## Chapter 1

# *The Organization of Matter*

### What Is Matter?

I once asked a physicist friend the simple question, "What is matter?" He responded with a glare of astonishment and then finally said, "You're kidding, right?" I was not kidding. I was quite certain that the question was intelligible and that any competent physicist would be able to give it a straightforward answer. I was mistaken. After my initial disappointment I made it a practice to put the question to every physicist I happened to meet. I have since had dozens of responses, none of them satisfying in the way I had hoped. *What is matter?* You cannot be serious. I do not have the slightest idea. Matter is what everything is. Matter just is. Matter is as matter does. Matter is a theoretical tool. Go ask a philosopher. And so the answers went.

It turns out that the nature of matter is not something physicists normally think about. They prefer to concern themselves with *states* of matter, not its essence. If you push hard enough a physicist may give you a circular answer. Matter is composed of subatomic particles that are themselves manifestations of energy—you know, $E = mc^2$. But at the end of the day it becomes clear that physics has no satisfying answer to our question. Physicists like to duck the question by insisting that it is a philosophical issue, not a scientific one. But philosophers are equally inclined to view it as a question for physics. One gets the impression that it is simply not the fashionable question these days.

From the seventeenth through the nineteenth centuries, however, the matter question was intensely fashionable as the mechanistic worldview of the new science was unfolding. At the heart of the mechanistic perspective was the corpuscular theory of matter, a slightly modified version of ancient Greek atomism. According to the corpuscular theory God had fashioned innumerable atoms at the moment of creation, each one solid, indestructible, and imperceptibly small. Atoms were thought to belong to various families, or species, each of these being present in nature by diverse and invariant proportion, and each characterized by unique geometric and chemical properties. That is, each species of atoms had its own essential nature, interacting with the forces of attraction to produce the various structures and qualities of the perceived world. While each atomic species (element) had its own peculiar properties, all particles of matter shared certain generic characteristics. They were extended in space, solid, massy, hard, impenetrable and movable. But more important, they were inert, passive, uncreative and soulless—entirely at the mercy of external "active principles" inherent in nature's laws.

The inertness of matter was a novel feature of the new mechanical worldview. Prior to the seventeenth century matter was thought to possess active properties, which meant that it was unnecessary to draw absolute distinctions of kind between inanimate, animate, and sentient beings. Distinctions between matter, life, and mind were not deep, they only *became* deep when matter was pronounced categorically inert. This new way of thinking about matter had the benefit of releasing scientific inquiry from the restrictive influence of theology, as the machine of nature could now be seen to crank along lawfully without need of continuous divine supervision. As liberating as the concept of inertness was for science, it meant that philosophy would be condemned to more than three centuries of toil over the mind-body problem. But that is another story.

Returning now to the point about the old-fashionedness of the matter question: What makes it old-fashioned? The question is old-fashioned because it appears to assume that there are some nifty little analogies on hand in terms of which we can form a satisfying answer. But there are no such analogies. The classical picture of matter was intelligible because matter could be pictured—atoms were tiny clods of hard stuff (somewhat like billiard balls). So we could understand. But contemporary physics does not lend itself to pool hall analogies, and all attempts to impose them succeed only in generating mind-numbing paradoxes. Quantum theory makes exquisite sense to the disciplined mathematical intuition of a few experts, but not to the rest of us.

The matter question has become increasingly elusive throughout the twentieth century. Already by the turn of the century the major theoretical moorings of classical mechanics had been abandoned, and by midcentury they had been replaced by an array of bewildering theoretical entities and dynamics. In the classical view matter was discrete and radiation was continuous, but according to the new physics matter can behave in wavelike patterns and radiation can behave like particles. In the classical view atoms were simple and solid units, but in the new physics they are complicated systems of interrelated events. A century ago atoms were the primary building blocks of material objects, but today more than sixty subatomic particles have been postulated. In the nineteenth century space was space and time was time, but in relativity theory space and time are inseparable. In classical physics matter was constituted in space, but in contemporary theory space is constituted by matter. Classical mechanics was committed to determinism, but quantum mechanics makes a principle of indeterminacy. In the old picture matter was matter, but in the new physics some matter is antimatter. In the nineteenth century matter was categorically inert, but today matter sizzles with bizarre agency. In the old days matter was full of theoretical integrity, but today, in the words of an eminent theorist, "matter is weird stuff." This is why physicists will stare at you in wonder if you ask them what matter is.

It would appear that Everybody's Story has got off to a disappointing start by asking the wrong question. But if we can't ask what matter *is* then what can we ask? We might fare better by shifting the focus of our inquiry from substance to process. All the indications are that we will understand matter best if we look at what it *does,* not what it *is.* Matter is what matter does. If we desire to know how things are then perhaps we should ask how they came to be.

## How Did Matter Come to be Organized as It Is?

In the beginning was ultimate singularity. That is, before there was a universe everything that would become the universe was trapped inside a tiny morsel of incomprehensible heat and density. Before space or time, before matter and energy, before anything at all was the mysterious source: dark, quiet, profound unity. And then there was chaos, as the ultimate singularity released itself in the big bang—an event of such almighty force that it continues, even after fifteen billion years, to overpower the combined gravitational force of the entire universe.

Within a fraction of a microsecond after the moment of creation the forces of nature established their domains of influence and possibilities for future events began to fall within limits defined by the laws of physics. Space and time were themselves in the making, making way for the awesome events of unleashed energy. The universe expanded at an instantaneous rate, drawing out of the vacuum a sizzling gas of particles and antiparticles. In a blaze of spontaneous creation all forms of elementary particles split into existence together with their antiparticles, only to collide with each other and disappear instantly in the heavy traffic. A simultaneity of creation and annihilation produced an expanding chaotic fireball of blinding intensity. The paradox of this earliest phase of the universe is that the creation of matter was so prolific that most of it choked out of existence.

As it happened, there was a slight excess of particles over antiparticles, so as the fireball expanded and the collision rate dropped, there remained a sufficient number of unscathed particles for the universe to make something of itself.

Initially the universe was too hot for any physical structures to endure. But after about one second of expansion and cooling it became possible for free-floating quarks to join together to form neutrons and protons, which would later combine to form the nuclei of atoms. Still no atoms though. For several hundred thousand years the universe remained too hot for nuclei to succeed at capturing electrons. But when conditions were right copious amounts of hydrogen and helium atoms began to form, and for the next billion years or so the universe billowed forth in an expanding cloud of cooling gas. The organization of matter had commenced. The first phase of organization was extensive and enduring, but it was not complex. Hydrogen and helium are the simplest atomic structures we know. The heavier and more complex atoms were prevented their debut because the universe cooled too rapidly. Complex atoms require extreme heat for the necessary nuclear reactions to take place, but the window of opportunity had too quickly closed. Heavier atoms would have to wait for the heat of another day.

For the first billion years or so, the organization of matter was limited to the *microcosmic* assembly of simple atoms. But then the universe entered into a new phase of *macrocosmic* organization. The density of the expanding cloud of gas was not perfectly uniform. Some regions within the cloud were more dense and lumpy than others. Over time the influence of gravity took its effect by exaggerating the irregularities so that the cloud grew even lumpier. Different patterns of motion developed in distinct regions of the cloud, and slowly the gaseous universe began to fragment—in roughly the same way we observe rain clouds breaking apart in the sky. The result was that the original cloud distorted into distinct billows, and then gradually reorganized into separate clouds, each moving away from all the rest. These fragmented clouds—over 100 billion of them—were destined to become galaxies. The process of galaxy fragmentation was completed by the time the universe was a mere 5 billion years old.

Organization at the macrocosmic level continued. The initial patterns of motion that created the fragmentation process persisted in such a way that galaxies developed into many different shapes and sizes. And within each of these giant cloud galaxies there were pockets of greater and lesser density. In time, gravity exaggerated the irregularities until lumps of matter began to swell. As the relentless pull of gravity had its way, vast regions of atoms and elementary particles were drawn together with immense force. These regions became more and more dense with matter, and in the process the friction of colliding particles generated heat. So now we see a conspiracy of gravity, heat, and electromagnetic energy working together to give birth to the first stars. Stars are clouds of matter that become so dense and so hot that they ignite into nuclear furnaces. The whole process, from gassy lump to raging inferno, takes about ten million years.

There is nothing ordinary about a star, each one a dramatic contest between the inward force of gravity and the outward force of pressure. A star may hang in the balance for billions of years before one or the other force prevails. If there is sufficient matter contained in a star then eventually gravity will dominate and the star will collapse into a black hole. But if the pressures within prevail then the outer layers of the star will blow off in a giant explosion—a supernova. Meanwhile, during the contest of forces, the internal regions of a star can get hot enough for microcosmic organization to resume. When hydrogen atoms, helium atoms, and free particles become densely compacted under extreme heat the processes of nuclear fusion are triggered to synthesize the nuclei of heavier elements, from carbon all the way up to iron. Elements heavier than iron are synthesized in the explosion of a supernova. When a star goes supernova it splatters newly minted atoms into space to drift about as interstellar dust.

Microcosmic organization now continues apace. Free floating atoms of every kind are now available to obey the laws of chemistry, which means that under certain conditions they will combine with other atoms to produce a rich diversity of molecules. In recent years scientists have found evidence of highly complex molecules—hydrocarbons and amino acids—that have assembled themselves by chance out of the interstellar ashes of supernovae.

As a galaxy becomes strewn with the debris of supernovae explosions conditions begin to favor the construction of many new stars. Second- and third-generation stars form in the usual way—gravity collects matter into a ball until friction heats it to the nuclear flash point. Then it is a contest of the forces of contraction and expansion. This is precisely how our own sun was formed about five billion years ago. In the case of our sun there happened to be an abundance of interstellar dust in the vicinity that was prevented from collapsing into the fireball by a swirling motion. The result was a central ball of fire surrounded by a disk of orbiting matter. It is hard to say what caused this particular pattern of motion—some scientists hypothesize that shock waves from a nearby supernova could have done the trick. But whatever the causes were, the effect was to arrange the sun at the center with ten concentric swirling bands of matter at the outside. And it was from the matter in these swirling bands that the planets of our solar system were formed about 4.6 billion years ago.

Our solar system includes four rocky planets (the four bands closest to the sun), then a beltway of asteroids, and then four gaseous planets, and the icy Pluto. The rocky planets formed in roughly the same way that hailstones form, that is, by accretion, or aggregation. The earth, third removed from the sun, started out as a clump in the swirling disk, and as it swept through space its own gravitational field collected additional particles until it had vacuumed up most of the matter in its orbit. As the earth grew larger it became hotter (gravity, density, and friction again), eventually reaching the point where most of its matter melted down. This semifluid state allowed for a lot of shifting and sorting of the earth's materials. Heavy molten iron gravitated toward the center leaving lighter materials to be pushed toward the surface, resulting in concentric layers of iron and rock.

For its first 800 million years the earth remained very hot and was under constant bombardment by radiation and meteor showers (more bits of matter coming aboard). But then about 3.8 billion years ago the earth cooled, forming a rocky crust, called the *lithosphere*. Once the lithosphere became organized a variety of factors conspired to form the *hydrosphere* and the *atmosphere*. Radiation from the sun, condensation of water vapor, radioactive decay, and periodic outgassing from the still-molten interior produced an abundance of water and various atmospheric gases. Much of the earth's crusty surface was broken up and recycled in this process, leaving only a few fragments surrounded by water. The land masses we recognize today as continents are remnants of the earliest rocky crust. These land masses sit atop the active lithosphere, a system of eight to ten rocky plates that glide smoothly over the surface of the more plastic layers below. Over the eons the continents have ferried about the surface of the earth as the plates were mobilized by incessant motion within the fluid interior. Some 200 million years ago the land masses congregated in a supercontinent, Pangaea, only to separate again and take up their present—albeit temporary—positions.

The *biosphere* is the region of the earth's surface that supports life. More accurately, the biosphere is a highly complex geologically based biochemical system that developed out of the interactions between land (lithosphere), water (hydrosphere), and air (atmosphere). It was at the intersection of these major components of our young planet that microcosmic organization flourished to bring forth living creatures.

## Interlude: The Grandeur and Grace of Matter

A few pages back I made mention of a "monotony of matter" to characterize the prelife period of the universe. Bad choice of words. Matter is not in the least monotonous. It is busy, creative, surprising, and melodic. If matter is as matter does, then matter is order-seeking, system-building, self-organizing, well-informed, excited stuff. And if modern physics had but one lesson to teach about this stuff it would be that matter is not to be underestimated, never to be taken for granted. Matter is just as grand as it can be. Still, nothing is more natural for us than to take matter for granted. After all, it does not seem very special. It is everywhere, it is everything. Matter is just as ordinary as it can be.

In the preface I said this book was all about leaving us with a sense of gratitude. And now I am at the point of suggesting it is appropriate that we feel grateful for matter. Gratitude, we saw, is an emotional response that evolved to regulate reciprocal behavior. We are moved to feel gratitude whenever we gain a favor or escape a loss, whereupon we find ourselves predisposed to reciprocate. I will address the question of reciprocity later on (including what or whom we have reason to be grateful *to*). But for the moment let us just consider what reasons there might be to feel thankful for matter.

Bear in mind that being grateful for matter cannot be meaningfully separated from a sense of gratitude for the entire domain of physical reality, that is, the whole universe. Matter, energy, space, time, and the natural laws governing these cannot be completely distinguished. Our question, then, is whether we have reason to be thankful for the universe.

What a silly question. Of *course* we do! Without the physical universe there would be no possibility of life, pure and simple. The lives we have are inconceivable apart from the physical universe that makes and sustains them. Nevertheless, even though we have sufficient *reason* to be thankful for the universe, we seldom have sufficient *cause*. Let me illustrate. Suppose you agree to do a favor for some business friends by hand delivering a large amount of money (say, $100,000) to their bank. You are going near the bank anyway, and there is no inconvenience involved. So you take the briefcase full of cash and off you go across town in your car. You finally arrive safely in the parking lot of the bank. Can you find reasons to be grateful that the trip has gone well? Sure, plenty of them. Yet you do not *feel* particularly grateful. That is, nothing in the reasons has caused an emotional response. But now suppose you step out of the car and there, teetering on the very edge of the roof, right where you carelessly left it, is the briefcase full of cash. Now you *feel* the gratitude.

The more we learn about the scientific account of creation the more we find ourselves left with such an experience. When you step out of your car to see the briefcase balanced on the edge of the roof your first thought is stunned disbelief. But there it is! Similarly, when we consider the odds against our universe producing the lives we have we feel more rational with the conclusion that none of it could have happened. But here it is!

For beginners let us go back to the creation of subatomic particles in the early universe. There in the big bang we saw that the universe expanded at an instantaneous rate, drawing out of the vacuum a sizzling gas of particles and antiparticles, simultaneously splitting into existence only to collide with each other and to vanish completely. We also observed that in this blaze of creation-annihilation there was "a slight excess of particles over antiparticles," leaving enough particles unscathed for the universe to make something of itself. It turns out that "slight excess" is more than a slight understatement. The excess was one in a billion. That is, for every billion antiparticles there were a billion and one particles. This means that if the early universe had been more evenly balanced by a factor of one-billionth then it would have been completely annihilated in the big bang. Odds like that make your trip to the bank look like a sure thing.

But if this is not enough, consider the expansion rate of the universe. The rate of expansion in our universe amounts to a sort of compromise between the explosive force of the big bang and the contractive force of gravity. On the one hand, if the explosive force were any greater (or if the gravitational force any less), then the universe would have expanded more rapidly than it did—too rapidly for any galaxies or stars to form. On the other hand, if the explosive force were any less (or gravity any greater), then the universe would have long since collapsed into a tiny cinder. So the universe we have (and thus the lives we have) is contingent on just the right balance between outward and inward forces. This is an astonishing fact, but it approaches the downright incredible when we consider the tolerance factor. That is, *how much* could the outward force or the inward force be varied and still result in a livable universe? The number works out to be one part in $10^{60}$. In other words, by all odds we are not here.

If you are still unimpressed then consider the improbability of the periodic table of elements. We have the atomic elements that we do because the strong and weak nuclear forces are what they are. If the strong force were any weaker (by a minute fraction) then we would indeed have a monotony of matter, for the universe would be limited to hydrogen atoms. But if the strong force were any stronger then all the hydrogen in the early universe would have fused into helium—with the consequence that there would be no water, no stars, and no life. The fine tuning of the nuclear force is also relevant for the construction of heavier elements. If the strong force were any weaker then carbon atoms (the staple ingredient of life) could never have formed in the solar furnaces. But if it were slightly stronger then carbon atoms would have been fused into oxygen. There is no getting around it: the diversity of atomic elements is not to be taken for granted. Things could easily have been otherwise.

And now for the clincher. It appears that these highly improbable features of the universe are fundamentally independent, which actually multiplies the improbability of our being here. What are the chances for a coincidence of this *series* of improbabilities? Uncertain, but certainly very slight. It is as if a blind man, driving drunk through a war zone, were to arrive safely at the bank.

It strains the imagination and defies all rational expectation to suppose that improbability of this magnitude must be accepted as the brute fact of a chance universe. The difficulty of contending with the mental strain of such brute facts has encouraged speculative attempts to bring the odds into a more manageable range. One way of reducing the odds is to suppose the presence of transcendent purpose and design, that is, God. If the universe is seen as a mechanism for carrying out divine purposes then an unfathomable coincidence of chance events translates neatly into the intelligible consequence of creative design.

Another option for reducing the odds against our existence is to suppose a plurality of universes, the idea being that if our universe is one of zillions then extreme improbability resolves into eventual certainty. Wait long enough and *every* possible universe will have its turn. Several possibilities have been put forward to give imaginative substance to this option. One of these makes the conjecture that our universe is a momentary episode in a continuous oscillating series of expansion-contraction-expansion, and so on, *ad infinitum*. Another interesting possibility is that multiple universes inflate within an infinite expanse, each one with unique properties and duration, like so many bubbles in a boundless vat of oatmeal.

It appears, therefore, that we have one credulous option and two imaginative options for contending with the more puzzling aspects of the cosmic narrative. The credulous option accepts colossal improbabilities as brute facts. The theological-metaphysical option imagines a transcendent, or perhaps immanent, principle of intelligent design. And the pluralistic option imagines superordinate domains of space or time in which our universe appears as one among many.

Each of these options is burdened with immense intellectual difficulties. And while there are at present no objectively compelling reasons to prefer any of them, one can easily see how various subjective factors might draw individuals to each. What is more difficult to understand, however, is how anyone could suppose that the deep mystery behind the cosmic narrative might be diminished by the imagination. In this respect both theology and speculative science are deluding themselves by pretending to take us beyond the strain of the credulous option. A brute fact is a brute fact, and as brute facts go transcendent deities and multiple worlds are inherently no easier to swallow than impossible odds.

At the end of the day there remains the grandeur and the grace of the universe, full of enduring promise, inviting us to relent in wonder at the mystery of it all. Here is a mystery to command our curious efforts to understand, but here too is a mystery to provoke in us the raw sense that we are blessed.