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News that Inspires

Ed Johnson: Beauty & Science
by Richard Whitaker

The opportunity to interview Ed Johnson, a renowned molecular biologist, appeared almost by chance last year on the occasion of a family get together. To my delight, thanks to an invitation from my brother, John, Ed was there with his wife Becky. Ed and my brother go back over forty years. Both are passionate fly fishermen, and the friendship between fly fishermen is something like a family link. Ed I knew had been Nobel Laureate, Paul Greengard's, first graduate student at Yale and had participated in research integral to Greengard's prize. After receiving his Ph.D. at Yale, Johnson pursued postdoctoral studies at Rockefeller University. Currently he is at Eastern Virginia Medical School where he teaches and runs a research laboratory.
I thought it would be interesting to talk with Johnson, even though I'm not a scientist. I had no idea where our conversation might go, but it came as a surprise that soon creativity, passion and beauty showed up as central themes. Passion, Johnson argues, is the element that makes it possible for a real breakthrough in thought to take place. And beauty, he explained, goes a long way in establishing the bona fides of the results of scientific experiments. Upon his home, he sent me an example of one of his beautiful electron microscopy photographs.

Richard Whittaker: Maybe you could describe briefly your position and a general description of the work you do.

Ed Johnson: I am a molecular biologist and do experiments toward basic molecular understanding of cancer and AIDs. A lot of people don't know that these two are related, but they are very much related because they both take over the cell's DNA replication machinery. The way viruses optimize themselves is very similar to the way that cancer cells evolve to survive in the hostile human environments, basically. I like to think of myself as having quite a passion for what I do.

RW: What do you think the hesitation is when you say that you "like to think of yourself" as having a passion?

EJ: Well, there are a lot of misconceptions that the public has about science and scientists. For one thing, there's hardly ever a good scientist in a movie. Plenty of mad ones. People don't necessarily appreciate the fact that scientists devote not just a great deal of energy in thinking about their problem, but devote a great deal of personal emotion to the problems that they work on. We get involved. I love to recall some words from a lecture that Vladimir Nabokov used to give on Tolstoy. He used to say that Tolstoy wrote with the precision of the artist and the passion of the scientist. Inevitably some person would raise the hand and say, "Sir, didn't you get those reversed?" But, of course, he didn't.
Science is based, to a certain extent, on precision. The definition of science is to make observations in a controlled setting and to put numbers on them. Science's observations are quantified and have to be done in such a way that statistically the results can be

verified by doing them over and over and over again. If I do this, I'm going to get that. Now what if I stretch it a little bit? If I do this, is that going to make a treatment for some disease? So it progresses by leaps, but leaps based on quantifiable, reproducible steps.
Now the conundrum is (it's not really a conundrum, but you have to think about this) whenever a scientist sees a piece of data—and let's face it, today most data is digital; you see a digital photograph of something, okay, that's not a scientific result, that's an observation—but the real ultimate decision of whether or not that piece of data is going to get used is completely subjective!
The scientist must look at that and decide whether or not he thinks it's pretty. By "pretty" I mean it tickles his brain in such a way that it gives him some kind of charge.

RW: Or could you say, "gives him a feeling?"

EJ: Gives him a feeling! A literal, emotional feeling. It's subjective. To put it analytically, you look at your piece of data and you decide whether or not you think it looks pretty. Now there is a lot of scientific precision that goes into this passionate decision.
First of all, the piece of data has to look representative—if you're going to publish it. People are not going to see all of the data. They are going to see this little picture of it. So it has to be representative of what you usually see. Second of all, someone looking at it has to be able to get the feeling that it's something he could do if he followed your instructions.
So I guess the essence of what I'm saying is that when you make this subjective decision about whether to include a particular point of data or a photograph in your results, it has to look pretty, to a certain extent! You have to be ethical about it, too. Now I'm going to become a little more specific and talk about photographs.

RW: Could I interrupt you? We can get back to this, but you've touched on some points I'd like to hear more about. First of all I think it's fascinating that you're talking about the importance of feeling. You say "tickle the brain." I mean this moment must incorporate a knowledge that has many facets. There's a point at which a decision is made. Do you think that there is an intelligence of another order that plays a role in the subjective moment? You're willing to say that feeling plays a role in this?

EJ: Absolutely!

RW: What would you want to say about the role of feeling as such?

EJ: Well, scientifically feeling comes from your brain. It doesn't come from your heart or something else. I personally would not ascribe a higher intelligence to it. That is to say, I'm not a Creationist or somebody who believes in Intelligent Design when I do my experiments. I think it comes from chemical reactions in your brain.

RW: Can we just say that human intelligence is a broader field than what our typical measurements can disclose?

EJ: Oh, human intelligence, right now, can't be explained scientifically! And there's a very good chance that it will never be explained scientifically. The idea of free will in science would seem to contradict the idea that everything is driven by entropy proceeding toward the greatest state of disorder. Free will, in fact life in general, is acting in the opposite direction. So when I say "feeling" I do mean an emotional expression that is inexplicable and that's capable of not necessarily overriding, but certainly driving, intelligence. It's an extra intelligence and I believe it comes from your brain, not from some puppeteer up there.

RW: Let's dispense with the idea of the supernatural. Let's just talk about the human organism.

EJ: Emotions are not, well frankly, they are not scientifically explicable right now.

RW: But there is a point at which a recognition appears.
Would you accept that word?

EJ: Yes. I would.

RW: Recognition. And sometimes it is accompanied by feeling?

EJ: A recognition and a feeling that what you're looking at has something special to it. Even if you can't quite pin down exactly what you want to say about it. You know that this data point has something special about it and it can keep you from going to sleep at night! I wake up having dreams about experiments that I can't quite explain, but I know that they mean something.

RW: So that is fascinating. That recognition. What is it that recognizes?

EJ: Well, I can tell you that among the many really good scientists I've known, virtually all of them have the talent of becoming super-passionate about something that they observe. Okay? I think that is a talent that not all people possess.

RW: Is something in this quality we call passion, that is even necessary to reach a certain capacity to see, or something like that?

EJ: I think you can be a scientist who never thinks very deeply about what you're doing. Certainly, you can't really make an important discovery thinking along that level. You have to have the ability to make a quantum shift from one idea to the next step based on what you see, and you can't do that without getting passionate about it. It has to bother you so much that the leap basically overtakes you. The best scientists do that.
Watson and Crick, the fathers of DNA, they saw the same data that several other people did. They made the shift because, basically, they weren't sleeping at night thinking about this.

RW: And you are passionate.

EJ: I don't mean to equate myself with the very best scientists, but I definitely do get passionate about my experiments! I like to think that they move me to take steps I wouldn't otherwise take, and which are beneficial.

RW: I'm going to quote my brother who goes fishing with you and has known you for forty years. He says that you get hunches. That's the word he uses. My brother says that your hunches tend to pan out. You seem to have an ability, he says, that's uncanny.

EJ: Well, a lot of times they don't pan out! But I am very persistent, and I do follow up on hunches with a great deal of perseverance once they move me to that stage.

RW: What are some of the hunches that have been most important to you?

EJ: With regard to cancer, we discovered a protein that plays a role in many processes including DNA replication. We thought that due to the central importance of this protein—it's extremely evolutionarily conserved—that it must be playing a role our bodies find essential. We found, fairly early on—and this was due to a hunch—that it was deleted in many cases of acute leukemia. So we proceeded, and now I'm going to call a hunch a hypothesis, with the hypothesis that the protein was protective against getting cancer and the loss of this protein would reduce this protection thereby allowing a person to get cancer.

So we followed up on that hunch with a series of experiments. We did find that when you reduce the levels of this protein, which I'm going to call per-alpha, that when that protein is reduced it predisposes that person to developing leukemia. The phenomenon of how that protein is reduced was a major advance that involved a shift in thinking that we made.

RW: When you say "we"…

EJ: Our laboratory.

RW: Okay. What was your role?

EJ: I direct the laboratory and, at the time, there was about a dozen people. All science is teamwork.

RW: So I'm asking for your own moments where you happened to be that person for whom the shift occurred. That has happened for you, right?

EJ: It has, and on a number of occasions. And this one that involves per-alpha in protecting against cancer, and how its reduction leads to cancers, that was a major one, and it still is. I can take a certain amount of credit for that, and there are others as well.

You know, about 4% of all people with AIDS die of a disease called PML, which is a viral infection. It's a virus that infects the brain. If you think world-wide, that's forty million people. Four percent of that is a large number, so it's a major killer. Now this happens to be a virus that 93% of adults have—the JC virus it's called. It's in our kidneys and urine, but we don't get sick at all. People with AIDS get a brain infection.

So there was a moment of thought. Okay? Now most people all over the world would think, well, when the immune system is suppressed, that could allow this virus to pop out. But we wanted to take it a step further. So we examined the records of thousands of people at Mount Sinai, a major hospital I was at, who had immuno-suppression for cancer or transplant surgery, and none of those came up with an autopsy for PML. So it wasn't just simple immuno-suppression. Immuno-suppression was probably involved, but we thought that since the HIV virus infects the brain and this other virus also infects the brain, that the HIV virus might be having a direct effect on the JC virus. So that was a leap. Nobody had ever really tied one virus into directly affecting the course of infection, especially the replication of, another virus. But in a series of about thirty-five papers over the year, we've shown that it really does seem to be the case. That was based on what John Whittaker, your brother, would call a hunch.

RW: Now I believe you were a student of Paul…

EJ: Paul Greengard.

RW: And that was while you were a graduate student at Yale?

EJ: Yes. I was Paul's very first graduate student. He was a new professor at Yale and I was a new graduate student.

RW: And you guys connected pretty well, I take it.

EJ: We did. Paul rapidly built up a very large group. But yes, I had a wonderful relationship with Paul. He was my mentor. He was the first person I really looked up to as a serious research scientist. To this day he still has a passion for experiment.

RW: And you were involved with his work in some ways which eventually was recognized with a Nobel Prize, right?

EJ: That's right. Paul won the Nobel Prize in Physiology or Medicine in the year 2000. I worked with him many years earlier and put my small little grain on the anthill with him there. I look back with a great deal of pride on the work I did in Paul's laboratory. No question. And of course, I'm very proud of Paul, who has had just a stellar career.

RW: Okay. Let's get back that moment where a point of data strikes one as important.

EJ: Let's get specific and talk about photographs. Much of the data coming from my laboratory is in fact photographs of living cells. Now if you do an experiment that involves molecular changes in the cell, there are a number of ways that have been developed over the last few years to record the data photographically. We can tag proteins, that is, put little chemicals on them that fluoresce.

RW: That's a pretty technical thing, I imagine. There must be a lot of proteins to deal with.

EJ: It is indeed a technical thing. But we can tag specific ones. We can label individual proteins in living cells, and we can label individual proteins in cells that have been fixed in a particular moment in time. That cell is now a dead cell, but a fixed one caught in the act of doing what it is doing. You can do this with multiple proteins. You use different colored fluorescent probes and then take photographs of them.

RW: Now you do a lot of that in your lab?

EJ: Yes. In fact, in terms of microscopic techniques, my laboratory has pioneered some and also made technical advances in others. That's allowed us to take some really important photographs.

RW: It occurs to me, and this is a term I wonder how you will feel about it—would you say that craft is an important part of what comes into play in this lab work?

EJ: There is no question about it. When you take any piece of data to prepare it for presentation to your peers, it takes craft. It also takes judgment. And I mentioned that you have to be ethical about it, too.

RW: Would you say something more about the ethics?

EJ: You know, a photograph is a moment in time. You can capture just about anything you want in a moment in time, but it will have no scientific value unless it's representative of the conditions you say existed when you took that photograph. So the number one consideration is that it has to look like "the usual" thing you see when you use those conditions. If it's pretty, but it's not exactly what you usually see, then you're misrepresenting your experiment. That's unethical.

RW: You're describing honesty.

EJ: Honesty. That's common sense, basically. Mind you, no scientist who's any good at all wants to be wrong about something. That's a disaster, scientifically. So you want to make sure you present something that is representative. But now there are several considerations about how you do that. You want to present something that looks pretty and there are some real good scientific reasons for doing that. If you present a photograph of your experiment that's a little bit ugly, your peers are likely to think you didn't repeat that experiment enough times to get a pretty looking result. You have to satisfy your peers.

RW: You're saying that aesthetics, within the scientific community, is equated somehow with validity, or truth or worth. Or is this just an irrational thing?

EJ: No. The emotions are tied up with it, but the other scientists are going to look at your photography, and they are smart. They are going to say, well, look, that co-localization doesn't really show a nice bright color there. It's a bit muddled. Maybe it's not a very good co-localization.

RW: Co-localization means two things in one place, right?

EJ: Two proteins occupying the same space in a particular structure in a cell. The way we do it is that we take a photograph of the cell under red fluorescence, then take an entirely separate photograph under green fluorescence. We do this with con-focal lasers. Then we superimpose these photographs and where the red and green superimpose, we make that appear bright yellow.

RW: And that is the co-localization.

EJ: That's right. But if it's a little muddy and the red and green don't quite go to the same place, then you won't see bright yellow, and it won't look pretty. Your peers will see that and ask, is he really getting co-localization?

RW: So aesthetics is actually used in the judgment of the quality of the data.

EJ: No question. So that when you publish your work the craft involved goes into taking enough photographs so that your superimposition looks really, really sharp. Then you have to make sure that the data are themselves really good. It goes into being really, really careful. You want your result to stand out. You don't want colors outside the cell that would indicate that you got the tags for your proteins all over the place. You want the backgrounds to be sharp and dark, with nothing there. You want your structures to show up brightly against the backgrounds, etc.

RW: Say a little about your own relationship with craft in your career as a scientist.

EJ: I took my first electron micrographs when I was in college. I can even go back further. I made an x-ray machine when I was in high school.

RW: An x-ray machine?

EJ: That's right. I made it with a Ford coil and a cathode ray tube. It made x-rays and, of course, I x-rayed all my old girlfriends. What I didn't realize at the time was that basically I

was subjecting myself, not to mention my subjects, to a great deal of x radiation. Fortunately I didn't use any one subject to any dangerous degree except myself. That's when I was about fourteen, I guess.
Then I took my first electron micrographs just a few years later when I was a freshman in college at Pomona. And when I was in Paul Greengard's lab, electron microscopy was a very important part of my photography, which was of neurons in the brain at that point. And I perfected a technique, while I was at Rockefeller University, of taking photographs of specially stained DNA molecules. There are a few people who do this—not too many, though. We got some really beautiful pictures of DNA replication that are some of the best ones that have been published.

RW: I seem to recall my brother telling me that when you were a student at Pomona you were able to succeed in making some delicate separation of materials for an experiment that even surprised your professor. Does that ring a bell at all?

EJ: I did that a few different times. I did gas chromatic separations of fatty acids from blue green algae that I isolated from Badwater Springs in Death Valley. The idea was to try to culture these blue-green algae in the laboratory and see how they could grow in seven-molar magnesium—because that's an extremely unusual way for an organism to live. So the idea was to isolate the cell wall components, which are lipids. We did that and separated them and detected a number of really unusual fatty acids in the lipids of the walls of this blue-green algae.

RW: So this was a challenge to get that data.

EJ: The real challenge was getting the algae and trying to keep them alive in the laboratory!

RW: It took some craft, I'd guess.

EJ: Absolutely!

RW: How did you do that?

EJ: By trial and error. We did some plain spectrometry on samples of dried salts from Badwater Springs to find out what metals were in the minerals in the springs. Then I had to synthesize, by mixing together all these minerals, a culture broth that the algae would grow in. We got them to grow for a little while that way. I went on to grad school before the algae were permanently propagated, but they were growing and reproducing to a certain extent in this medium. So that was a success, I thought.

RW: Well, I think it's interesting to bring up the subject of craft in the context of science. I guess it's obvious, but I don't recall hearing this word used in the context of science.

EJ: It is though. It is. Scientists are almost universally tinkerers. When it comes to something like growing cells, growing cancer cells, we're constantly trying to improve the methodology. That extends to the point of building new equipment to do certain things. Some of the very best scientists have actually been, although they wouldn't classify themselves as such, very good engineers.

RW: Here's a general question. Your lab turns out a lot of photos. This is visual information.

EJ: And photographs I've taken with my own two hands have appeared on the covers of several different journals. They've appeared in many textbooks, usually without any attribution to me, whatsoever!

RW: How does that work? Who screwed up there?

EJ: People see the publications and they just take the photos and reprint them in their own publications. You'd be surprised. I could cite examples, but I don't want to mention names.

RW: You've decided to tolerate that.

EJ: Well yeah. I'm almost proud of it in some ways [laughs].

RW: No lawsuits.

EJ: No, no.

RW: So when I think of science, I think well, mathematics is very important. In chemistry you've got molecular formulas. You have symbols. And how does the visual language, or the visual mode, work in the world of science?

EJ: The visual is extremely important in terms of the things I do. You can say a picture is worth a thousand words. Well, in science a picture is worth a thousand amino acids sequences! You can present this in very technical terms, but if you can say that these two proteins go to the same place—here, just look at it!
You know, that makes a point a little bit stronger. You can't just present the visual data. The numbers have to back it up. Science is quantification, as I mentioned. If you say, "We saw this," then you should have, somewhere in your publication, "we took five hundred photographs of five thousand nuclei and we saw this four hundred and ninety five times. And the other five times we saw, etc. You need the numbers. But given that, you should present the nicest, prettiest photograph that represents the point you're making, one that will make people want to look at it two or three times.

RW: Let's try on the word "beauty." Is that too high flown a word?

EJ: Absolutely not! I mean, scientific data, even if it's not a photograph, can be positively beautiful! If you read Watson and Crick's Nature paper on the structure of DNA, and you look at that double helix you just sigh, ahhh. That explains it all! You don't have to see a whole lot more than the simple drawing that they presented at the end of their paper about how DNA can replicate. That's all it takes. That's beautiful, and that's not even a photograph. The photograph they got, which is also in the paper— it's x-ray crystallography—that would only be beautiful to a scientist who is familiar with x-ray crystallography. But to scientist, that's beautiful.

RW: I wonder what might you hazard to say, in a larger sense, about beauty?

EJ: Well, I would hazard to say that the presentation and the craft that goes into a good scientific publication is a work of art. I'm sure a lot of people would hate to mix categories in that way. But there's feeling, beauty, craft and a profound ability to move others emotionally in a very important scientific finding.
So harken back to Nabokov again. Mind you, he was quite a scientific thinker, too. He was a butterfly collector, so that's entomology. He did record his observations and he was very

meticulous about it. You may say, well, that's not an experimental scientist, but it's similar to Charles Darwin who recorded his observations meticulously, which then led to a quantum shift in his thinking.
Now when Nabokov spoke of Tolstoy and referred to the precision of the artist, Tolstoy agonized over every word he put down on paper. Nobody was more meticulous than in his descriptions of Anna Karenina. The last moments of her life are utterly incomparable in Russian, and in English.

RW: Do you know Russian?

EJ: Yes, and I've read Tolstoy in Russian. So when Nabokov talks about the passion of scientists, well, I think that a scientist has a passion for beauty that's based on a synthesis of all the different elements he has to put into the presentation of his data. That passion moves the scientists to make the synthetic quantum leaps that take his or her art to the next step.

RW: I want to bring up the question of wonder. Now some people would say that science is a force that sucks the wonder out of life. Other people say…

EJ: I totally disagree.

RW: Okay. Talk about that.

EJ: Science doesn't suck wonder out of anything! Science is revelatory! I mean if you wonder about something, great. Put that wonder into a question and try to figure out how you can do something to answer that question and put numbers on it. All of the sudden you're a scientist. But I don't think science makes anything less wonderful.
I'm willing to speak to Creationism on this issue. Scientists don't disagree with people who believe in a higher order of things. How can we? We don't know about them. On the other hand, when you try to answer questions that give other people on earth some predictive value, like should I take this and is it going to help my cancer? Okay. Then you've got to have experiments done in a controlled setting.

RW: Well you're not seeing art and science at two opposite ends of some spectrum. I think that's interesting.

EJ: I firmly believe that they are not at two opposite ends.

RW: Now I know someone who had a great passion for science as a young man. He followed it up through school until at a certain point, he found it was destroying his sense of wonder. He stopped and went in another direction. I think he feels very strongly that it's necessary for science to keep in touch with some sense of wonder.

EJ: I don't know this person, but I can say that the way science is taught in schools and universities does not easily generate a lot of excitement among certain people who it should be attracting. I mean, if people really do want to experience a sense of wonder, they should definitely have a really good scientific teacher. I was fortunate in that regard.

RW: Getting back to the visual—we live in this world where we have this narrow band in the electromagnetic spectrum that our eyes function with, just this little part…

EJ: You're probably wondering, am I saying that a blind person can't do science?

RW: Not at all. No. I'm on a mystical thing here. I'm saying we see these very small slices of this spectrum and can be moved by the beauty of them. I mean, the spectrum of reality is vast and we are aware only of this small band in it, but even in this small band there is a tremendous richness.
You would agree, would you not, that a photograph that only has reds, greens and yellows can be so rich and so beautiful that it is amazing. Yet it is only a tiny little slice of something much vaster. Do you see where I'm going? I mean this is a mysterious world that we're in.

EJ: I really think that when you're talking about a mystery that excites scientists, philosophers and artists alike, I think the field right now would be consciousness. I mean if there's one thing that will cause a sense of wonderment with any scientist it's how the chemicals in the brain can allow me to say this sentence. You know?
Paul Greengard has contributed as much as anybody in this field, rudimentary as it is right now. My own lab has contributed, too, separate from my work with Paul as to how neurons work.
Nevertheless, we're not even close to beginning to explain how a thought can form, or how one person can make a decision. You're left to go to the Heisenberg uncertainty principle. I mean, if everything is chemically determined, that means that the electrons and the chemicals in our brains have to react in a certain way. When two chemicals to come together, in order for the free energy to allow those two chemicals to react, they're going to do it in one way and only in one way. So it all depends on the state of the electrons, because chemistry is the science of electrons.
But Heisenberg's great, moving insight was that you can't tell the position of the electron at any given time because whatever you do to determine where it is, changes it. So there is an uncertainty about exactly where it is going to be. It ultimately comes down to two chemicals reacting that unmeasurable way multiplied over millions and millions of times. That can account for something like free will. How, nobody has the faintest clue.

RW: Just by chance I happened to be reading an excerpt from Teilhard de Chardin yesterday. He talks about the within of things and the without of things. Science deals with the without of things. For science, consciousness is problematic. It's the within of things.

EJ: It's problematic for everybody! Not just scientists! If anybody can explain consciousness, by all means, I'm willing to listen!

RW: Well, at the time he wrote his books, I don't think there was much going on in science in regard to this question.

EJ: It's still very rudimentary today. But there are people. For example, trying to take photographs of PET scans, Positive Electron Topography scans, of the brain showing different regions thinking at different times when certain questions are asked. Now is that rudimentary, or what?

RW: Well, Chardin said something about depending on the scale at which you look at matter, certain things are apparent. But they are not clear on a different scale. The earth's continents move around clearly if you're looking at them in geological time, but for us, they appear to be fixed. The minerals of nature would seem to be inert, but what about the odd element that is radioactive? What the hell is that? Chardin makes an analogy between radioactivity in the mineral world, and consciousness in the world of organic life. I haven't been able to think very clearly about that, but just on the surface, it has a certain appealing quality to it.

EJ: I agree that it has an appealing quality. The metaphor is that radioactivity is taking physics to its most elementary level. The components of the nucleus of an atom are coming apart, right? You're talking about getting as small as you can possibly get. You're out of chemistry and into nuclear physics.

RW: Well, you've got limestone, basalt, granite, this rock, that one, sand, and then, all of the sudden here's this funny mineral that's doing something really strange! It's sending out vibrations or something!

EJ: Okay. With consciouness. You've got rocks. You've got plants. They're alive. You've got snails. They're alive. Then after a few evolutionary steps, you've got people making sentences. So the question is, is there something elementary in those people making sentences in the way there is something elementary in a radioactive element breaking down?
So there is an analogy there that makes a certain amount of sense. We've come a lot farther toward explaining how an atom does that than we've come with consciousness.

RW: Are you interested yourself, as a scientist, in this question of consciousness?

EJ: Yes, very much so. We've taken some beautiful photographs, as a matter of fact, of nerves in action. And what these photographs purport to show is how chemicals from the centers of the nerve cells go way out into nerve processes to do important things out there where they connect with other nerves. So it's getting at the question of how nerves communicate with each other. We've discovered a protein that moves along these nerve processes and it moves along with RNA molecules of a certain type. It carries those RNA molecules and allows things to happen that will reinforce a thought process—a thought process, being ridiculously defined as two nerves making electrical contact with each other!

RW: Are you at all tempted to hypothesize that there may be some fundamental property of matter, quantum matter, that we would have to say is mysteriously alive, if not exactly sentient? That is, do we know all there is to know about matter?

EJ: Right now anything that is alive is mysterious! There is a sense of wonderment. Everybody should appreciate that and think of living things in terms of what makes them tick. I think it's miraculous. Now I don't use that word lightly, because, as a scientist, I like to try to explain miracles.

RW: But you were saying earlier there's the second law of thermodynamics, which is given such weight, but then there is this other thing, life, which is going in the opposite direction.

EJ: The opposite direction. We're making positive entropy. It's going the opposite way of the second law of thermodynamics. You can say, statistically, it's all going to run down in the long-term scheme of things. You can say that. But you wouldn't have any basis for saying that life and increasing order is not long term, or that it doesn't run backwards in some sense for a long, long time.

RW: Maybe this would be interesting to you. I consider it mysterious that a certain chord on the piano, a few notes, a shift to a minor chord, even a color affects my feelings. Is that a mysterious thing for you?

EJ: It is a mysterious thing to me. Of course, the analogy extends to being moved by looking at scientific data or hearing scientific data. You can hear scientific data.

RW: What do you mean?

EJ: There are experiments that involve listening to certain sounds. The ticking of a Geiger counter or even musical chords. You can’t listen to individual living cells. That would be an interesting thing to try to do.

RW: Do you ever think that some of the early thinkers, Pythagoras, for instance, who speak of the world as based on the octave, or the idea of the world sound, OM. People have had, at certain times, apparently, in certain states of consciousness, perceptions that we can’t quite quantify, but which may be accounts of something real.

EJ: There’s no question. You know science is a very late development. I guess you can trace modern science back to the Greeks with Aristotelean logic, the development of the concept of zero by the Mayans, stuff like that. But scientific thinking by humans, well, some of the greatest, most moving discoveries came before recorded history of any kind. Certainly people were moved on the emotional level to think about things before there was a logic as a language with which to express them. So the early religions definitely served their purpose for providing a language, but more than that, an emotional context in which to put thinking that really moved you. I can imagine people building Stonehenge and looking at the vernal equinox and the sun shining through and being incredibly moved, and then thinking, what a damn good job I did putting those stones just right with my mathematical calculations to get the sun right there like that![laughs]

RW: One last question. You said that some of your co-workers think you spend too much time on your scientific photography.

EJ: I generally take most of the photographs myself. With the electron microscope, I take every one. I can literally spend twelve hours at the microscope staring endlessly at molecules until I get just the right photographs. Then comes the processing part.
Now with the con-focal microscope I direct the team. It frequently takes two or three people working at the same time to actually get a single photograph. Some people do the preparation. Another gets the slide on there. Another person is looking at the computer screen and adjusting it while I am looking into the scope. Then the processing, in which the photographs are made presentable to my peers—I always do that myself. It’s not that I don’t trust other people to do it, but I generally cannot let those pictures just sit there. They have to look just right.
So I do spend hours and hours and hours. It delays publication. And not only that, but in science, you have to pay for your photographs! With a color page, the journal will charge you three thousand dollars for that! Then with the last pictures for publication I took, there were eleven figures. Nine of them were color photographs. So I paid a fortune to have that thing published, but I just couldn’t let those photos go.

RW: Is there a joy in that?

EJ: Oh, yes. Very much so. And I’m very happy to get feedback. You know, “I read your paper. Those photographs are incredible.” I say, thank you, thank you. I don’t say it out loud, but it’s there.