be those who will make a better start for the next civilization. It's not that we have no chance. It's just that we're going through a very severe time of trial.

The other upbeat thing is that I'm quite old. I was a student at the beginning of World War II, and I remember the feelings before the war started. They were so similar to those now. That's why I compare Kyoto with Munich. There were liberal, good intentions everywhere about what could be done. The left said, let's disarm, and then Hitler will see us as no threat, and the right said, no, give him all the arms he needs, and then he will destroy the Communists, or the Communists and the Nazis will destroy each other in a big battle. It was negative, useless talk, but the moment the war actually started, everybody pulled together and made all the sacrifices necessary. They'd even sacrifice their lives. My goodness. The tribal forces pulled them together, and I do hope that the same thing happens again. Remembering my experience as a young man, I realize that it wasn't bad. It was amazing how cheerful people were in spite of their deprivation and how they found it a rather wonderful time to have survived. I think the same will happen again. We have already been through no less than seven events of this kind as humans. Humans have been on earth for one million years, roughly, as a species, and, during that time, there have been seven changes, from glaciations to interglacials, which are comparable in extent to the change in the opposite direction, upwards instead of downwards, which is occurring now. We've survived those changes, which must have been devastating. Just imagine that, fourteen thousand years ago, you lived in a small city civilization somewhere in Southeast Asia. What would you have thought of somebody like me who said, do you realize that in a relatively short time the sea level will be 120 metres higher?

Every Object, Well Contemplated, Changes Who You Are

ARTHUR ZAJONC

Goethe says, "Every object well-contemplated opens a new organ [of perception] in us." You have to live in that world of phenomena. You have to attend carefully. "Every object well-contemplated" — not just casually contemplated, but well contemplated, attended to over time, repeatedly — changes who you are, changes who you are to the point where you begin to see things that you didn't see originally, and perhaps which no one before you has seen.

— Arthur Zajonc

Johann Wolfgang von Goethe died nearly two centuries ago. Arthur Zajonc works at the cutting edge of contemporary quantum physics. But it is great German poet who Zajonc thinks can best show us how we ought to contemplate the puzzling discoveries of modern physics. Many of Goethe's literary contemporaries denounced the science of their time. The English poet John Keats called Isaac Newton's science "a cold philosophy" from whose "mere touch . . . all charms fly." It would, Keats said, "unweave a rainbow" or "clip an angel's wings." Goethe agreed with Keats, but he didn't stop at just criticizing Newton's philosophy. He wanted to show a different way of doing science, an alternative to

the mechanical philosophy that would not unweave a rainbow. "The highest," Goethe wrote, "is to understand that all fact is really theory. The blue of the sky reveals to us the basic law of colour. Search nothing beyond the phenomena, they themselves are the theory."

Arthur Zajonc believes that Goethe's way of knowing points towards what he has hopefully named "the science of the future." We talked about Goethe when I interviewed him at his home near Amherst College in western Massachusetts, where he teaches physics. He told me first that he had been drawn to science as a boy and had believed it would provide an access to the truth of things, but then he was disenchanted.

ARTHUR ZAJONC

This longed-for insight which I thought science would provide for me — and, in particular, physics would provide, through the language of mathematics and experimental science — began to become, you might say, paler. I wasn't getting the full dimensionality, the full picture of what science had seemed to promise. You end up with a more and more abstract and a more and more remote understanding of the natural world around you. The equations begin to feel like they're interposing themselves between you and the natural world, as opposed to only elucidating it and getting you deeper.

While I was studying science and physics, I felt a great longing and, at the same time, a certain disappointment. That was a critical period in my maturation as a scientist, trying to sort out how to understand this science, which I felt had such promise, but which, in the end, was not delivering on that promise.

That launched me, you might say, into a study of the philosophy and the history of science, of the traditions out of which what I was studying in classroom settings actually emerged. When you're studying physics, you just get the latest stuff. You don't actually understand what the context was that produced this. I began reading quite widely in the history and philosophy of science, talking to professors outside of the narrow mainstream of physics instruction, and began to broaden my perspectives. That was an important watershed that took place when I was probably twenty-one or something of that sort.

DAVID CAYLEY

Arthur Zajonc's studies in the history of science put him in touch with inspiring figures such as Michael Faraday, the blacksmith's son who discovered electromagnetism and became, in Zajonc's words, the "greatest experimental scientist of all time." One of Faraday's colleagues, John Tyndall, described him as a man in whom the contemplation of nature produced a spiritual exaltation. "His religious feeling and his science could not be kept apart," Tyndall wrote. "There was an habitual overflow of the one into the other." The encounter with Faraday and others of his kind convinced Zajonc that there was more than one way of doing science.

AZ: You have two strands of scientific inquiry. One, you might say, is the Enlightenment strand, which is a kind of mechanical philosophy and an articulation of science in almost a redeemer role of providing insight and clarity. But there's a second strand which is, you might say, much more in contact with the material experience that Faraday was so excited by, the actual world of phenomena, the world of effects, the lived experience of doing science and discovering scientific insights. Ironically, I think, very often in science instruction, that second strand, the experiential strand, is de-emphasized, and the formal, analytical presentation is emphasized. As a consequence, one receives what I call the "pale version" — this somewhat denatured version of science without the experiential dimension. Every once in a while, there's a lab that you do, but it's pretty cookbook. There's not much in the way of actual originality. Even the phenomena themselves are diminutive. They're not very impressive. Whereas when you're actually looking back into the history of science, the moments of discovery are experiences: Isaac Newton's falling apple. He's looking at the moon. He sees the apple fall. He sees those two disparate phenomena as one effect, as one and the same. He stands before a set of phenomena, and he does the theory, but he does the theory in the original sense of the word "theory": to see or to behold. The formal, analytical treatment which we are taught, or which I teach to my students, comes much after the fact.

When people say science is often off-putting, it's too abstract, it's too hard, it's alienating, it's distancing, I can sympathize. That's

something I actually lived through, and it took a lot of work for me to recontextualize, to bring the philosophical, the actual experiential dimensions back in. Often I had to go outside of the narrow mainstream of science. My studies of Goethe's science, for example, were very much part of that exploration. Here's a person who is known to the West as a poet, the author of *Faust* and other works, not as a scientist, but who spent much of his time, especially in his mature years, working with colour, biology, botany, and the like.

DC: Goethe's studies were carried on outside "the narrow mainstream of science." Hermann von Helmholtz, Goethe's countryman, was typical in his dismissal: Goethe, Helmholtz said, was a poet who focused only on nature's "beautiful show" and ignored the less glamorous backstage machinery that actually produces the show. Even so, Goethe himself remarked late in his life that he thought his scientific work was a greater legacy than his literary efforts. This work began with botanical research that he undertook when he was a minister in the government of the Duke of Weimar, but his scientific thinking really flowered during a trip to Italy in 1786, a trip undertaken to escape the cares of the court at Weimar.

AZ: Basically, Goethe runs away. He just leaves a letter for the duke. He departs under an assumed name at night, and he starts his journey over the Alps. When he comes to Italy, he's stunned by the landscape, and he's stunned especially by the differences in flora and fauna, the plants and animals, especially the plants that he knows from eastern Germany. The plant forms, which he's very familiar with from his own gardens, take on entirely new dimensions, shapes, sizes, textures, scents. It seems as if the context, which he has never really fully appreciated, provides an entirely new possibility for the development and metamorphosis of these plants. He begins to work most energetically at his "theory of metamorphosis" for plants, plant morphology, in this very different domain of experiences, this very different environment: more sun, more water, and so on. These plants flourish in ways he hasn't experienced before. He begins to write letters back to Germany concerning his understandings and his theory of plant metamorphosis.

He comes to a point — I think it's in the gardens of Palermo — where he experiences what he called the *Urpflanze*, the archetypal plant. In it, through all of these different metamorphoses and transformations, he begins to see a principle, as it were, which is eternal or somehow accessible as a defining nature of the plant world. From this experience, he feels he can predict all kinds of new species that are completely plausible, that is to say, which could exist in the world. He actually feels he can, in some ways, internally apprehend or see this, let's call it, "living principle" that stands behind the plant world.

Through a very meticulous study, first in Weimar, then in another whole environment in Italy, he develops a set of capacities in himself to apprehend — in the root sense of the word "theory" again, to see, to behold internally — a kind of living principle. It's not an abstract equation. It's not a genetic code that he's looking at, although some people have suggested he was intuiting something along those lines. No, no, I think it was much more a kind of internal apprehension of a principle which is alive in all the plant world.

That was the kind of work that Goethe did in the sciences. It wasn't work which was formal in the mathematical sense. He wasn't doing theory in the sense in which we use the word today. It was a working through of experience, often systematized through careful studies and sequences of what we would now call experiments, in both the physical sciences and the life sciences, that led him to an apprehension, what he once called an aperçu, by which he grasped that which is implicit as a living principle — in this case, in the plant world.

Then, at the same time he's there [in Italy], he's painting with a group of expatriate German painters, and, as he's painting, he has questions for them, quite interesting ones. He says, in a little essay called "Confessions of the Author," that he wanted to know why they used a particular colour to render the sky or the landscape around them. What determined their colour palette? They indicated that it was the *cognoscenti*, the art critics, that they were trying to please. They followed the style which was in vogue. This really annoyed him. Art should be done according to eternal principles, not according to what happens to be popular in the galleries down in Milan or someplace. This experience sent him on a chase, you could say, on a kind

of inquiry, when he came back to Weimar. He came back with this burning question: what is the truth that's at the heart of the aesthetic use of colour? How is it that, if one were a true artist, one would use colour? He wasn't looking for a pedantic answer, but, as he wandered the ruins of Rome, he said, he could see there a principle which was as eternal and as true as any natural scientific principle. The arts were that objective, in a certain sense. This was an ancient culture and a very different period from his own — the art was very different from the art of his time — but he could see nonetheless that the principles that underlie all art were as true and eternal as the laws of nature. It was disconcerting to him, to say the least, that taste should be capricious, that it should just be what the critics like.

So he goes home, and he tells us that he pulls out an encyclopedia, opens it up to "colour," and finds the wave theory of light and the particle theory of light, and he realizes there's absolutely nothing here for an artist, nothing that's of any use. After some further explorations in the books that he has about him, he says, he was about to give up and just think it's hopeless, there's nothing in science that could benefit him or answer his questions. And then he realized that he had experience. He could refer to the world of colour himself. He could undertake an investigation himself simply by starting to look into the world of colour in a systematic and thorough enough way. Then he would come to insights, to the kind of living principles that are at the heart of that universe of colour, no longer the universe of plants and plant life, metamorphosis, but now whatever that world is, that universe of colour.

DC: Goethe carried on this investigation for more than twenty years, finally publishing his *Theory of Colours* in 1810. The book disputed many of the ideas of Isaac Newton, whose *Opticks* then completely dominated all discussion of the phenomena of light and colour. Goethe differed with Newton on many points. Newton held that light was corpuscular, composed of invisible particles. Goethe stuck to what he could see. Newton believed darkness was merely the absence of light. Goethe treated darkness as an active agent in the production of colour effects. But these factual differences are not what matter most to Arthur

Zajonc. What interests him above all is the two men's different stances. Newton looked behind the appearances while Goethe's approach was completely phenomenological. He described colours as "the deeds and sufferings of light."

AZ: They had very different ways of doing science. Newton was looking for a hypothesis concerning, you could say, the ultimate nature of light and the ultimate nature of colour. Goethe says, right at the beginning of his colour theory, that to expect that one can come to the true nature of anything abstractly — by that, he meant the way Newton was going about things, through theoretical discussions, selective experiments, and similar activities — is hopeless. Rather, what one should do is proceed by way of the history of the effects of light and colour. He gives an analogy. He says, to tell me about the nature of a person abstractly — and by that, I would say, something like what his IQ is, his height and weight, his personality . . .

DC: He's an introvert, an extrovert — that kind of description?

AZ: That kind of description . . . is a very pale and diminished description of that person. Tell me how he walks, his manner of speaking, the way he dresses, his interactions with others, and I immediately form a picture of his character. You can just feel the novelist or the playwright in him in that moment. A playwright can't, prior to the play or in the cast list, give the character types for all his characters. They simply appear on stage, and within the first five or ten minutes, if he's a competent playwright, each one of the characters is fully before you. You know who they are. You see into their souls, but you see into their souls through what they do, how they speak, what their mannerisms are, the way they dress, and all the rest. Goethe felt that this is the way one discovered the truth about the nature of reality, about the nature of the material and living world around us. It was not through an abstract description of personality types or something equivalent but through actually studying the effects, the performance of nature, and one encounters that through experiment, through observation. So one should do the same thing with this world of colour, and then you

will infer, you will intuit, again, the kind of living principle that's at the heart of this domain of inquiry.

Now, Newton, by contrast, modelled his way of investigation on geometry and the proofs of geometry. His *Opticks* is set up in the format of axioms, postulates, theorems, and the like, and then he introduces certain kinds of experiments to support particulars of his theory. Goethe felt this was contrived. In other words, they weren't insights borne out of experience; they were hypotheses that were proposed prior to experience or on the basis of very limited experience, and then selected experiments were brought forward in support. One ended up with not so much an intuited core, a living principle, to which one was working through the phenomena themselves. Instead, one replaced that living principle by a model or what was called in those days a hypothesis. Then that model or hypothesis began to dominate. It took over your thinking. No longer did you experience a person as a person or nature as nature, you experienced them in terms of the models. The genetic code would be a contemporary example. All of the mind is to be encountered in the neuroscience of the brain. We have biomedical models and we have physical models and so forth today in abundance, and they become instantiated into the world. They become reified or made concrete. "Misplaced concreteness" is one of the great problems, Whitehead says concerning these models. We concretize them in ways which are problematic. The models themselves are innocent. As long as we have multiple models — and often contradictory models, as we discover we often need to have in things like quantum mechanics — we can see that the model is, in large part, an indication of our own mentality as much as it is a statement about the state of the world around us.

We fall in love with our models, and we practise then a kind of idolatry; the model becomes an idol. The idol, we forget, is just a pointer to something beyond, which is the living principle. We fall in love with the idol, and science becomes the practice of idolatry. Now, real scientists break through these idols again and again and again historically, so that's what you find in the history and philosophy of science: there's a realization, oh, my gosh, this is as much a picture of me as it is a picture of the world. Let me look at it differently. Let me get a different insight. Then a new model emerges, one which gives complementary

insights into that same domain. And so the multiplication of models, even conflicting models, I think, is a great boon to science. The idea that you're going to find a single model which will somehow give an account of everything is hubris and, I think, a deception.

Goethe's style, you could say, the way his science differed from Newton's science, was that he rejected that kind of enterprise. What he does doesn't look like science in many ways, but if you look at the actual practice that he undertakes, it is faithful to the core principles of science, namely, it's empirically grounded, it proceeds from one methodical experience to the next, and it comes to a kind of insight, a moment of aperçu, of discovery. Goethe will not translate this into a mathematical form but will allow it to live as fresh experience. Then he will seek to apply it in various domains, in his own case very often in an artistic way.

Now, one last comment, because for me it's important: I think all good science — that is, original science — actually proceeds in the way Goethe describes . . .

DC: Including Newton?

AZ: . . . including Newton, in that, when Newton sees the apple's fall as the same as the moon's going overhead, he is seeing something. He's not writing down any equations. That comes later. He is living into the phenomena the way Goethe was living into the phenomena, and he's driven to it, interestingly enough, because there's a plague going on in Cambridge. He has to be back home with his mother in Lincolnshire, and while he's there, he has his two years of miraculous discovery — the so-called *anni mirabiles* — the two miraculous years in which everything happens. He is, in some sense, thrown back on his own resources, and he's thinking and observing, and he's pondering the questions of celestial motion, terrestrial motion, and their relationships. Thus he sees the celestial motion of the moon going overhead as the apple falling. To see the union of those two is an original insight. Then he develops the calculus in order to prove to himself that, yes, this is mathematically supportable. He creates all kinds of other methods of scientific investigation to support that, but the original insight

takes place in a way that Goethe describes, I think, quite beautifully, the way that was, for Goethe, the heart of everything. That's what he was interested in. It was the artistic act, the creative act. He's not particularly interested in the explication, the theorization and so forth, of that insight.

DC: Mathematics is a way of recreating or remembering an experience. It's an important difference between Newton and Goethe that Newton had this ability; he invented a whole branch of mathematics, while Goethe did not. Zajonc knows mathematics, but he warns that mathematics can have its dangers.

AZ: There are two sides to the work that mathematics brings into science. Let's speak first about what you might call the positive and, perhaps, the beautiful side of what it brings. It brings on the one hand the kind of pristine clarity and lucidity which we all, all physicists, just delight in. It's just part of the pleasure of the discipline.

It also brings, surprisingly, a kind of unearned or undeserved power. By that I mean that sometimes you find yourself being led by the hand of mathematics further than you've gone yourself. I've been speaking about these insights, these aperçus, these moments of perception, and then about how you can mathematize those in part. However, sometimes, after having mathematized that insight, you find implications in the mathematics — something which you did not notice originally. In other words, the mathematics becomes generative. You begin to explore the mathematics, and you realize, oh, but there's another layer to this, one which I didn't notice phenomenologically. The power of the mathematics itself allows me to develop my insight further than I would have otherwise. This is probably nowhere more explicit than in quantum mechanics. Most eminent physicists agree that quantum mechanical systems defy understanding, in the conventional sense of understanding, in the way we normally understand physical systems. The eminent physicist Richard Feynman once said that people who think they understand quantum mechanics have rocks in their heads. He could do the mathematics — dead easy — but understanding quantum mechanics defied even his brilliance. In other words, mathematics

provides for you a set of tools and methods which allows you to be, in some sense, more powerful, more insightful in the world than you actually are.

These are the two aspects of mathematics. On the one hand, mathematics can clarify and codify our insights and even allow us to explore and extend our understandings beyond our original insights. It leads us further. But there's another aspect which is also important to hold up: through the fact that mathematics is so centrally important in physics, it becomes the dominant form of modelling. You take a world which is complex, rich, textured, nuanced, infinitely contradictory, and you simplify and idealize and abstract that world into a form which is clear and lucid and unambiguous. In a certain sense, in that moment, you've also denatured it. You've taken away the multi-dimensionality of that world for a single dimension or for two dimensions. You can use those insights gained through clarification and simplification to great effect, but the danger, as with all models, is that they become idols. They become everything, and then everything is seen from that single viewpoint. It's that one monochromatic, blinkered eye that you see through. You see well, but you see only in one direction, one dimension, whereas nature provides itself with an infinite variety, infinite dimensionality. We have to be careful not to fall so in love with our own creation that we blind ourselves to all those other dimensions or think of them only as mere derivatives of that fundamental equation.

I think if one is self-conscious — and this is where the philosophy and history of science help us — if we're self-conscious about what it is we're doing, the tools we're using, the limitations of those tools, the fact that they don't merit being universalized and totalized, then the model is an aid to us. We should multiply the models again, find the ones that are contradictory, delight in the contradictions, and realize that the world is infinitely complex.

DC: Through his explorations in the history and philosophy of science, and in Goethe's work in particular, Arthur Zajonc restored his faith in science as a vivid experience of an inexhaustible reality. Models and formulas, he realized, stand between us and the world only when they become idols, only when we mistake the map for the territory. The

contrast between Newton and Goethe was not the only thing drawing him to this conclusion. There was also the more recent history of his own field, physics. Beginning in the early twentieth century, physics had begun to reach into domains where no single model seemed to apply and philosophical puzzles proliferated. There was Einstein's theory of relativity, with its revelation that space and time are relationships and not independent realities. And then there was quantum mechanics, his specialty, in which matter itself seemed to decompose.

AZ: You could say that relativity theory has to do with undermining our conventional understandings of the space and time in which events and processes unfold, in which those objects have a life. Now, you say, let's look at the objects themselves, not just the space in which they happen to be moving around, which has already now gotten very interesting because of Einstein. Let's look at the objects themselves. What are they? What is an object? How does it come into existence? What is it made of? Well, what we know is that it's made of molecules, and the molecules are made of atoms, and the atoms are made of electrons, protons, and neutrons, and the protons and neutrons are made of quarks that are bound together by gluons, and so on, right? We tell a little story that goes all the way down. But then you ask, what are these fundamental constituents that we now have? Take the simplest example, the electron. It's a fundamental particle. We think it's not made of anything else. In other words, there's nothing like a sub-electron. So you ask the simplest of all questions: how big is it? After all, if the universe is made of spatially extended objects, things that have size, then the fundamental particles must be like bricks. You're going to stack them up, one on top of the other. An extended universe must be made of extended objects. So how big are the fundamental particles? Well, the answer is zero. They have no size. They have a location. They have a mass. They carry charge. Yet they have no size. They are point particles, as far as we can tell. Wrap your head around that. This great world of extended objects, you and me included, boils down to a set of things — for lack of a better word at this moment . . .

DC: . . . which aren't things at all . . .

AZ: . . . which aren't things at all, which aren't things at all. These point particles, though, have relationships to one another, that is, force relationships of attraction and repulsion, so they can configure themselves. Thus you have, as it were, nonentities which actually have attributes, attributes like mass and charge. They have no size, but they have a location. They are in relationships, but those attributes and relationships are also not simple. I'm still talking at this level about a kind of building-block universe, where the building blocks have gotten infinitely small, but now I have to explain that those properties which I said they have are no longer simple. They are quantum attributes, which means that that they don't have definite values. Think of an attribute. You have a certain height, you have a certain eye colour, you have a certain set of biometrics by which the immigration and naturalization people will be able to identify you when you come into the US. All those things are definites, and it's by those definites, that sequence of attributes, that we know each other.

But what if those attributes were ambiguous, not just ambiguous because I didn't know them, but fundamentally ambiguous? What if you had two heights, if you had two eye colours, if everything was in what we call in quantum physics "the coherent superposition state"? That is to say, it is both this and that. It's some kind of new relationship which is non-classical, which can't be thought of in a conventional way — it's not that you have one eye which is blue and one eye which is brown — but there's a kind of ambiguity concerning your eye colour such that, if I measure your eye colour, it comes up blue on one occasion and it comes up brown on another, but if I don't measure your eye colour, it has its own ambiguous — we say "superposed" — state, which I can make use of. It's not just ignorance concerning eye colour. It's actually a positive attribute. The ambiguity is a definite attribute or state of affairs which allows me to do certain experiments and which nowadays, with the advent of something called quantum computation, even allows me to build certain kinds of new machines which live off this ambiguity at the fundamental level, at the nature of substance. Not only have I disappeared the large-scale universe down to zero points, point-like particles, which are now in new kinds of relationships, but the very properties which we normally think of as inherent in these point-like

particles are themselves in states which are quantum mechanical or ambiguous. Quantum mechanical and ambiguous, again, not in the sense that they're not known, but in the positive sense that our minds are not actually competent to understand them. Our mathematics are competent, our experiments are competent, we're driven to this conclusion, but to wrap our minds around this new state of affairs has proven essentially impossible. Niels Bohr felt it would always be impossible. When Feynman said that people who think they understand quantum mechanics have rocks in their heads, that's what he means. He says, we can do the math, we can do the experiments, we can build the quantum mechanical machines, we can sell them in the marketplace. Can we understand them in the way we understand the clockwork universe? No, because it is not clockwork. These new kinds of attributes, these quantum superposition states and so forth, require a new mentality.

DC: The fundamental ambiguity that Zajonc is talking about here is most easily illustrated by the nature of light. Light manifests as either a wave or a particle, depending on how the measurement is taken. Unmeasured light seems to have both characters at once — what he calls the coherent superposition state — and there simply is no unambiguous way to describe this state of affairs.

AZ: When we speak of light as having both a wave nature and a particle nature, these are two kinds of concepts. These are two concepts of the nature of reality — wave nature, particle nature — that are contradictory; you can't entertain them both at the same time. Something either has a particle character or it has a wave character. Each of them is well defined in its own right, but together they are contradictory. Niels Bohr called this feature of the new physics "complementarity." We are driven to have both concepts. We need both. These are the two models, if you will, in the language we were using before. These two models are both required, but they are contradictory, so we speak about them as complementary, and the principle of complementarity prevails.

DC: Quantum mechanics cannot circumscribe the reality it studies within a single description. It has to use multiple models, contradictory

models. This inevitability of contradiction has led some physicists to say that we will never get to the bottom of things, but this is not Zajonc's view. He applies Goethe's maxim: "Every object well contemplated opens a new organ of perception in us." Yet isn't Goethe talking about the everyday world of visible, tangible things? Can his insight really be applied in the completely imperceptible realm of quantum effects? Zajonc's answer is a qualified yes.

AZ: Goethe is advocating for a phenomenology, and in quantum mechanics you're entering into a domain where essentially there are no phenomena, at least no phenomena that are visible to the eye or to the normal five senses, which was Goethe's whole locus. Goethe had particular reasons for being concerned with sensible things, aesthetic reasons. He was interested in the aesthetic use of colour, so he wanted to know what people's experience of colour was. It was no good for him to say, red corresponds to 600 nanometres. Can you experience 600 nanometres? What does it feel like to experience it? It doesn't feel like anything, so the measurement has no aesthetic value. He needed a form of exploration and a kind of science which was close to human experience. His questions were aesthetic and, in a certain sense, moral. He calls this combination *sittlich*, the "moral" use of colour, but it's both aesthetic and moral. By moral, he means to refer not so much to good and bad as to more emotive and affective responses — the psychological dimensions of colour. That was his orientation.

Now, you're moving, through technology, across a threshold. At some point, let's say in an experiment involving a single photon, you're beyond phenomena. You still have effects. These effects are registered by very specialized devices, gathered together over time in computers, and represented through mathematical methods and charts and graphs and the like; then we interpret them. But it's all by inference. These are two different worlds.

I kept thinking about this issue, and recently I wrote a book, together with a colleague, George Greenstein, called *The Quantum Challenge*. In that book, I basically give my response to the question, what would a Goethean quantum mechanical theory look like? How do you do quantum mechanics from a Goethean perspective? What I

try to do in that book is to lay out a series of experiments. These are real experiments — they're not just thought experiments or abstract mathematics. Each one of them is designed to bring you as close as you can get to an experimental result which is, in Goethe's language, an archetypal phenomenon, except in this case there are no phenomena. You have archetypal *results*. You have to imagine your way across the threshold that divides the perceptible from the imperceptible. You no longer use direct perception, but the experimental apparatus is as simple as it can possibly be and still work. We've tried to clear away debris and minimize the inessentials so you just have the most clearly articulated, contemporary example of each of the primary concepts of quantum mechanics laid out. No one had ever done that. Previous presentations had all been more theoretical and cobbled together from thought experiments. The book has gotten quite a bit of appreciation because what teachers are able to do is lead students, step by step, experiment by experiment, through these archetypal moments. They're no longer archetypal phenomena in Goethe's classic sense, but they are archetypal experiments.

What does it mean? This is an interesting question. What is different for having sacrificed the direct experience of the phenomenon? When you look at a red colour or at a painting in a gallery, you have an inner response. There is a felt reaction, not only intellectual engagement but also a full, multi-sensory, internal response that is part of the phenomenal experience — very important. As you cross over into these more abstract realms of experience, that inner, lived response is diminished and replaced by a kind of pure intellectual response. I think that's an important threshold, a crossover.

You could say that many of our modern technologies do that for us. I grew up with my head under the hood of a car, fixing the engine. It's a lived experience. You actually get your hands dirty. You get grease on your fingertips, and the smells are there, and there's the joy of getting it to work and getting it to work better and faster and all that stuff. It's actually already different with electronics, especially modern electronics. It doesn't smell like much anymore. It doesn't feel like much anymore. There's no kind of visceral response. Increasingly, our technologies have that character. They provide us with services, but

getting inside your cellphone is a hard thing to do. Whereas when I was twelve, my dad brought home a set of phones, and I took them apart and put them together, and I understood how they worked, basically. Now? Forget it.

We're in a space and time where we're surrounded increasingly by domains which are obscure to us, which are hidden from us, hidden not just because we're stupid but hidden from us almost absolutely. Perhaps what's lost there, and what's maybe of importance, is, again, the aesthetic and moral dimension. As long as you're coupled into the sensual domain, the aesthetic dimension, the moral dimension is also present with you. When you move across into the world of equations, abstract vector spaces and the like, which we inhabit when we're talking about quantum mechanics, the only aesthetics are the abstract aesthetics that apply to high mathematics. There's none of the sensuality. You're missing the aesthetic dimension that you have in the lived experience of colour, scent, sound, and so forth.

You can ask yourself, is anything endangered in that transition? If we inhabit a world which is that abstract, which is that disconnected from body, how do we make moral judgments? How do we make aesthetic judgments unless we import them from another domain of life, unless we bring them along with us? I think some of that comes up with the Manhattan Project and with the genetic technologies that we currently have. They're disconnected from lived experience. How do you live your way into the calculations that stand behind the atomic bomb until the thing goes off? Then, all of a sudden, you realize what you did. In my view, we confront that increasingly: our technologies, our insights outstrip our moral development in part because we've disconnected our technologies and insights from the body, from sensual experience. It's a characteristic of the new science. It started in physics, but it's making its way into molecular biology and now into neuroscience. As we increasingly rarefy and make more abstract these domains of discourse, these domains of exploration, they become disjunct, disconnected from the normal grounds by which we judge the aesthetic and moral dimensions of life. Consequently, we need to re-embed those discoveries somehow back into our lives. But we need to do so consciously. It's not just part of our nature. It doesn't just come naturally anymore because

we're beyond nature in a certain sense. We've extended nature into a domain where our normal equipment isn't sufficient.

I was asking before, do we have the concepts to understand relativity and quantum mechanics? One can ask as well, do we have the moral competencies to handle them? It's not just our intellectual concepts that are at a loss, that we're having to retool. We're also trying to develop moral capacities and aesthetic capacities that can, in some sense, re-embed these new dimensions of science that emerged first in the discoveries of quantum mechanics, relativity, atomic weaponry, and so forth and that now are equally advanced in molecular biology, genetics, and neuroscience.

DC: New technologies and new realms of scientific exploration take us beyond the body and into domains where we lack any moral or aesthetic grounding. This is why Zajonc keeps returning to Goethe. Quantum mechanics can make us wonderfully aware of certain deficiencies in our understanding, but only contemplation can make us whole.

AZ: I come back to Goethe. To me, these two were knit together in my biography. Quantum mechanics does one whole piece of the work — it raises wonderful puzzles, it points out many of the shortcomings in our classical understanding — but it doesn't do all the work. We can't rely on it to do everything. The other piece of the work, which Goethe brings, is a return, again and again, to human experience and the possibility of developing that experience beyond our current horizon. Our current horizon, that is to say, is nothing more than the limitations of our own capacities, and, he says, "Contemplate well and new capacities will open." If we are in a new terrain, a terrain which is posing these deep mysteries concerning the ultimate nature of reality, pay attention, contemplate well.

Another part of my life has been that world of contemplating well — the contemplative life. Parallel with the time that I'm talking about when I was studying Goethe, I was also reading in the mystical and spiritual traditions. Goethe's language, his language of contemplating well, resonates, to me, with the best of those traditions, which are not really traditions about metaphysics so much as about experience. I think

we can leave aside our pre-commitments due to religious traditions As valuable and as important as they may be individually, they tend to separate us.

Our traditions have their place, and their honourable place, in world history, whether we're Christian or Jewish or Muslim or Buddhist or whatever. But we can also proceed scientifically, and science, at root is grounded completely in experience. It's an empirical endeavour. Is it possible to broaden the range of that experience, and, if so, how? The methods I have found most valuable in that regard are the contemplative methods. Increasingly in my teaching, and in my writing and so forth I weave those dimensions into my work. My work with the Dalai Lama in the *Mind and Life Dialogues* joins both of those strands. We're really working hard to look at the nature of reality from both a scientific standpoint and a Buddhist, philosophical standpoint. As the Dalai Lama says — and I agree with this — the more understanding we have concerning our own nature and the nature of the world in which we live, the better is our chance of mitigating suffering, because often our actions are based on delusions, are based on reifications that arise from our own thinking, our own very narrow-minded and parochial thinking. If we can get outside the box, get outside of that thinking and begin to appreciate the context in which we have been living up until now and change that context, change the way we think, then we can reduce the attachments, we can reduce the suffering that we endure ourselves and that we inflict on others. This is not only an intellectual enterprise. It's actually an act of loving compassion to become clear, to become honest about the world in which we are.

It's not good enough to just work your way through these problems intellectually. You have to change who you are, and the way you change who you are is through contemplation, through contemplative practice. I've been working for ten years or so with several hundred or a thousand other faculty in universities around the United States and Canada to bring that kind of message to students and to say, listen. On the one side, there is a pedagogy of information, where you need to know certain things. On the other side there's a pedagogy of transformation and that transformation takes place at the hand of reflection, takes place at the hand of contemplating well. What are the methods? Some

of the methods are drawn out of Goethe and out of William James and his philosophy of experience and radical empiricism. Some of them are drawn out of the contemplative traditions of Asia and the West. Buddhism and [Rudolf] Steiner are two main sources for me. These are traditions which I think can be enfolded into a sensible pedagogy for young adults and beyond, and which ultimately extend our horizon and do so in a way which is honouring the scientific tradition, which has rooted itself throughout in experience and reason. We want the same in this more expansive understanding of our own capacities. We can expand those capacities through reflection and contemplation so that experience is broadened, and we can bring reason, not only reason which is familiar to us, but maybe even a new kind of reason which can take up these quantum challenges, take up the new experiences that we gain at the hand of introspection and reflection. It's a new kind of thinking joined also to an enlarged domain of experience.

What Needs to Be Subtracted

WENDELL BERRY

The standard of science must be nature, insofar as nature contains us, comprehends us, and ultimately judges our behaviour.

— Wendell Berry

Wendell Berry is known to the reading public mainly for his poems, essays, and novels, not his commentaries on science. However, in the year 2000 he published a surprising book called *Life Is a Miracle: An Essay Against Modern Superstition*. The superstition the book denounces is the belief that science will one day give us a complete account of things. Science is admirable, he argues, but it can only be deployed wisely when we recognize the limits to our knowledge. Science must submit to the judgment of nature.

Berry's first encounter with the misuse of science was in agriculture. For more than forty years, along with his writing, he has worked a hill farm in the part of Kentucky where he was raised and where his family has farmed for generations. During that time, he has watched the end stages of what he has named "the unsettling of America" — larger, less diversified farms, fewer, more indebted farmers, degradation of land, rural communities broken and scattered. And he has seen the