an equation tells you what has to come next, according to logic. In the example here, you give the radius of any circle, and this equation says what its circumference has to be. I think the Babylonians or somebody figured the thing out first. They went out and measured the radii and the circumferences of a whole bunch of circles, of all different sizes, and gradually realized that a precise mathematical law held every time. It saved them a lot of trouble when they found it. Equations in science are all like this, except usually much more involved.

They start with some law about nature, and tell you what logically follows from the law, step by step. They give rules for how things ought to behave."

"Does every single item in the world have an equation for how it behaves?" asked Papa Joe.

"Most Scientists would say yes--for the physical world, that is--although in some cases we haven't yet figured out what the equations are."

"So, if I understand you right, you believe that everything in nature follows rules. Whatever the thing is, you'll eventually find an equation for it, and it'll stand up and salute."

"But what's the alternative?" I asked. "To be constantly afraid that at any moment houses might float off the earth, or stars might change into wheelbarrows, or people might start talking backwards? The world we're born into is strange enough as it is. We've got to believe that, at bottom, nature is at least rational. Scientists might not discover all the rules straight off, but we trust that we'll find them."

"I can see where that view might bring you some comfort," said the old gentleman.

"What's changed in this century," I continued, "is that we don't have a physical feeling for all of the rules we've been finding. The Babylonians could draw their circles and measure them with string to test their equations. Sir Isaac Newton could compare the prediction of his law of gravity with the observed motion of the planets. But many of the new rules deal with things we can't touch or see, and some of them plain violate common sense."

"I gave up common sense a few evenings ago," said the old gentleman, chuckling, "with the heavens all bursting apart and those things flying around the earth looking at invisible light. Your new equations and your new gadgets should be very happy together.

But I still don't have any idea of these new rules you've been talking about."

"Let me give some examples," I said. "The ones that come to mind are from physics."

"Fine, but please hold to a slow trot, if you don't mind."

I got up to stoke the fire and pour us some tea. "In the first third of the century," I went on, "physicists discovered a new set of rules, brimful of equations, called quantum mechanics. Quantum mechanics concerns the behavior of atoms, and particles even smaller than atoms. One of the rules amounts to this: a subatomic particle can be at several places at the same time."

"Young man, you're galloping."

"I can't help it. The difficulty is that all our experience with the world is based on objects much larger than atoms. Golf balls and marbles are things you can pick up with your hands. They have edges. They stay where you put them. But as you go to smaller and smaller sizes, matter begins behaving differently. When you get down to atoms and smaller, your whole idea of a solid object falls apart. A particle that size, like an electron, doesn't act like a little sphere with sharp edges marking the boundary between itself and the rest of the world. An electron acts like a haze, a blur covering all places it might be at the moment. If you throw identical marbles with identical aim at a wall, they'll all hit the wall in the same spot. But if you do the same with electrons, they'll hit it in many different spots. That's what the equations of quantum mechanics tell you. And those same equations have made very accurate predictions about many other things that have been measured and verified. So if you have faith in the theory--and physicists these days do--then you have to accept this slippery business with electrons. It goes against common sense, but there it is."

The old gentleman had got up from his chair again. "I'm beginning to get your meaning," he said. "Would you mind giving me some idea of how your physicists go about finding these equations and rules?"

"It's not much like the Babylonian method of trial and error. For many phenomena, we'd never stumble on the right rules that way. There are too many choices. Somehow, we've got to sniff out the trial."

I paused a moment, and Papa Joe took a deep, lingering whiff of the aromas drifting his way from the pipe.

"Simplicity seems the best guide," I continued, "although nobody knows why. Scientists these days are constantly searching for the fewest and simplest rules possible. Two rules for a thing are better than three. A short rule is better than a long one. I know I'm being vague. Let me give an analogy. To scientists, nature is a vast game of chess. They see the board every now and then with their experiments, study what squares the pieces are on, and from this try to figure out the rules of play. At first, they might guess that every piece moves one square at a time, like a pawn. When this doesn't work, they'll try something slightly more elaborate, and so on, but never anything more complicated than the facts require. What's astonishing is that this kind of approach works remarkably well. It seems that nature loves simplicity.

"Take the case of the electron," I went on. "The precise equations for electrons were worked out by Professor Dirac fifty years ago. Now Dirac was a theorist, a pure pencil-and-paper man. I suspect he'd never been under the hood of a car in his life. But he had great faith in this idea of simplicity. So for the electron, he figured out the simplest and prettiest rules possible, consistent with the other rules he already knew. And his rules have held up for fifty years, tested by countless experiments. A more complicated theory would have been wrong. Out of his theory, by the way, came an unexpected prediction of a new kind of particle never before seen, a close cousin of the electron, called a positron. Professor Dirac

wasn't looking for positrons; they just marched out of his equations for electrons. A few years after his prediction, real positrons began turning up in the Lab."

"Remarkable," said Papa Joe.

"There are quite a few stories like that one. With every success, scientists have gotten more sure of themselves. In recent years, physicists have staked their reputations and millions of dollars hunting subatomic particles predicted by their theories."

My great-grandfather whistled softly. "I'd hate to be ruined by a positron that wouldn't come out of the brush," he said. "You know, I reckon it would be easier for me to follow you if I knew more math."

"Well, I'm cutting some corners, it's true," I said. "But you've been keeping up better than I would on something this new."

"What I admire most in these scientists," said Papa Joe, "is how they're willing to trust their equations against common sense. I don't believe I could follow the plans for a house that seemed upside down. That takes faith."

"I agree. You'd want to be darn sure of your architect. And you wouldn't move in right away." We sat for a time without talking, listening to the faint bark of a dog down the street.

"Tell me about some other theories that seem contrary," said the old gentleman.

"You remember the black holes from last night?"

"Yes, They were my favorites."

"Black holes were predicted by Professor Einstein's new theory of gravity. According to the theory, if you went to live near a black hole and then came back to earth, you'd be much younger than if you'd stayed

here. The gravity of the thing slows down time in its vicinity."

"Confound it," shouted the old gentleman. "I'll go along with your fuzzy atoms and particles, whatever they're good for, But time is time. A year is a year, isn't it? I must have misheard you."

"You didn't mishear me, Papa Joe, although I agree that the idea seems preposterous. You see, Professor Einstein's theories propose that the flow of time is not fixed, as it seems. Time depends on motion and on gravity. The effect is tiny unless you're moving at extremely high speeds or being pulled by a very high gravity, and that's why you don't notice it. But sensitive instruments and clocks have verified the effect. It's taken me years to get used to the idea."

"Now that I think of it, I remember a big commotion over one of Einstein's predictions being proved."

I nodded. "You're probably remembering the famous experiment during the solar eclipse of 1919. One of Einstein's theories predicted that light should be attracted by the sun, the way a planet is. The effect is very small, because light travels much faster than planets, but it's there and it's measurable. To test the prediction, you examine some stars just past the edge of the sun. According to Einstein, the starlight should be deflected by the sun on its way to the earth, and the images of the stars should be slightly distorted. Some astronomers did the measurement at the first convenient eclipse, when stars could be seen near the sun, and confirmed the effect. These days, most scientists believe just about every prediction of Einstein's theories. even the ones not yet proved."

"I wonder whether Professor Einstein was bothered by this odd business with time slowing down," said Papa Joe.

"I don't think so," I replied. "From what I can tell, Einstein believed that the new ideas were logical and natural, given certain facts. He had this wonderful

way of starting from scratch, without taking anything for granted. And he never expected to experience all the mysteries of nature with his body. To him, it was pleasure enough to get a mental glimpse now and then, and imagine the rest."

As I got up to stretch, the church clock in town chimed eleven. The old gentleman was back at his spot near the window, looking out at the night. I joined him there. Sirius, the brightest star in the sky, was in easy view, as well as half a dozen constellations--celestial pictures of hunters and serpents and lions and dogs, ancient visions of men and women looking for order.

"You know," said Papa Joe, "I believe your faith is contagious. These last few nights I've felt so tiny I could fit inside an atom, and so big I could step from one star to the next." He paused, staring out the window. "I proposed to your great-grandmother on a night like this." Papa Joe turned and took a long look around the room. "You take care of that pipe."

I stood for a moment beside my great-grandfather, shoulder to shoulder, and then he melted away.

Conversations with Papa Joe appeared serially in "Science 84-86", which was my first introduction to the writings of Alan Lightman. It was a great joy to discover this story as one of many essays in the collection titled, "A Modern Day Yankee In A Connecticut Court". I chose to reproduce "Conversations with Papa Joe" over four months, in its entirety, to treat you to a fine story--but also to a story that teaches some very fundamental ideas about astronomy and how we do astronomy and science. Papa Joe was certainly a likable character--a curious man with a good head on his shoulders.