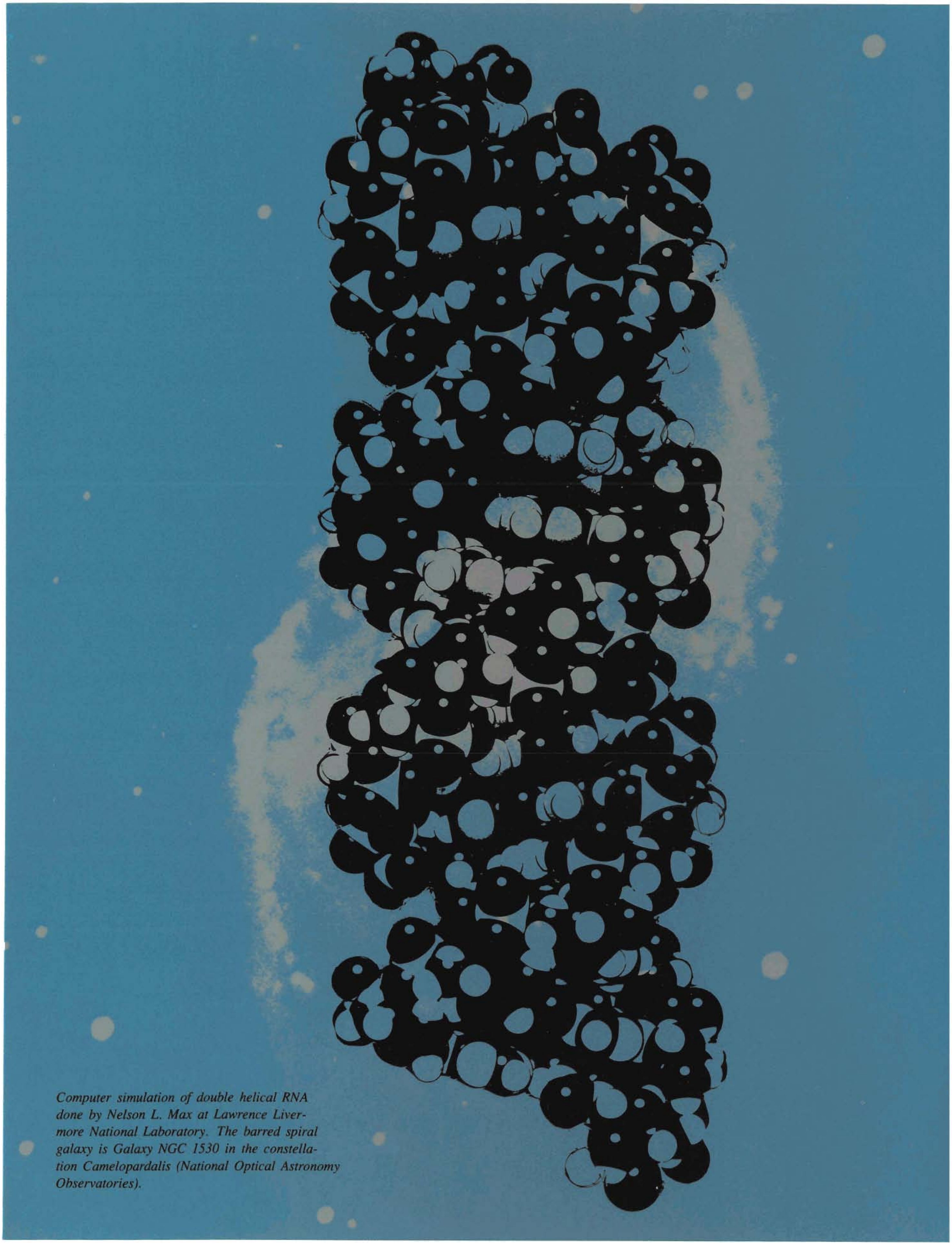

Computer simulation of double helical RNA done by Nelson L. Max at Lawrence Livermore National Laboratory. The barred spiral galaxy is Galaxy NGC 1530 in the constellation Camelopardalis (National Optical Astronomy Observatories).

Cosmology of Life and Mind

by George Wald

I am coming toward the end of my life as a scientist facing two great problems. Both are rooted in science, and I think I approach both as only a scientist would. Yet I also think that both problems are irrevocably unassimilable as science. That is not strange, because one involves cosmology and the other consciousness. I will begin with the cosmology.

We have realized for some time that we live in a *historical* universe, one in which not only living organisms but stars and galaxies are born, mature, grow old, and die. There is good reason to believe the universe to be permeated with life—a universe in which life arises, given enough time, *wherever* the conditions exist that make life possible.

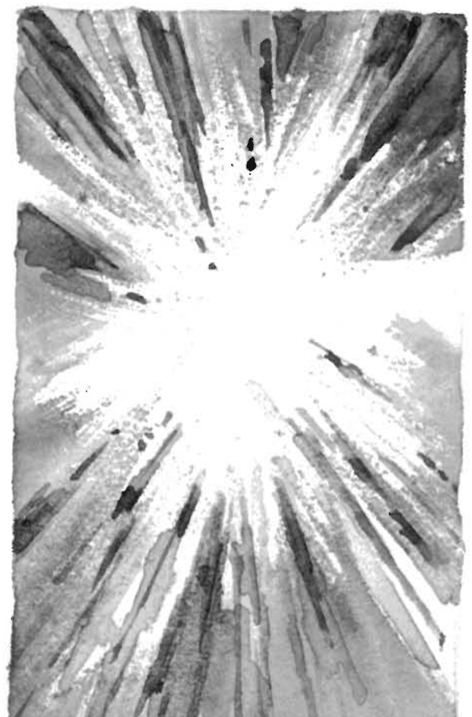
How many such places are there? I like Arthur Eddington's old dictum: 10^{11}, or a hundred billion, stars make a galaxy, 10^{11} galaxies make a universe. Our own galaxy, the Milky Way, has about 10^{11} stars. With the earth nearing five billion people, a lot of us are feeling crowded—but a hundred billion stars are in the Milky Way. It is a vast thing: light, traveling at 186,000 miles per second, takes about 100,000 years to cross it from edge to edge. Yet vast though it is, the Milky Way is just a tiny spot in the universe we know. The lowest reasonable estimate of the fraction of stars in the Milky Way with a planet that could support life is 1 per cent, or a billion such places just in the Milky Way. With a billion such galaxies already in view of our telescopes, the lowest estimate of the number of places in the known universe that could support life is on the order of one billion billion, or 10^{18}.

My main theme is that if *any* of a large and increasingly recognized number of physical properties of this universe were different from what it is, life, which seems so prevalent, would be impossible, here or anywhere. I will outline a skeleton of this argument and give it structure by climbing the scale of the states of organization of matter. So I start with the elementary particles.

For the most part, our universe is made of four kinds of elementary particles: neutrons, protons, electrons, and particles of radiation called photons. (I leave out neutrinos, which interact only negligibly with matter, and also the hundreds of particles that come out of high-energy nuclear reactions.) The first three—protons, electrons, and neutrons—exist not only as particles but as antiparticles. The particles constitute matter; the antiparticles antimatter. If one looks at objects far out in the universe, one cannot be sure whether they are made of matter or antimatter, for all our information arrives via radiation, and photons do not differentiate. They are, as we say, their own antiparticles.

Why do we have a universe of matter at all? In 1952 I was giving the Vanuxem Lectures at Princeton University on the origins of life and biochemical evolution. Albert Einstein, whom I had come to know, was walking with me before the first lecture and asked, "Why do you think the natural amino acids are all left-handed?" As you know, all amino acids except the simplest, glycine, exist in two geometries that are mirror images of each other—like right and left hands. However, all the *natural* amino acids happen to be left-handed. Einstein went on to say, "I have wondered for years how the electron came out to be negative. Negative and positive are perfectly symmetrical principles in physics, so why is the electron negative?" All I could think of was: the negative electron won in the fight. I said, "That is exactly what I think of those left-handed amino acids—they won in the fight." But he was talking about a different fight—the fight between matter and antimatter. As he said, these types of matter are perfectly symmetrical. Thus, the neatest idea of what went into the big bang at the start of the known universe were equal amounts of matter and antimatter.

In the fantastic compression of the initial stages of the big bang, there must have been a wild fire storm. Whenever a particle of matter contacts its antimatter partner, mutual annihilation results and the masses of both particles are converted to radiation. Thus, at the end of the big bang there should have been a universe of radiation with *neither* matter nor antimatter. In fact, Arno Penzias and Robert Wilson of Bell Laboratories discovered a background of microwave radiation filling the universe that comes equally from all directions and is thought to be the residue of the fire storm in the big bang. The radiation is identical with the radiation that would come off a black body, say a piece of black iron, at the very cold temperature of 2.8 degrees above absolute zero, or approximately −270 degrees centigrade.



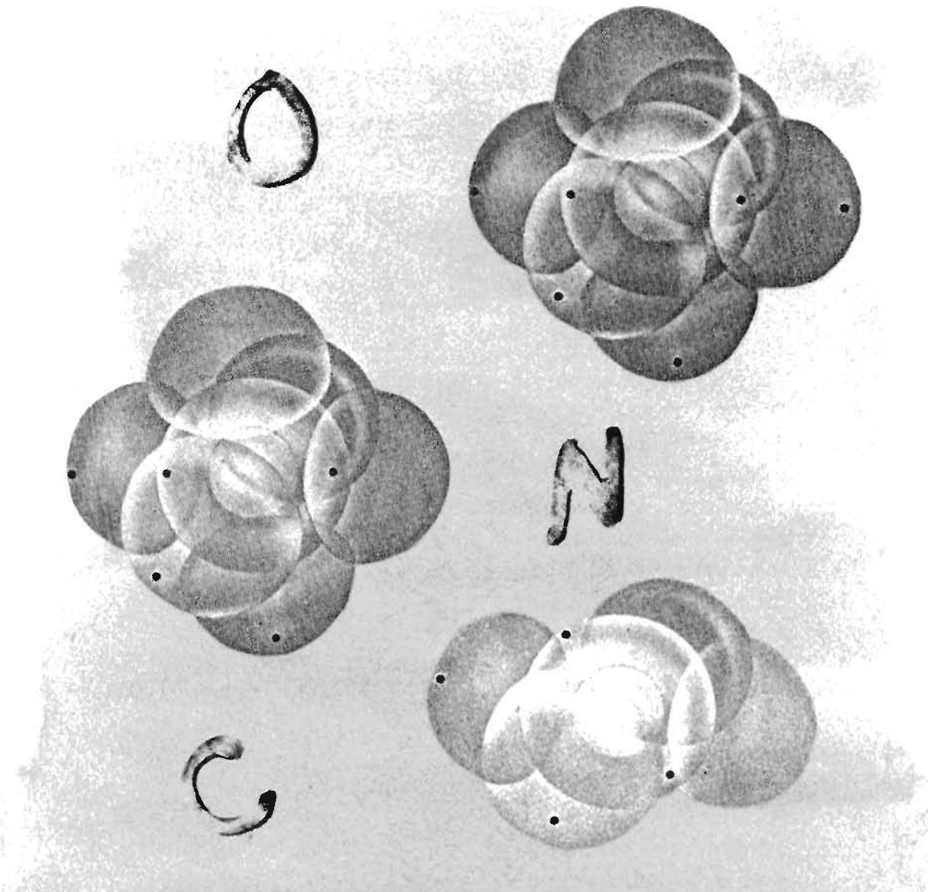
At the end of the big bang, there should have been a universe of radiation with neither matter nor antimatter.

One now realizes there are roughly a billion times as many photons of that residual radiation moving around in the universe as there are particles with mass. So we have to modify our neat idea to include a little discrepancy, a little mistake if you will: for every billion parts of antimatter involved in the big bang there were one billion and one parts of matter. Thus, when the fire storm of mutual annihilation had exhausted itself, one part in one billion of matter was left over. This residue constitutes the matter of our universe, that is, the galaxies and stars and planets and us. This little one part per billion mistake is the first element in my story.

Now how is it that we find ourselves in a universe well supplied with protons and electrons as well as neutrons? The reason is that free neutrons—neutrons outside of atomic nuclei and outside of highly dense neutron stars—disintegrate with a half life of 10.6 minutes into an electron, a proton, and radiation. If you start with a collection of free neutrons, ten minutes later half are still neutrons, but the other half is everything else you need to make a universe like ours.

Why does the reaction go in that direction? Only because a neutron is a tiny bit more massive than a proton plus an electron. Any such reaction has to go in the direction of lower mass. But the loss of mass in this case is less than one part in a thousand—in fact, eight parts in ten thousand. But what if the reaction went the other way? If it did, we would be in a universe of neutrons. The neutrons would have long since mopped up all the protons and electrons, and we would not have the chemical elements, molecules, new radiation, or, of course, life. Another small but vital discrepancy.

We need to consider two further properties of elementary particles: their masses and electric charges. The



A strange attribute critical to the properties of carbon, nitrogen, and oxygen is the fact that these are the only elements that form real double and triple chemical bonds.

nuclei of all atoms are made of protons and neutrons, which are heavy particles—each almost two thousand times the mass of an electron. The result is that almost the entire mass of an atom is concentrated in a nucleus that holds its position no matter what the electrons roaming around the periphery are doing. This fact is very important because it is the reason anything stays put in the universe. What would our universe be like if the nuclear particles and the electrons were somewhat closer together in mass? The motions of any one particle would produce reciprocal motions in the others; they would revolve around each other, and all matter would be fluid, none would be solid. Could indeed such atoms form stable bonds? You would not have molecules whose shapes you could draw with great confidence. This fact is critical because the shape of a molecule—the way one molecule fits into another—means everything in living organisms.

Here is another extraordinary circumstance. Although there is an enormous difference in mass between the proton and electron—one thousand eight hundred forty times—the magnitude of their electric charge is apparently identical. Why is it that the proton and the electron, which are so unlike in every other regard, have the same numerical charge?

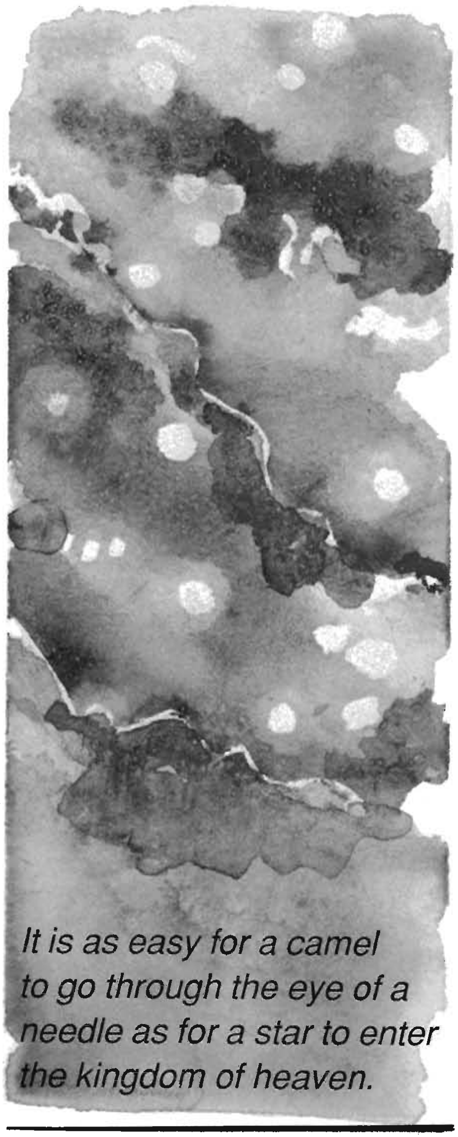
Is this a legitimate scientific question? In 1959 two of the world's most distinguished astrophysicists, R.A. Lyttleton and Herman Bondi, published a long paper in the *Proceedings of the Royal Society of London* in which they proposed that the proton and the electron differ in charge by the almost infinitesimal amount $2 \times 10^{-18}e$, where e is the tiny charge on either particle. One's first thought is who gives a damn about two billion billionths, but Lyttleton and Bondi explained that this tiny difference would result in a net charge on all particles, and thus there would be a net repulsion between all matter in the universe. Their hypothesis would account for the observed expansion of the universe. The only trouble I have with this idea is that the universe would do *nothing* but expand. Such a tiny difference in charge is enough to completely overwhelm the force of gravity that brings matter together, and so there would be no galaxies, no stars, no planets, and, worst of all, no physicists.

Before the ink was dry on that paper, John King and his group at the Massachusetts Institute of Technology were searching for a measurable difference in charge. By now they have shown that any difference has to be less than $10^{-20}e$. However, the growing consensus for the existence of quarks, which have *fractional* charge, has not made the equivalence of charge on the electron and proton any easier to understand. The electron is an indivisible unitary particle—an electron is an electron is an electron—whereas a proton consists of three quarks, two up and one down. It is a little strange that the sum of the quark charges is exactly equal to the charge of an electron.

Let us move up a step in organization to the elements. Of the 92 natural elements, 99 per cent of living matter is made of just four: hydrogen, oxygen, nitrogen, and carbon. I think it has to be this way wherever life arises in the universe because those four elements have unique properties critical to the existence of life. There are no other elements like them in the periodic table. Although I studied chemistry a long time ago, I suspect some of the same silly things are still being said. We were told that if you move vertically down a column of elements in the periodic table, those elements repeat properties. Well, any kid with a chemistry set knows better. Under oxygen is sulfur; try breathing sulfur sometime. Under nitrogen is phosphorus; there isn't any phosphorus in that kid's chemistry set because it is too dangerous: it bursts spontaneously into flames when exposed to air. Under carbon is silicon; there is about 130 times as much silicon in the crust of the earth as carbon. Then why are we made of carbon?

A strange attribute critical to the properties of these four elements is that carbon, nitrogen, and oxygen are the only elements that form real double and triple chemical bonds. What is the importance of this for life? Well, just compare two molecules that, based on the positions of their central atoms in the periodic table, should be very much alike: carbon dioxide and silicon dioxide. Carbon dioxide is a symmetrical molecule in which the carbon atom is tied to two adjacent oxygen atoms by double bonds. Those multiple bonds completely saturate the combining tendencies of all three atoms, and carbon dioxide can float off into the air as a perfectly happy and independent molecule and dissolve in the waters of the earth. Those are the places where living organisms find their carbon.

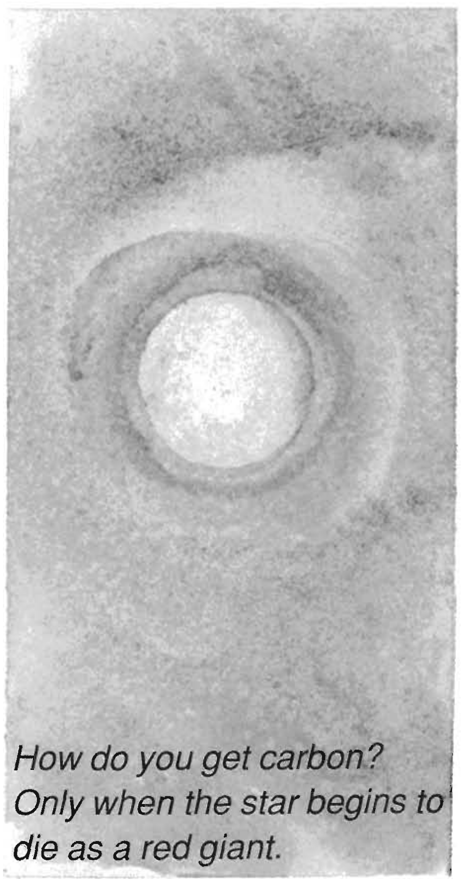
Silicon dioxide cannot form a double bond. Thus each silicon atom is tied to each oxygen with a single bond, leaving four half-formed bonds, or lone electrons, two on the silicon and one on each of the oxygens. These electrons are just dying to combine with something, but with what? Each silicon dioxide molecule combines with its neighbors until an enormous supermolecule has formed—in fact, a rock. The reason quartz is so hard to break is that you have to break a lot of chemical bonds. That is why silicon is fine for making rocks, whereas carbon is fine for making living organisms. One can make similar arguments for oxygen and nitrogen.



Now we move up another step and examine molecular organization. The most important molecule, by far, in living organisms is water. But water is the strangest molecule in the whole of chemistry, and its strangest property is that ice floats. If ice did not float, I doubt there would be life. Everything contracts on cooling, including water down to 4 degrees centigrade. However, between 4 degrees and the freezing point at 0 degrees, water expands so rapidly that ice is less dense than liquid water, and it floats. If water shrank as it cooled like everything else, colder water would be heavier and would keep sinking. Freezing would begin not at the top of the lake or ocean but at the bottom, and, in the end, the body of water would freeze solid, a disaster for underwater life. Where I live the best time to go fishing is in the winter. You take your fishing equipment in one hand and a bottle of whiskey in the other and cut yourself a hole in the ice. Up to that point the fish were having a ball, getting along fine down there. Another problem that would arise if large bodies of water froze solid is that a big chunk of ice takes forever to melt. With a relatively thin skin of ice on top, the first warm weather melts it, spring arrives, and everything is happy again.

Now I take a big jump to the stars. It is as easy for a camel to go through the eye of a needle as for a star to enter the kingdom of heaven. The needle's eye in this case is the first step in the fusion of hydrogen to helium. Every main-sequence star lives by fusing hydrogen to helium. A physicist at Oak Ridge during the Manhattan project who became an administrator and then an Episcopal priest was once quoted in the *New Yorker* as having said, "God must love hydrogen bombs because He made so many of them in the form of stars." The man should have known better, both as a physicist and a priest, because you can make stars out of hydrogen but you cannot make hydrogen bombs out of hydrogen. You have to use the rare, heavy isotopes of hydrogen in bombs. A mixture, say fifty-fifty of deuterium and tritium, is needed because the conversion of ordinary hydrogen to deuterium is perhaps the slowest reaction known. It takes a hundred billion years, which is the only reason stars last so long. They are *not* hydrogen bombs, although once you get to deuterium even a star could explode. As a result, stars last a long time, and life has a chance to start evolving at those with suitable planets.

Why is the conversion of hydrogen to deuterium so slow? The nuclei of normal hydrogen are simply positively charged protons, and even at the temperatures of main-sequence stars, say around five million degrees, the collision of two protons will most likely result in their just bouncing off each other. The rare event that has to occur if such a collision is to generate deuterium is for one of the protons to disintegrate and change to a neutron *as* it collides with the other proton. That is an improbable event. But main-sequence stars have lots of time and just keep slowly turning sets of four hydrogen nuclei into pairs of deuterium nuclei and then into helium nuclei. The slight



How do you get carbon? Only when the star begins to die as a red giant.

loss of mass in the reaction is turned into radiation, which is our sunlight.

How do you get carbon? The first thought is just to keep adding protons. This will not work because if one proton is added to helium, the result is a mass-five isotope, and there is no atomic nucleus with mass five. What is the path around this barrier? Well, the only alternative is to fuse helium nuclei, but that reaction requires a very much higher temperature, say a hundred million degrees, which is only achieved when the star begins to die as a red giant. When the core of a red giant gets that hot, the helium nuclei begin to fuse.

From this point on it should just be simple arithmetic, but there is another barrier. When two helium nuclei fuse, the result is a mass-eight isotope of beryllium, which is one of the most unstable atomic nuclei to exist, disintegrating in 10^{-16} second. Fortunately again, there just happens to be an excited state of the carbon-12 nucleus whose energy is equal to the energy in a beryllium-8 nucleus *plus* a helium-4 nucleus *plus* the kinetic energy at the temperature at which these nuclei can collide. This wild coincidence is a fortunate energy resonance that turns a very improbable reaction into a very efficient one. So beryllium-8 fuses with helium-4 to make carbon-12. The important point is that there are multiple barriers in the synthesis of the elements, but each of these barriers is overcome in a very ingenious way.

Once carbon is formed in a red giant, two protons can be added to the carbon-12 nucleus to give mass 14, which brings nitrogen into the universe. Add helium-4 to the carbon-12 and you have mass 16, which brings oxygen into the universe. The story goes on and on this way, but eventually such stars grow unstable and explode, sending their material off into space. Finally, suns and planets such as ours grow out of this material.

Eventually red giants grow unstable and explode, sending their material off into space. Suns and planets such as ours grow out of this material.

Now just think! Life, wherever it arises in the universe, has to invent a way to keep going, and that way must depend on the energy given off by a nearby star. As we know, life on the earth runs on sunlight through the process of photosynthesis. How do we get our sunlight? We get it from the various reactions of the elements that constitute life itself. The first way is to fuse hydrogen to helium—the proton-proton chain. The second way uses a catalytic process—the carbon-nitrogen-oxygen cycle—which starts by fusing carbon with 2 protons to yield nitrogen-14, then picks up 2 more protons to give oxygen-16, then splits the oxygen nucleus into helium and a carbon nucleus. The net result of both processes is exactly the same: four hydrogens have been turned into a helium. The four elements—carbon, nitrogen, oxygen, and hydrogen—that are the chief constituents of life on the earth are also vitally important to the source of energy that supports that life. Along with helium, these four are the most plentiful elements in the universe.

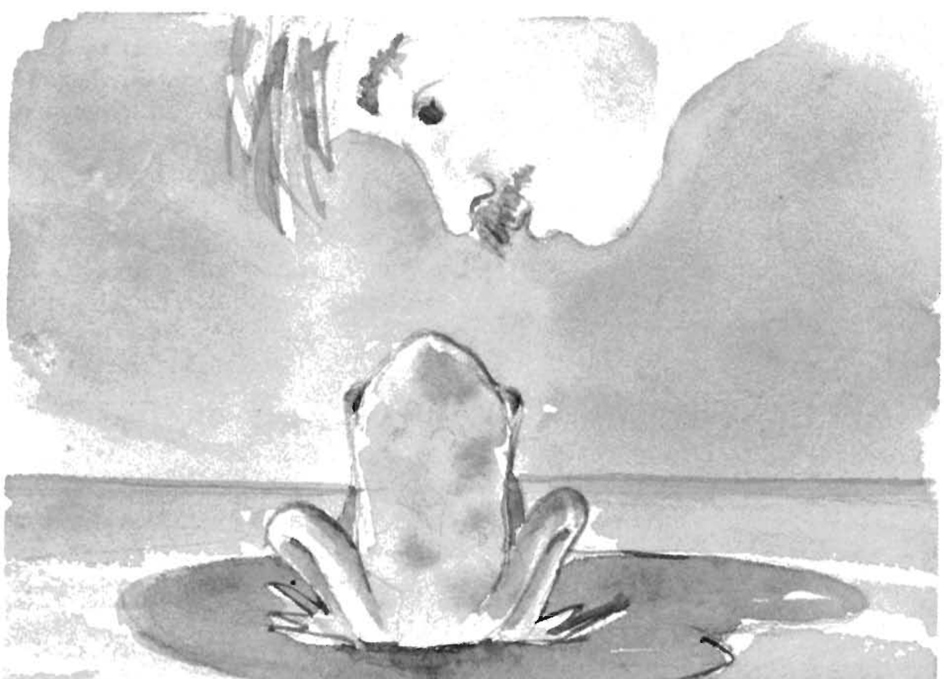
The last cosmic element in my story is equally strange, but was worked out by one of the brightest physicists alive, Stephen Hawking. There are two great forces operating in the universe: the force of dispersion and expansion powered by the big bang and the force of aggregation powered by gravity. It is all very strange because the forces are *exactly* in balance in our universe. You would think the ratio of the two could be anything, but they are *exactly* equal.

Hence we find ourselves in a very strange universe that, as a whole, is expanding but that also has islands here and there within which gravity is holding things together. For example, our own galaxy, the Milky Way, is in a rather smallish local cluster with the Andromeda galaxy and some smaller galaxies. Within our cluster there is no expansion. Our knowledge about the expanding universe comes, of course, from measurements of Doppler shifts of the light from distant sources. In general, the farther out you look the redder is the shift, indicating an overall expansion. However, the *first* spectral shift ever observed, by the American astronomer Slipher back in 1912, was not a red shift. He was looking at Andromeda in our local cluster, and he observed a *blue* shift because Andromeda is moving *toward* us at about 125 kilometers per second. To see the red shift from the earth you have to look beyond our local cluster, out to a radius of about two million light years, to where everything is expanding.

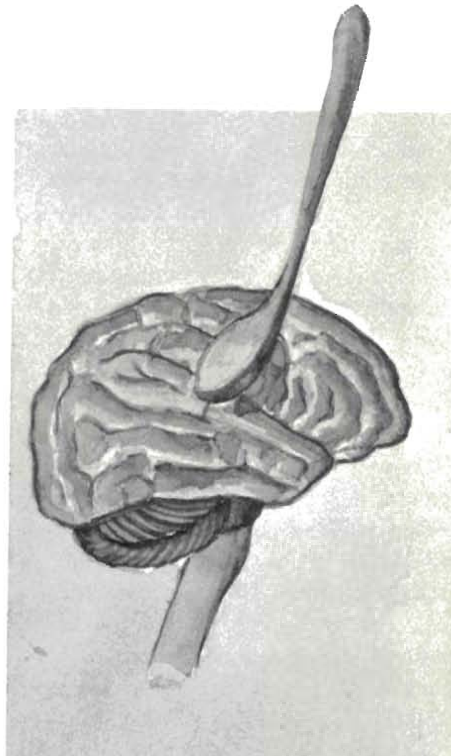
Now what if the two forces were *not* in balance, and gravity dominated instead? Our universe would still begin with a big bang, but gravity would slow the expansion until eventually the universe reached a limit. What would then follow would be the big crunch, which would either allow insufficient *time* for life to arise and evolve or would all too quickly destroy it. On the other hand, say the forces of dispersion dominated. Then matter would just fly apart without aggregation, and there would be no stars or planets. There would be no *place* for life. Fortunately, the two forces are in exact balance.

Let me summarize the first problem. We find ourselves in a universe of prolific, abundant life, but the only way this seems possible is for it to be a very peculiar universe. Any imaginative intelligence can dream up many alternative universes, any of which could be a fine, stable, but *lifeless* universe. Our living universe is a very particular universe in that the more one knows of its physics the more one sees how finely balanced and intricately meshed it is—as if it were *intended* to breed life. The fact that so many barriers and problems are solved so precisely seems pretty strange. Of course, from our self-centered point of view, these particular solutions represent the best way to make a universe. But what I want to know is how did the universe find that out? Which brings me to my next problem, that of consciousness.

For me the problem of consciousness was unavoidable because I have spent most of my scientific life working



If you do everything you can with frog retinas and human retinas, you find they are fantastically alike. Now I know that I see. Does a frog see?



Since consciousness gives us no signals, it is an embarrassment to scientists, particularly biologists.

on vision. I learned my business on the retinas of frogs. If you do everything you can with frog retinas and human retinas, you find they are fantastically alike. In both cases there are two types of receptors—rods and cones—there are three primary cell layers, and the chemistry of visual pigments is very much alike. Everything is very much alike.

But I know that *I see*. Does a frog see? It reacts to light, but so does a photoelectrically activated garage door. Does the frog know it is reacting? Is it self-aware? There is nothing I can do as a scientist to answer that kind of a question. Absolutely nothing. So during the time I worked on all kinds of animal eyes, this problem was lurking in the background. I was occupied with easier questions then, but now the problem has moved to the foreground. Let me tell you what I can about it.

Although there is nothing I can do as a scientist to identify either the presence or absence of consciousness, I am quite convinced when I deal with another person that he *is* conscious because he is so much like me. The only primary data are what transpires in my own consciousness. Yet another person also gives all kinds of evidences of consciousness—especially in that he tells me about it.

I think that probably all mammals are conscious. I think that probably birds are conscious—why else would they sing? Frogs I worry about, fish even more. I worked on the beautiful iridescent eyes of scallops, which have about eighty eyes. They are perhaps the most complex eyes anatomically in the animal kingdom and are magnificent. But I never saw any indication that a scallop *used* its eyes. I also worked on the eyes of worms from the Bay of Naples. These are worms that live in warm seas with great bulging eyes that have everything you could ask for in an eye, but, again, there was no indication that they saw anything. We could find no behavioral responses to light at all.

Although I may think my dog has consciousness, there is nothing I can do as a scientist to bolster such thoughts to the level of evidence. How about the garage door: Does it resent opening when I flash it a signal? I think not. Does a computer that just beat a good human chess player feel elated? Again, I think not. But there is nothing I can do about obtaining evidence for those conclusions either. Consciousness gives us no signals—none. Not even a signal that it is present, let alone *what* is in it. That is the problem.

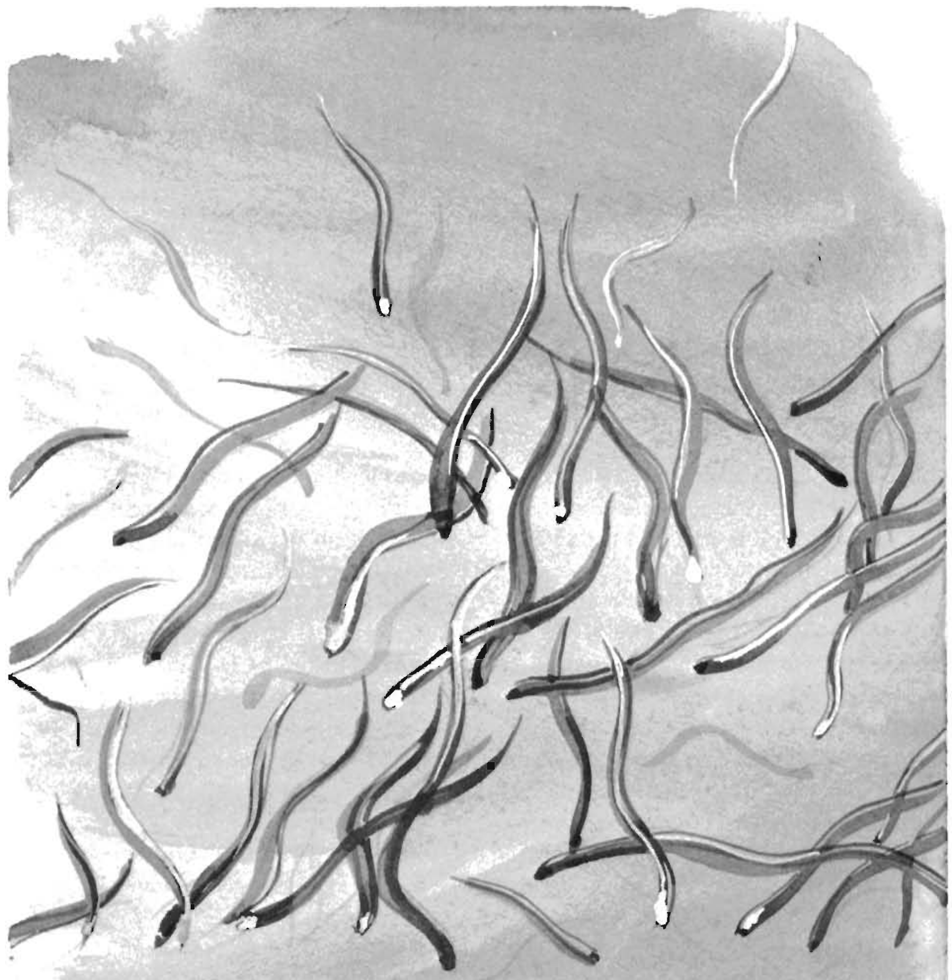
Now since consciousness gives us no signals, it is an embarrassment to scientists, particularly biologists. Biologists are made very uncomfortable by the subject, because they have always thought, as I did, that consciousness is a property of higher organisms and, as such, ought to be something they know about and can explain, at least partially, to other scientists. But they have nothing to say. It is an embarrassment. One way out is to declare that consciousness is nonexistent. P. W. Bridgman, for example, once said that consciousness was just a way of talking. He believed that for anything to be real it had to have an operational definition. There are no operations that define consciousness. In the same discussion the behavioral psychologist B. F. Skinner held that consciousness is in a private world, whereas science is in a public world, so consciousness cannot enter science, and we can forget about it. The difficulty is: no consciousness, no science, no reality. It is not some iffy phenomenon that we just project on reality; it is at the base, at the foundations.

Now I want to raise a strange question. Since consciousness is not definable and gives no signals, where is it? The famous brain surgeon Wilder Penfield from McGill University in Montreal had absolutely unique opportunities to work with the exposed brains of unanesthetized patients. The exposed brain, by the way, feels no pain, and on one occassion Wilder said to me that once the brain is exposed he could operate on it with a spoon. Wilder was exploring the human brain for therapeutic purposes, and always for the sake of the patient, but, among other things, he searched for the center of consciousness. During one discussion with him, I asked why he thought consciousness was in the brain? He chuckled and said, "Well, I'll keep on trying." Then a couple of years later I met him again and he said, "I'll tell you one thing, it's not in the cerebral cortex."

Sometime later people became interested in the reticular formation located in the brain stem of mammals. This part of the brain is an arousal center, and, for a while, people were saying that *it* is the center of consciousness. Incidentally the reticular formation is very low down in the brain stem. The next lower part of the system is the spinal cord.

The trouble with all such arguments is that it is analogous to pulling one of the transistors out of your TV set and saying that the transistor is the source of the program because the program stopped. The reality is that the process takes a lot of machinery and it is hard to know if you are dealing just with some of the machinery or a real source.

The problem, however, is deeper than just having trouble finding the center of consciousness. How can you talk about the location of something that gives no identifiable physical signals. It is absurd. Consciousness has no location. The problem is similar to the controversy that, for a time, surrounded Heisenberg's uncertainty principle. The question was whether technology—the measurement process—was failing or whether reality was just that way. Most physicists now agree with Bohr that, yes, that is the way reality is. You can't specify the position and motion of an electron because *it doesn't have* a specific position and motion. That is the way it is with consciousness. It has no location.



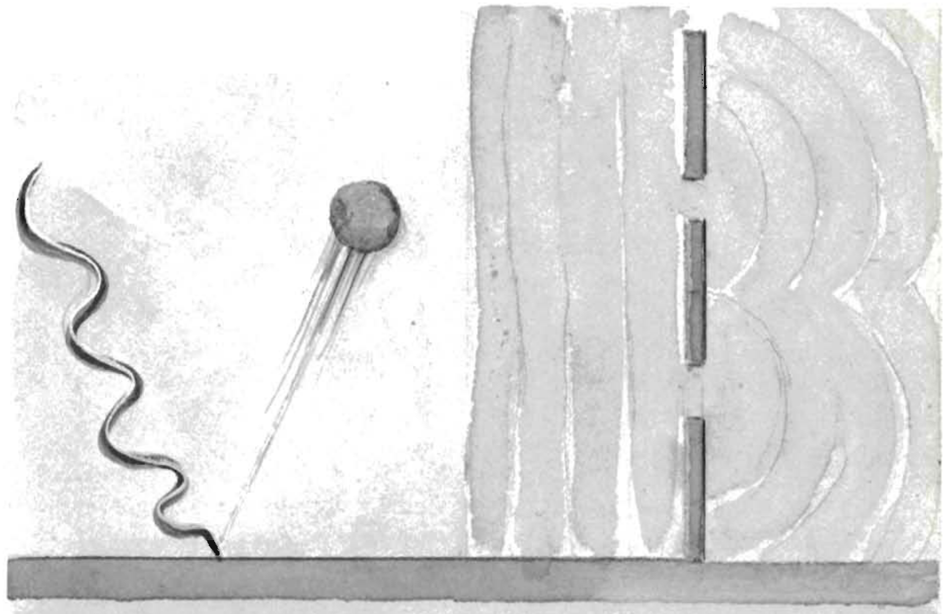
It takes the European eels three years to get back home, but there is as yet no record of a baby eel ever getting balled up and coming to the wrong continent.

A few years ago it occurred to me that these two problems—a universe that breeds life by overcoming obstacles with many special tricks and a consciousness that has no location—could be put together. At the time I was both elated and embarrassed. I was embarrassed because the thought seemed so strange to me as a scientist. But I was also elated because, as an experimentalist, I have learned that if an experiment gives you a beautiful result, enjoy it! Heaven knows whether such results will ever happen again. At any rate, within a couple of weeks, I realized that I was in the best of company.

What was the thought? Previously I had always thought of consciousness, or mind, as something that required a particularly complex central nervous system and was present only in the highest organisms. The thought now was that mind had been there all the time, and the reason this is a life-breeding universe is that the pervasive, constant presence of mind had guided the universe that way.

I was once talking to Bohr, when, to my amazement, he told a story about the love life of eels, which I think may help illustrate what I am now trying to say. Bohr's father, Christian Bohr, was a very fine physiologist, and Bohr had a great interest in biology. There are certain so-called freshwater eels that grow in fresh water for five to fifteen years but, on reaching sexual maturity, leave and migrate into the ocean. At this point they will never eat again. At best they are excellent food for us, since they are all good muscle. There are two species in the Atlantic that come, respectively, from the European and the American shores, but both migrate to overlapping areas in the South Atlantic close to Bermuda. This region is the deepest and saltiest part of the ocean, and it is where the eels spawn at great depths and die. All of them die, but the larval eels make their way back alone to their freshwater homes. It takes the American eels about fifteen months to reach our shores and come up the rivers. It takes the European eels *three years* to get back home, but there is as yet no record of a baby eel ever getting balled up and coming to the wrong continent. Bohr told all this and then said a wonderful thing: "It is just because they do not know where they are going that they always do it perfectly."

As you can see, I feel that our growing scientific knowledge—whether it be



One has as little reason to ask for the presence of matter without its complementary aspect of mind as to ask for particles that are not also simultaneously waves.

about the actions of elementary particles or the actions of eels—points unmistakbably to the idea of a pervasive mind intertwined and inseparable from the material universe. This thought may sound pretty crazy, but such thinking is not only millennia old in the eastern philosophies but arose again and again among the monumental generation of physicists in the first half of this century.

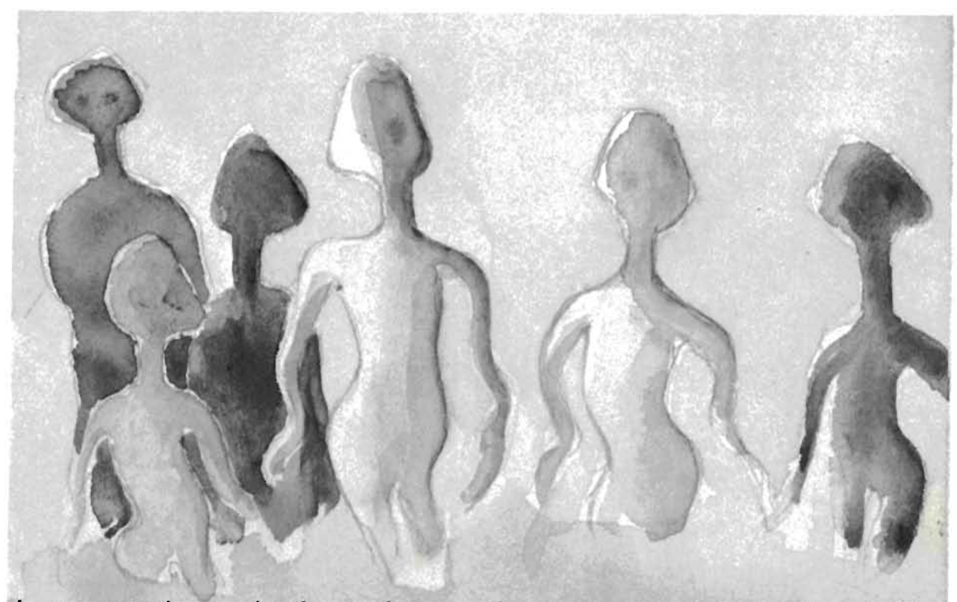
In 1928 Eddington said, "The stuff of the world is mind-stuff ... The mind-stuff is not spread in space and time. It is not something that you are going to get into science ... Recognizing that the physical world is entirely abstract and without 'actuality' apart from its linkage to consciousness, we restore consciousness to the fundamental position ..." Eddington was a pretty good physicist in his time.

Von Weizsäcker talked about his Identity Hypothesis, which he felt to be a unique but intelligible interpretation of quantum theory. "Consciousness and matter," he said, "are different aspects of the same reality."

However, the quote I like best is that of Wolfgang Pauli, who said, "To us ... the only acceptable point of view appears to be the one that recognizes *both* sides of reality—the quantitative and the qualitative, the physical and the psychical—as compatible with each other, and can embrace them simultaneously. It would be most satisfactory if *physis* and *psyche* (i.e., matter and mind) could be seen as the complementary aspects of the same reality." Just realize what Pauli is saying to us: one has as little reason to ask for the presence of matter without its complementary aspect of mind as to ask for particles that are not also simultaneously waves.

Athough this matter of mind embarrasses biologists, it is much easier to talk with physicists about it because they tend to deal with mind, day in and day out. The nineteenth-century scientists harped on the idea of an external world that can be observed without disturbing it. That world was truly objective because one could experiment without entering or affecting the part of the world being observed. However, at the very center of modern physics is the realization that you cannot keep yourself out of the experiment, and, in fact, all scientific observations are ultimately subjective.

There is a simple example of the entry of consciousness into physics experiments. Any physicist setting up an experiment on radiation, or elementary particles for that matter, must decide beforehand which set of properties—particle or wave—they intend to find. If a wave experiment is set up, they get a wave answer. If a particle experiment is set up, they get a particle answer. One cannot get both answers in one experiment.



In many places in the universe there must exist creatures like ourselves.

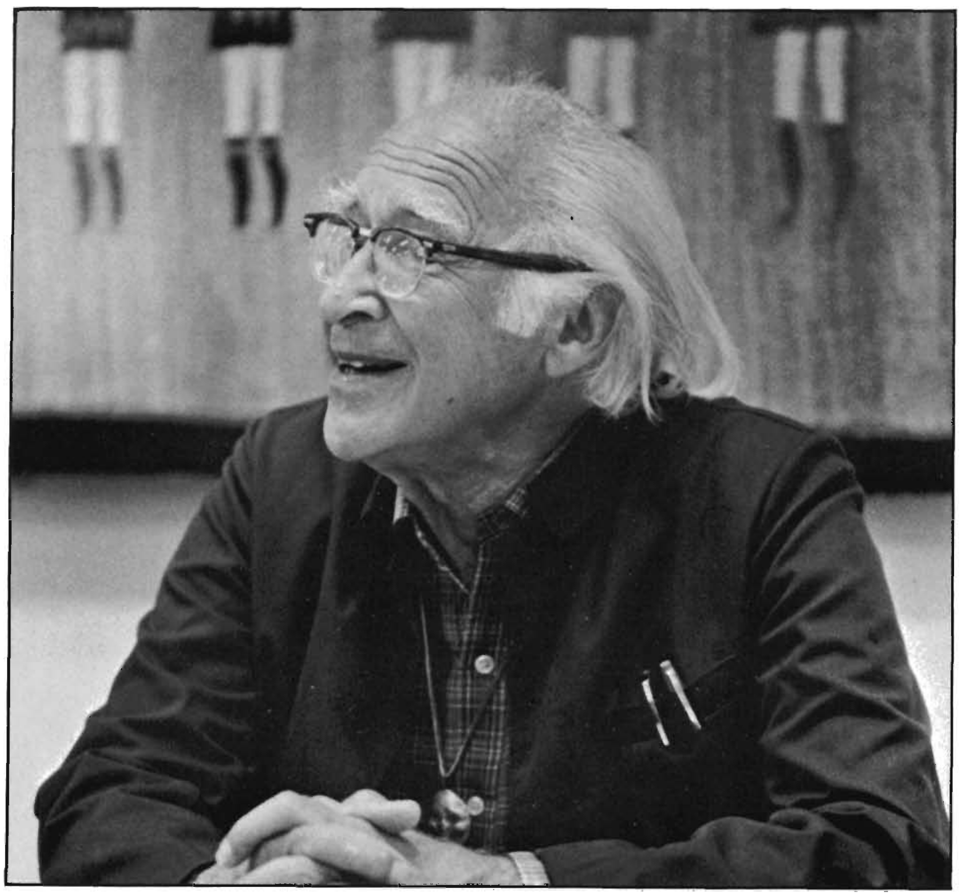
I think we live in a world of chance—without chance there are no phenomena—but not a world of accident. The universe has this weird fitting together. Arriving at this point of view I ask myself, what for? If mind was there all the time why would it take the trouble to make matter? One possible answer is, of course, at the heart of the anthropic principle, which, briefly, is that the universe has a design that makes it certain there will be physicists.

The driving force of evolution, according to Charles Darwin, is what he called natural selection. It has three components: the constant production of variations, both advantageous and disadvantageous; a mechanism for inheritance; and a competitive element. As a result, variations that work better are retained whereas variations that work less well are discarded.

In many places in the universe there must exist creatures like ourselves. By this I do not mean they are like us anatomically—former creatures on the earth were different anatomically from the current ones. But they would be like us in the creation of art, science, and technology. In some of these places they should have developed far beyond us. After all, what is ten million years in cosmic time? Such creatures form societies and invent languages and writing that form mechanisms for cultural inheritance. Those creatures make cultures, and those cultures are constantly pouring out variations, advantageous and disadvantageous. With libraries and educational systems, each generation does not have to start from scratch as regards its culture. Then there is the competition of cultures. Some rise, flourish, then disappear; yet aspects of that culture may be retained because they work better.

So one has a new kind of natural selection and a new mechanism of evolution that does not replace but rather adds to the ongoing anatomical and physiological evolution. This new phase of evolution now includes means for the independent evolution of consciousness. The prospect of this independent evolution of the pervasive, ever-present mind gives our species a transcendent worth and dignity and tells us our place in the universe: it is to know and create, and to try to understand, as we alone can do under our sun. ■

George Wald received his Ph.D. in zoology from Columbia University in 1934 and then joined Harvard University, where he has been ever since. He was the first to identify vitamin A in the retina, and most of our knowledge today regarding processes by which retinal pigments in the human eye convert light into sight comes from his work and that of his associates. These discoveries have had a profound effect on sight restoration of children, especially children in developing countries where blindness is, unfortunately, a common problem. Among Dr. Wald's many prestigious awards and honors is the 1967 Nobel Prize in Physiology or Medicine.



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