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### The Laws of the Void

*Since you must admit that there is nothing outside the universe, it can have no limit and is accordingly without end or measure. It makes no odds in which part of it you may take your stand; whatever spot anyone may occupy, the universe stretches away from him just the same in all directions without limit.*

—Lucretius, c. 60 B.C.E.

#### The Platonic Order

I have been developing the scenario by which our universe could have evolved naturally from an initial state of emptiness into the vast cosmos visible to us today, with its local pockets of order like Earth. Although certainly not proven, this picture is suggested by modern physics and cosmology. While this scenario may not turn out to be correct or need modification as our knowledge evolves, it at least represents a counterexample serving to refute the claims one hears frequently these days that current scientific knowledge necessarily points to a supernatural creation of the universe.

We have seen that zero external energy was required to produce the mass and energy of our universe. We have seen that order can spontaneously arise from disorder. We have seen that complexity can evolve from simplicity. We have seen that time has no fundamental arrow, and so the very concepts of cosmic beginnings and causal creation are problematical. No known scientific principles are necessarily violated in a model of our universe that is causally self-contained, in which everything that happens, happens within.

In this context, I need to make it clear that when I talk about "our universe," I mean all that we see with our unaided eyes plus what we see when we look into our most powerful telescopes and microscopes. It also includes what we infer from the less direct data gathered by our most sophisticated instruments in experiments of every variety, in all scientific fields. The possibility exists of other universes besides our own. Multiple universes are suggested by modern cosmological theories, although, since they cannot be observed, their scientific status may be questioned. However, nothing in our current knowledge rules them out, so we cannot simply eliminate them from all scientifically consistent speculation, especially when otherwise successful theories betoken their presence.

The notion of multiple universes, in this context, is not to be confused with the parallel universes that are often referred to in discussions of quantum mechanics. In the *many-worlds* interpretation of quantum mechanics,<sup>1</sup> all the different paths that a physical system may take are viewed as occurring, *in reality*, in different "worlds." Unlike the multiple universes suggested by modern cosmology, quantum many worlds are viewed as interacting with one another to produce observed quantum effects that appear puzzling or even bizarre. While the many-worlds interpretation has many adherents, and the associated mathematical formalism has great merit, othe

viable interpretations of quantum mechanics remain with no consensus on which, if any, is the correct one. In any case, this need not concern us here.<sup>2</sup>

Even in the context of other possible universes, I claim that ours shows evidence of being self-contained. If it appeared as a quantum fluctuation in a larger universe, that process was a noncausal one. Even if this were not the case and our universe was brought into being by some causal process such as the act of a creator god, the data indicate that it was once in a state of complete chaos and so currently retains no memory of that creative act. This conclusion is obtained by extrapolating the big bang back to the earliest definable moment within our universe. This moment, as we saw in chapter 7, is not  $t = 0$  but  $t \approx 10^{-43}$  second, the Planck time. At that time, our universe was confined within a sphere of radius  $10^{-35}$  meter, the Planck length. According to the Heisenberg uncertainty principle of quantum mechanics, no smaller distances or times can be operationally defined (see appendix A), so no information exists inside a Planck sphere. Thus, our universe at this earliest time had maximum entropy (see appendix C). It was a kind of black hole that cannot be seen into and so exists in a state of maximum disorder. Even if the universe was created—and we have seen that nothing requires that it was—nothing in the "mind" of the creator could have carried through to even the first tiny fraction of a second after creation. If a creator play any role in our universe, it must be through actions taken after the Planck time.

All of this is based on currently known principles of physics. Still, you are likely to ask: Where did the scientific principles themselves come from? In this chapter I will tackle this question and in the process further elaborate the model of a wholly natural and self-contained universe.

Theists, and even some nontheistic scientists, argue that the very existence of scientific principles themselves provides evidence for a Platonic order to the universe that transcends the realm of our observations. As physicist and Templeton Prize-winner Paul Davies has put it:

*The very fact that the universe is creative, and that the laws have permitted complex structures to emerge and develop to the point of consciousness—in other words, that the universe has organized its own self-awareness—is for me powerful evidence that there is "something going on" behind it all. The impression of design is overwhelming.<sup>3</sup>*

Contemporary trends in liberal Christian theology and its supposed rapprochement with science have moved it closer to a pantheist position in which deity is to be found in the order of nature. The Christian God is seen as a creative entity—transcending space, time, and matter—that is ultimately responsible for all that exists. And here is where some scientists and theologians currently seem to share a common ground—in the notion that ultimate reality is not to be found in the quarks, atoms, rocks, trees, planets, and stars of experience and observation. Rather that reality exists in the mathematical perfection of the equations of physics and in the theological perfection of an entity existing, along with those equations, in a realm beyond human observation. This god is knowable, not by his appearance before us but by his presence as that perfect reality. We all exist in the "mind

of God."

Of course, the Christian concept of God has always been a curious mixture of Hebrew, Greek, and Eastern mystical traditions, among others. Perhaps, that is the secret to its longevity. The gospel writers shaped their stories of Jesus around the model of the god-man of Mithraism and other Middle Eastern cults, with a little Osiris and Dionysus thrown in. This helped make the new religion attractive to the masses. Early church theologians, especially Augustine of Hippo (d. 430), provided a philosophical model of a transcendent God that was strongly reminiscent of Plato's Form of the Good, though molded to fit the YHWH of Judaism. This helped make Christianity intellectually respectable. So this combination—lots of magic, miracles, festivals, and rituals for the common folk, combined with a rational theology for the intelligentsia—has survived to the twenty-first century.

Until recently, the application of Platonism to science has not been widespread, or at least not discussed much in the open. It represents just the sort of talk, rather disconnected from the observable world, that most scientists disdain. Today, however, we find a number of theoretical physicists joining in the Platonic chorus. Although avowed atheists or agnostics, Stephen Hawking, Roger Penrose, Steven Weinberg, and other prominent theoretical physicists and mathematicians warble Platonic melodies of a reality manifested in the equations of mathematics and physics. They view *quantum fields* and space-time *metric tensors* as "more real" than quarks and electrons.

Many physicists have speculated that theoretical developments will eventually lead to a "theory of everything" (TOE) in which all the basic principles of physics will be shown to follow from a minimal set of assumptions, perhaps just statements of self-consistency. In that case, as Einstein suggested, there may have been nothing for God to do.<sup>4</sup> One route that is now being intensely explored is *string theory*, or its more recent extension called *M-theory*.<sup>5</sup> Since this theory is still far from being experimentally testable, we will have to wait and see. What I will try to show here is that, independent of M-theory or any other TOE, many of the most important principles of physics do indeed follow from little more than arguments of consistency, while others may be simply a product of chance.

In contrast to Platonic theorists, I am a mundane experimental physicist who sees reality as composed of objects that kick back at you when you kick them. Kick a rock with your foot, and it kicks back. Kick an atom or an electron with a photon, and it kicks a photon back to you. By measuring the properties of these photons, you can learn about the atom or electron. The properties of matter inferred from these measurements seem more real to me than metric tensors and quantum fields.

A reality of uncuttable atoms, that is, elementary objects (not to be confused with the "atoms" of chemistry), moving around in an otherwise empty void, as suggested by Leucippus and Democritus twenty-five centuries ago, is buttressed by the highly successful standard model of elementary particles and forces developed in the 1970s. This model continues to offer the simplest picture consistent with all the data. Tied in with the rest of physics, the standard model suggests a plausible, purely natural, explanation for the laws of physics. As we will see, universal laws, such as

energy and momentum conservation, are simply mathematical statements about the natural symmetries of space and time. Other laws may have resulted from the spontaneous breakdown of those symmetries. Indeed, the laws of physics indicate that the universe looks as it does because it has the same basic properties as an empty void, just what would be expected if it appeared spontaneously, without cause or creation, out of the void

## The Properties of the Void

What are the properties of the void? The void, as I visualize it, is not "nothing" in the absolute, philosophical sense. If we take nothing to literally mean "no thing," then it cannot even be described. For if it is to be described, it must have some properties and, then, it is not *no thing* but *some thing*. Being an experimental physicist whose head spins at such thoughts, I will define "void" as that minimal arena that permits any experiment at all.<sup>6</sup>

Aristotle argued that the void cannot logically exist. However, any logical argument depends on its premises, and scientific questions are never settled by logic alone. Ultimately, science relies on observations. So let us approach the problem of the void as experimental physicists would. Imagine we are engaged in a research project entitled: *An Experimental Investigation into the Properties of the Void*. This will be what Einstein called a *gedankenexperiment*, a thought experiment carried out in the mind and on paper.

In our thought experiment, we imagine a region of space in which we have removed all the matter and energy. What is left is the void. Now, it may be objected that this void is still "something" rather than "no-thing," so I must make it clear that I am hypothesizing the ontology mentioned above, and justified in *Timeless Reality*, in which reality is composed of "atoms" and the void and no more. When we remove all the atoms, then we are left with "nothing," since there is no other element of reality. Of course, this ontology maybe wrong, but if I can show that it is sufficient to explain the data, then no one can claim that the universe, by its very existence, requires divine creation

In our thought experiment, we attempt to measure the properties of the void as we attempt to measure the properties of anything else—by utilizing some measuring instruments. The most familiar instruments of the elementary physics laboratory are the meter stick for measuring distance and the clock for measuring time. Let us choose to use these here. Note that, in doing so, we are simply deciding to describe the void in terms of space and time. This does not necessarily imply that the object of our inquiry is in any sense composed of "substances" called space and time. Rather, we simply make use of the readings off a meter stick and a clock to describe the observed goings-on inside the void in a certain language, namely, the language of space and time.

The choice of space-time language is not the only possibility. We might choose to use a different language determined by measuring instruments other than meter sticks and clocks. In particle physics experiments done in accelerators, for example, we use instruments that measure the energy and momenta of whatever entities trigger their electronic circuits. This usually provides enough information to describe particle collisions without ever introducing space-time variables.<sup>7</sup> I

fact, the theoretical equations that describe these interactions use energy and momentum as their independent variables, along with other quantities such as angular momentum, spin, electric charge and many other variables. At one time, back in the 1960s, one school of particle physics sought to do away with space and time altogether. That hasn't happened, but maybe someday it will. Modern M-theory, mentioned above, is motivated by some of those ideas.

Nevertheless, we are all familiar with space and time, and these variables remain the most intuitive. So, I will use space-time language in describing the void.

As our research proceeds, we might introduce other instruments besides meter sticks and clocks, but these still would be calibrated in terms of measurements of distance and time. In fact, even our meter stick is calibrated using a clock, the meter being defined by international convention as the distance light goes, in a vacuum, in  $1/3 \times 10^{-8}$  second.

Of course, no objects exist inside our void for which we can measure the time or distance. However, we can follow a procedure that is common in physics when studying the properties of various "fields" such as gravity or electromagnetism: We introduce a series of individual pointlike test particles into the void-field and watch how each behaves. This is, in principle, no different from Galileo's falling-body experiments, described in chapter 5, which measured the properties of Earth's invisible gravitational field. The void is no longer empty with the presence of the test particle, but we can at least make a working assumption that we can treat it as a separate entity.<sup>8</sup>

Let me try to state, as succinctly as I can, what I am doing here—lest the reader think it is too weird. We have some void over there. We put in some test particles and measure their positions, velocities, and accelerations as a function of time with a meter stick and clock. From these measurements, we try to infer some properties that describe the void. And we will compare those properties with those of our nonempty universe.

We start by attempting to measure the position of our test particle at various times. However, we have no reference point with respect to which we can do this. The particle can have a position we choose. As shown in figure 8.1, we can "translate" the origin of the spatial coordinate axes—the reference point that we use to measure position—to any place we choose. In other words all "places" are arbitrary. This leads us to our first observed property of the void: It contains no special position. We call this property *space translation symmetry*.

**Space translation symmetry: There is no special position.**

The next thing we notice is that we can walk around our test particle and view it from any angle without seeing any differences. As also shown in figure 8.1, we can rotate the axes of the spatial coordinate system to any direction we choose. In other words, all directions are arbitrary. This leads us to our second observed property of the void: It contains no special direction. We call this property *space rotation symmetry*.

**Space rotation symmetry: There is no special direction.**

Like our point particle, a perfect sphere has space rotation symmetry. No matter what angle you view it from, it looks the same. This symmetry is about any rotation axis you choose. By contrast, a cylinder has rotation symmetry about a single axis, the axis of the cylinder. A cone has similar symmetry. A snowflake also has symmetry about a single axis, but this symmetry is further restricted. While the cylinder or cone can be rotated by any angle about its axis and still look the same, the snowflake can only be rotated about angles in steps of sixty degrees. It has *discrete* symmetry, while the cylinder, cone, and sphere have *continuous* symmetries. Note that as you move from a sphere to a cylinder to a snowflake, you are moving from a simple object to a more complex one, from less structure to more structure. Thus, complexity is associated with low levels of symmetry—what we call *broken symmetry*. In any case, the void has the highest level of spatial symmetry. And that's not nothing.

Now, what about time? We have a clock to measure time, but nothing is available to specify when we should start the clock, what time we should label as  $t = 0$ , the origin of our time measurements. Obviously any arbitrary point in time will do. That is, we can "translate" the reference time that we use to measure time intervals to any time of our choosing (see figure 8.2). In other words, all "times" are arbitrary. We call this property *time translation symmetry*.

**Time translation symmetry: There is no special moment in time.**

Thus, the void is characterized by certain properties that we describe in terms of symmetry principles. This is not to imply necessarily that these principles exist as some kind of Platonic reality of which the void is a manifestation, although that is one possible metaphysical interpretation. Here we are just acting like experimentalists who give no thought to metaphysics. We are trying to make measurements with meter sticks and clocks. Time and space are simply operational concepts we ourselves have invented. Time is what we measure on a clock. Distance is what we measure with a meter stick. So far, we have not been able to make such measurements and that fact, in itself, has revealed certain properties of the void. In terms of concepts that we have already used with great success in the description of phenomena in our nonempty universe, an empty universe must be described in a way that makes no assumptions about a special position and direction in space, or moment in time.

The concepts described so far should be easy to understand. At the same time, they are very profound. What makes them profound is the fact that they apply to our nonempty universe, as well. Indeed, space translation symmetry was the great principle discovered by Copernicus, although, of course, it was not originally expressed in that fashion. Until Copernicus, Earth generally was regarded as a very special point in space—the fixed center of the universe (an assumption reflected in the Bible). As I have already noted, the Copernican revolution was a major paradigm shift that triggered the scientific advances which followed. It can even be argued that the growth of science began when the weight of this ancient misconception was cast aside, when humanity became

humble enough to realize that it was not at the focus of existence.

## **Symmetry and Conservation**

While students in elementary physics classes are not burdened with such abstract concepts as symmetry principles, these principles have become an integral part of modern physics. They lie in the background of all that is taught in physics classes and used in many practical applications—in engineering and other fields. The elementary physics student is trained to apply the laws of physics in practical problem solving, rather than to understand them in any deep way. The most important and useful of these laws are the great conservation principles of energy, linear momentum, and angular momentum. These are universal or global laws, that is, they seem to apply for all types of phenomena—from machines to chemical reactions to biological processes to stars and galaxies. As far as we can tell from astronomical observations, they apply everywhere in the universe and have done so for all time. Again, for clarity's sake, these laws are as follows:

***Conservation of energy: The total energy of an isolated system is constant.***

***Conservation of linear momentum: The total linear momentum of an isolated system is constant.***

***Conservation of angular momentum: The total angular momentum of an isolated system is constant.***<sup>9</sup>

A good part of the elementary physics student's time is spent solving problems by utilizing these powerful laws. Energy conservation, for example, enables one to compute the speed at which water will emerge from a small hole near the bottom of a tank of water, knowing only the height of the tank. Linear momentum conservation can be used to compute how fast a defensive back must run to stop a fullback in his tracks. Being less massive than the fullback, he has to run faster to cancel the fullback's linear momentum. Angular momentum conservation will tell you how fast a figure skater will spin when she pulls in her arms and explains why she speeds up.

In advanced, graduate-level physics courses, the student begins to learn of the deep connection between symmetry principles and universal conservation laws—that they are simply different ways of saying the same thing. Conservation of energy is shown to follow from time translation symmetry. Conservation of linear momentum follows from space translation symmetry. Conservation of angular momentum follows from space rotation symmetry.

Let me give just one example, for the case of linear momentum, that illustrates this connection. Consider an automobile moving along a highway at constant velocity, as shown in figure 8.3. Its mass is constant, and so, then, is its linear momentum which is the product of mass and velocity. Suppose equally spaced, identical telephone poles are situated along the highway, which are used to mark the car's position at the time it passes that point. If we were to watch a film

of the trip, we could not distinguish one pole, that is one position-marker, from another, that is, we have space translation symmetry.

Contrast this with the situation when the car brakes to a halt and its linear momentum is no longer constant. Watching the film in this case, we can single out one telephone pole as special—the one nearest where the car stops. Thus we see that a connection exists between conservation of linear momentum and our ability to single out a special position in space.

By a more sophisticated, mathematical analysis, the conservation laws can be proven to automatically exist for any physical system that possesses the corresponding symmetries and vice versa. This is called *Noether's theorem*, named after the mathematician Emmy Noether, who proved it in 1918. These laws are true in classical mechanics and carry over to quantum mechanics. As we have seen, these are precisely the space-time symmetries of the void. The fact that phenomena in our nonempty universe obey these conservation laws, when the caveat of an isolated system is applied, indicates that our universe possesses the symmetries of the void—exactly what would be expected had it spontaneously appeared from an initial state characterized as the void.

So if someone asks where the laws of conservation of energy, momentum, and angular momentum came from, the answer is: They came from nothing. No act of creation was necessary to produce those laws. If these conservation laws were not found to hold in the universe, then we would be able to make a good case for a creator because that would indeed be unnatural, if not supernatural. But the conservation laws are found to hold. They are natural and provide a good argument for the absence of a creator.

## **Relativity and the Laws of Motion**

Let us get back to our experiments on the properties of the void. Recall that we could define no special, or "absolute," position, direction, or moment in time. But if we cannot do this, how can we define the motion of the test particle? That requires a measurement of quantities such as velocity and acceleration with meter sticks and clocks. Velocity is the time rate of change of position, and acceleration is the time rate of change of velocity.

Thus, when Galileo championed Copernicus's idea that Earth moves about the Sun, contrary to scripture, he was challenged by some Church fathers with a very reasonable question: If Earth is moving, why don't we notice it? Instead of doubting his own telescopic observations, which convinced him of the reality of the Copernican view, Galileo attempted to make that view consistent with experience. He proposed that all *uniform* motion is relative, where uniform means constant velocity—motion in a straight line at constant speed.<sup>10</sup> Just as no special "frame of reference" exists to define an absolute position and direction in space, no special frame of reference exists that is absolutely at rest. We have no way of knowing whether a body is at rest or in uniform motion. This property is called the *principle of relativity*.

***Principle of relativity: There is no absolute uniform motion.***

One way to think of the principle is from the point of view—the *frame of reference*— of an observer inside a closed capsule in outer space (see figure 8.4). As long as the observer cannot see any outside reference point, such as Earth or the Sun, he has no way of knowing whether he is moving at constant velocity or is at rest. This would also be the condition for an observer all alone in the void. In that case, we do not even need a closed capsule, since there would be nothing outside to see. Today this principle is demonstrated every time we fly in a jet airliner. Except for vibrations from the engines, and occasional bumpy air, we have no sensation of hurtling through the sky at hundreds of kilometers an hour.

Similarly, but without the shared experience of jet airliner travel, Galileo pointed out, we stand on Earth with no sensation of hurtling through space at 30 kilometers per second. He explained that what we experience as "motion" is not velocity but *changes* in velocity—acceleration. Of course, the motion of Earth is not at constant velocity in its near-circular orbit around the Sun, but we do not sense this slight acceleration. Nor do we notice the acceleration that results from Earth's rotation about its axis, although, as we recall from chapter 5, that can be measured and is the source of cyclonic storms in the atmosphere. Again referring to our own experience, when we take off in an airliner, we are pressed against the back of our seats; when we land, we are pressed forward against our seat belts. What we experience is the acceleration and deceleration of the aircraft.

The principle of relativity is the first principle an elementary physics student learns because it constitutes the jumping-off point for the mechanics developed by Newton, who was born the year Galileo died. Newtonian mechanics is based on the three laws of motion.

### *Newton's Laws of Motion:*

- (1) **A body at rest will stay at rest, and a body in motion will stay in motion in a straight line with constant velocity unless acted on by an external force.**
- (2) **The total force on a body is equal to the time rate of change of the momentum of the body,**
- (3) **For every action there is an equal and opposite reaction.**

Common experience tells us that a body at rest will stay at rest unless it is acted on by a force. But since, according to Galilean relativity, one cannot distinguish between a body at rest and body in uniform motion, it follows that a body in uniform motion will stay in uniform motion with the same velocity unless acted on by an outside force. (Recall that the principle of relativity only excludes *absolute* uniform motion.) And Newton's first law of motion is exactly what would be expected for our test particle in the void. Later, in university-level introductory courses, students are shown that laws (1) and (3) follow from conservation of linear momentum and that (2) simply represents the quantitative definition of force as the agent for changing momentum. An isolated body has no forces acting on it and so has constant linear momentum. Since the linear momentum of a body is the product of its mass and velocity, when the mass is constant, the velocity remains

unchanged in magnitude and direction.<sup>11</sup> The third law of motion (3) is also the result of conservation of linear momentum. When you fire a gun, you experience a recoil in which your backward linear momentum balances the forward linear momentum of the bullet, the total linear momentum thus remaining constant.

In 1905 Einstein's special theory of relativity extended Galileo's principle of relativity to the case where the relative motion of bodies was a large fraction of the speed of light. To make it agree with observations in electrodynamics,<sup>12</sup> Einstein found it was necessary to discard the common perceptions that the time interval between events and the distance interval between two points in space are absolute. By absolute, I mean the same in all reference frames. We have already seen that no absolute position in space or moment in time exists. Einstein showed that the same is true for distance and time *intervals*. These depend on the relative motion of the observer making the measurements. Einstein found that the speed of light in a vacuum, on the other hand, *was* an absolute constant that had to be the same for all observers regardless of their relative motion.

If you and I are in separate spaceships moving relative to one another and we observe two supernova explosions, we will in general obtain different measurements for the distance between the stars that exploded and the time interval between the two events. One of us might observe them at the same time, but the other will not. As Einstein pointed out, we cannot even properly speak of things happening simultaneously as reported by any two observers in relative motion. Similarly, we cannot speak of two events occurring at the same place in all reference frames.

The procedure that enables one to compare the space and time intervals between events observed in different frames of reference is called the *Lorentz transformation*, named after physicist Hendrik Lorentz, who proposed it in the nineteenth century but did not realize its full implications.

We have already seen how rotational symmetry in familiar three-dimensional space leads to conservation of angular momentum. As proposed by Hermann Minkowski shortly after Einstein published the special theory of relativity, time can be mathematically treated as an added dimension in a four-dimensional space-time. If we make the assumption of rotational symmetry in four-dimensional space-time, then the Lorentz transformation follows. Thus the "laws" of special relativity, like the conservation laws, are also the natural consequence of a symmetry principle—*space-time rotation symmetry*.

***Space-time rotation symmetry: There is no absolute direction in space-time.***

When we combine all the translational and rotational space-time symmetries we have considered, we have what is called *Poincaré symmetry*. In our series of experiments with the void, we find that it possesses this set of symmetries. Poincaré symmetry is a property of the void, and apparently a property of our universe as well. Thus the principles of special relativity, as well as the great conservation principles, follow from and are consistent with the natural symmetries of the void. So far, we have found no need for a creator, a law-giver of any sort, in some of the most important

"laws" of physics.

## Gravity from the Void

In our experiment with the void, we found that we could define no special frame of reference in which a body was at rest. This agreed with Galileo's principle of relativity, extended by Einstein in the special theory of relativity. These principles applied to reference frames moving at constant velocities with respect to one another. However, for each of our test particles in the void, we also have no way of measuring its *acceleration*. Thus, at least as far as the void is concerned, whether or not a body is accelerating is also indeterminate.

Newton had made a distinction between accelerated and nonaccelerated reference frames. Newton's laws of motion only seem to apply to nonaccelerated systems, what we call *inertial* reference frames. A rotating system, like Earth, is a *noninertial* reference frame, and Newton's laws of motion can only be maintained in such frames by introducing "fictitious" forces such as the centrifugal and Coriolis forces. This has always puzzled physicists and philosophers. Suppose Earth were the only body in the universe, like our test particle in the void. How could we tell that it was rotating? What would it be rotating with respect to? Newton thought that it rotated with respect to absolute space. According to this view, space is something substantial.

Leibniz, however, rejected Newton's notion of absolute space, arguing that the concept of space was not separable from the relations of material bodies. If one has no matter, then one has no space—or time. This issue was intensely debated by some of the greatest philosophers for many years, with no resolution. In the nineteenth century, some progress was finally made when the physicist and philosopher Ernst Mach proposed that inertia is the net effect of the mass of Earth and other celestial bodies. This is called *Mach's principle*. It implies that one cannot detect acceleration, such as rotation, in the void and that we can extend the principle of relativity to include all motion, not just uniform motion.

In 1907 Einstein introduced the *principle of equivalence between inertia and gravitation* which eventually led to his theory of gravitation, called the *general theory of relativity*, which appeared in 1916.

### ***Principle of equivalence: Gravitation and acceleration are indistinguishable.***

Einstein used the example of a man inside an elevator in free fall (see figure 8.5). Every object inside the elevator will fall together, and the unfortunate person inside would have no way of knowing he was falling and not simply safely floating in a capsule in empty space.

The principle of equivalence can be formulated in a way similar to what I did above for the principle of Galilean relativity. Recall that this form of relativity says that an observer in a closed capsule cannot distinguish between being at rest and being in motion at constant velocity. The principle of equivalence states that an observer in a closed capsule cannot distinguish between being accelerated and being in the presence of a uniform gravitational field. The caveat "uniform" is added

here since it is in practice possible to tell you are on Earth rather than in an accelerated capsule by noting that objects dropped from different places will not fall along parallel lines but along lines that converge to the center of Earth.

Einstein proceeded to write down the equations that mathematically describe this situation. These equations had to conform to what the falling observer would see, namely, no evidence for a gravitational field. And, when properly transformed to the frame of reference of an observer on Earth, the equations had to conform to what Earth-bound observer would see, namely bodies accelerating measurably towards Earth. When Einstein did this, he obtained the equations of general relativity.<sup>13</sup>

Thus, in the modern view, gravity does not exist as a physical force field that surrounds a massive body, a tension in some elastic substance, such as the aether, as once was thought to be the case. Rather, gravity is an artifact—a fictitious force—that we introduce into our equations to describe what happens when two bodies accelerate toward one another with no evident interaction between them and no otherwise detectable "field." Those equations must reflect the fact that an observer in a closed capsule in free fall cannot detect the fact that he is accelerating. This is precisely the situation that would occur if the capsule were in an otherwise empty void. In that case acceleration cannot be defined. General relativity is just the extension of the principle of relativity to accelerated reference frames.

may have oversimplified the case. In order to describe gravity as a fictitious force, Einstein found it was necessary to discard the usual description of space in terms of *Euclidean geometry*. Long before, mathematicians had shown that one can relax Euclid's geometric axiom that parallel lines never meet. Einstein was the first to find a physical application for the resulting non-Euclidean geometry, using it to describe four-dimensional space-time in general relativity.

An example of a non-Euclidean space is the two-dimensional surface of a sphere. The lines of longitude on Earth are parallel, and yet they meet at the poles. On the surface of a sphere, the path of a great circle (any circle whose center is at the center of the sphere) is called a *geodesic*. In general, in any given geometry, the geodesic is the shortest distance between two points and is a straight line only in Euclidean space.

In classical mechanics, free particles—particles not acted on by any force—follow a geodesic path in space. Usually we think of this as a straight line, which is a good approximation until we get to the astronomical scale. In general relativity, bodies still follow geodesic paths, but these paths can be curved. The curvature of the geodesic a body follows is determined by the masses of other bodies in the vicinity. Thus Earth travels in a geodesic around the Sun. That motion is "more natural" than a straight line because the presence of the Sun "warps" the space around it.

While this might sound very complicated, and the mathematics takes some training to learn, the equations describing these geodesics follow from the assumption that they are the same—the technical term is *invariant*—from one frame of reference to the next. That is, they follow from a generalized principle of relativity that maintains the symmetries of the void.

Thus, once again, we have a great scientific theory, general relativity, following from

properties of the void. This concept—that much of physics is a formalized description of the properties of the void—is very profound. It is also very simple. Indeed, it is profound by virtue of its simplicity. The most powerful and universal principles that have been discovered by physicists turn out to be exactly those which result from taking great care to assure that their mathematical descriptions of phenomena possess the symmetries of the void. These great principles could not be otherwise, if the universe exploded, uncreated, out of the void. Thus, not only do these laws provide no evidence for a creator, they constitute a strong case for his nonexistence.

## Quantum Mechanics

Quantum mechanics is usually pictured as a great revolutionary break, a giant "paradigm shift," away from classical mechanics. While many of its philosophical implications, especially indeterminism, were perhaps revolutionary, the actual theory as originally developed independently by Heisenberg and Schrödinger follows rather directly from classical mechanics. Heisenberg made basically only one innovation: he postulated that observables be represented in the theory by non-commuting operators, that is, mathematical objects that do not obey the commutative law of real numbers,  $AB = BA$ . In the remainder of his program, he used the classical equations of motion as his guide.

Similarly, Schrödinger inferred his famous wave equation from the classical Hamilton-Jacobi equation of motion, which has the form of a wave equation. I have already mentioned that Noether's theorem applies to quantum mechanics as well as quantum mechanics. While the mathematical derivation is beyond the scope of this book, it can be shown that quantum mechanics also follows in a natural way from the classical mechanics.

## Forces, Structure, and Spontaneously Broken Symmetries

We have seen how much of physics—conservation of energy, linear momentum, angular momentum, and the principles of special relativity and general relativity are properties of the void. We have seen that our universe possesses these properties, strongly suggesting it evolved naturally from the void. This has brought us a long way, to an understanding of the origin of the most important "laws" of physics. However, we have still not accounted for the source of order and structure we see in our universe. This still leaves a gap for a god to be situated, and, indeed, this is where some physicist-theologians think they see an opening to enable them to reconcile their faith with science. Nevertheless, we can continue to refute the need to invoke divine design to explain the laws of physics by providing an alternate scenario grounded in natural processes.

Let us begin by going back to Newton's second law of motion. When a body is not isolated, the law of conservation of momentum does not apply, and its linear momentum can change. The total force on the body is then quantitatively defined, by Newton's second law of motion, as the time rate of change of the linear momentum. A similar set of laws exists for rotational motion, and they relate in the same way to angular momentum. *Torque* is the time rate of change of angular momentum. A rotating rigid body will remain rotating at constant angular velocity unless acted on

by an external torque. If the body is not rigid, as in the case of a figure skater doing a spin, the angular velocity can change, but the angular momentum still remains constant.

We can see how a force can come about in our experiments with the void by introducing a second test particle. Now we can begin to use our meter stick to measure the distance between particles, and we are no longer free to translate the position of one particle independent of the other although we can still translate the two together. Thus we can expect linear momentum conservation to apply to the system composed of the two particles, which is still isolated, but not to individual particles themselves. They can interact with one another, exchanging momentum. The simplest way to do that is for particle *A* to emit a third particle, *X*, which carries momentum across to particle *B* where *X* is absorbed. The total momentum and energy is conserved, but particles *A* and *B* recoil away from one another. Indeed, this is precisely the picture used in the standard model of elementary particles and forces.

Since conservation of linear momentum follows from space translation symmetry, the action of a force has the effect of breaking that symmetry. Or you can think of the act of breaking the symmetry as producing the force. (Note how causal language creates trouble here, unless you assume cause and effect are interchangeable, which they are at the fundamental level, as I show in *Timeless Reality*). In either case, it then becomes possible to single out one point in space as different from all others. For example, a ball tossed in the air will experience a change in its direction when it reaches its highest point and then starts to come down. That point is distinguishable from all the others along the path of the ball. Similarly, the action of a torque is to break rotation symmetry, selecting out a special direction of space, namely, the axis around which the torque is applied.

Forces and torques, then, are associated with broken symmetries. These broken symmetries supply complexity to the universe, as when water vapor freezes to produce a snowflake with less symmetry and, with the generation of information, greater complexity. The connection between forces and broken symmetries was one of the great discoveries of twentieth-century physics and provided the key for the development of the highly successful standard model of particles and forces. In the standard model, the electromagnetic, strong nuclear, and weak nuclear forces are all described in terms of spontaneous broken symmetries. Here the term "spontaneous" refers to the fact that the symmetries are not broken by some external deterministic action, by neither natural nor supernatural law, but randomly.

The basic equations of the quantum field theory comprising the standard model contain underlying symmetries—not just those of space and time already discussed but symmetries that relate to other "inner" dimensions. These symmetries are assumed to apply at extremely high energies, or temperatures, as existed in the first tiny fraction of a second of the big bang. All the particles and forces would have been originally identical, with equal amounts of matter and antimatter. As the universe expanded and cooled, these symmetries, according to the model, were spontaneously broken, leading to differences among the particles and forces and a large excess of matter over antimatter. In this way, the structure of the universe may have appeared, without cause

creation, the way a snowflake appears out of a less structured and more symmetric cloud of water vapor.

### **The Instability of the Void**

Now we are finally in a position to begin to shed a little light on the common question: Why is there something rather than nothing? The unstated assumption of this question is that nothing is somehow a more natural, stable state of affairs than something, and so we must explain the existence of something. If, on the other hand, something is more natural and stable than nothing, then the correct question is: Why should there be nothing rather than something?

Now, as I have already indicated, I am at a loss to describe "nothing" outside of a well specified ontology such as atoms and the void. If the term refers to "no thing," then it has no properties to describe.<sup>14</sup> It serves no useful purpose to rehash here the ancient philosophical debate over the meaning of the words "something" and "nothing." Therefore, I have chosen to stick to what I know best, empirical physics in which quantitative measurements are made with specified instruments, and theoretical physics in which those measurements are described mathematically. I accept the fact that all measurements are "theory-laden," in the sense that theory is used to define the terms of the measurements. I understand the process is not totally objective, but neither is it totally subjective. Rather, the procedure is "intersubjective." Common agreement is reached by multiple individuals on the terms by which the measurements will be performed, and these measurements are then carried out by multiple, disinterested, or even skeptical observers. Only when the observers agree on the results of a certain set of measurements are they taken seriously.

I have introduced the notion of the void as a physical concept—an emptiness that still can be studied by the introduction of test particles whose relative positions and movements can be measured with meter sticks and clocks. This does not mean that the void is a real substance or object. It does not kick back when you kick it. However, the test particles we place in the void kick back when we kick them.

We have seen that our nonempty universe possesses space-time properties which coincide with those of the void, strongly indicating that it could have formed from the void. We have seen that those properties can be expressed in terms of familiar principles of physics. We have seen that such a transition, from emptiness to nonemptiness, violates none of these principles of physics. But if the universe was a void, then why did it not stay a void? What nudged it from emptiness to nonemptiness? Maybe God had to do it after all!

Common sense would seem to say that the entity we call the void is more natural state of the universe. Theists continually argue that the transition void-to-universe must have been a miracle because of the decrease in entropy, or increase in order, that they imagine must have occurred, in apparent violation of the second law of thermodynamics. However, as we saw in chapter 6, the initial state of the universe was one of maximum entropy, the same as a formless void. Thus no violation of the second law occurred. Indeed, this is yet another property that the universe shared with the void, at least at that first moment—maximum entropy.

If we have learned anything at all from the past four hundred years of discovery, it is that common sense often leads one astray. It is common sense that Earth is flat and immovable at the center of the universe. It is common sense that we can always tell when we are in motion. It is common sense that time and space intervals are the same for all observers. It is common sense that living species and shining stars are fixed and immutable. All these, and many other conclusions based on common sense, have been shown to be wrong.

In fact, the physical world is filled with examples in which the more complex system is the more stable. I have used the snowflake several times as an example, and it can be used again here. The so-called phase transitions that familiar matter undergoes in moving from the vapor state to the liquid or solid states are changes from states of lower to higher complexity. Heat from the Sun is required to take something complex, like solid matter, and make it into something simpler, namely liquid or vapor. Take away the Sun and all the vapor and liquid on Earth will freeze to solid matter as they have on distant Pluto. The more complex solid state of matter is often the more stable one.

Note that these phase transitions do not violate the second law of thermodynamics. When a snowflake forms, as shown in figure 8.6, its loss of entropy is compensated by a gain in entropy of the surrounding air. If we could take that snowflake and keep it isolated from the rest of the universe, it would forever remain a snowflake. Heat is necessary to melt it back to its simpler state.

Another example is an iron magnet or ferromagnet, shown in figure 8.7. The stable state of a ferromagnet is one in which the magnetic domains inside an iron bar line up, giving a net magnetic field. To destroy the magnetic field, you must heat up the magnet above a certain critical temperature, called the Curie point, so that the domains move around randomly, canceling out each other's field. Note that the nonmagnetic state is simpler, more symmetric—and less stable—than the magnetic state. That is, the natural state of the iron bar is the more complex one, the one with broken symmetry.

Now, ferromagnetism is well described in terms of the theory of electromagnetism that was consolidated into a few equations in the late nineteenth century by Hendrik Lorentz and James Clerk Maxwell. Microscopic quantum effects in electromagnetism are fully accounted for in the theory of quantum electrodynamics, developed in the 1950s, that is now part of the more general standard model that also takes into account the nuclear forces. The basic equations of electromagnetism are symmetric to rotations about any axis. The ferromagnet, which singles out a particular direction—the direction of its net magnetic field—thus spontaneously breaks the symmetry of the underlying theory. Nothing in the theory says this breaking must take place along some specific axis.

If one starts with a spherical ball of iron at a temperature above the Curie point, it will have no net magnetic field, and thus it has rotational symmetry. The symmetry is spontaneously broken when the iron ball cools below the Curie point; but the direction of any net magnetic field that results is unknown, indeed undetermined, ahead of time. The direction that results is random. If one had a large number of balls of iron to begin with, a random distribution of directions would result and, overall, rotational symmetry would be maintained statistically. Thus the breaking of rotational

symmetry by any given iron ball is "local," while rotational symmetry remains in force "globally."

As I have mentioned, spontaneously broken symmetry was one of the key concepts that led to the development of the current standard model of elementary particles and forces. In this picture empty space—the void—is not stable. For this reason, it is referred to as the *false vacuum*. We can think of it as analogous to a hot ball of iron with no magnetic field. The lower energy *true vacuum*, on the other hand, is like a cool iron ball in a more stable state in which a magnetic field is present. In this case, it is not rotational symmetry that is broken, and the field is not magnetic, so the analog is not exact. But still, the nonzero field has an energy density and negative pressure.<sup>15</sup> As we have seen, this is precisely the condition that can lead to the exponential expansion of the universe that we call inflation.

Consequently, in the scenario suggested by modern physics and cosmology, the simple, symmetric void empty of matter transforms into the complex, asymmetric universe filled with matter because that universe is more stable than the void. We have a universe rather than a void because it is more natural. As the old saw goes, nature abhors a vacuum. If we had only emptiness, then we would have to ask why there was emptiness rather than fullness. But then, we would not be here to ask the question.

## Notes

1 Hugh Everett III, "'Relative State' Formulation of Quantum Mechanics," *Reviews of Modern Physics* 29 (1957): 454-62; Bryce DeWitt and Neill Graham, eds., *The Many-Worlds Interpretation of Quantum Mechanics* (Princeton: Princeton University Press, 1973); David Deutsch, *The Fabric of Reality* (New York: Allen Lane, 1997).

2 For more discussion, see my *The Unconscious Quantum: Metaphysics in Modern Physics and Cosmology*. (Amherst, N.Y.: Prometheus Books, 1995) and *Timeless Reality: Symmetry, Simplicity, and Multiple Universes*, (Amherst, N.Y.: Prometheus Books, 2000).

3 Paul Davies, *The Mind of God: The Scientific Basis for a Rational World* (New York: Simon and Schuster, 1992 ).

4 See Carl Sagan's introduction to Stephen Hawking's best seller, *A Brief History of Time: From the Big Bang to Black Holes* (New York: Bantam, 1988).

5 For a popular exposition, see Brian Greene, *The Elegant Universe: Superstrings, Hidden Dimensions, and the Quest for the Ultimate Theory* (New York: W.W. Norton, 1999).

6 Thanks to Brent Meeker for suggesting that I put it this way.

7 Momentum and energy are, in fact, the Fourier-transformed variables of spatial coordinates and time. So they are equivalent.

8 Some physicists might argue that such separation is impossible, in the light of the "nonlocality" of quantum mechanics. But in *Timeless Reality* I showed that this kind of separation can be done if one allows for time reversibility.

9 Here I have made the distinction between linear momentum and angular momentum that is familiar in elementary physics. The first is what is often simply called momentum, the product of a body's mass and its velocity. Angular momentum is defined with respect to some axis and is the linear momentum times the perpendicular distance to that axis. Also, for simplicity, I have not state these laws in the most general way. Under certain conditions, one or two of the conservation laws will apply for nonisolated systems.

10 In physics we make a technical distinction between speed and velocity. Velocity is a vector that has magnitude and direction. Speed is the magnitude of velocity.

11 If the mass is not constant, as for a rocket, then the velocity can change, but the momentum will remain constant.

12 By this time, electromagnetism was well described by a set of equations developed by James Clerk Maxwell. Einstein sought to explain the already well known fact that these equations violated Galilean relativity.

13 For a good discussion of this and further references, see Steven Weinberg, *Gravitation and Cosmology: Principles and Applications of the Theory of Relativity* (New York: John Wiley, 1972) While this book is highly technical, with many equations, it is still possible to read between the equations and obtain some valuable insights, since Weinberg is an excellent writer as well as a brilliant physicist.

14 For recent discussions of "nothing," see John D. Barrow, *The Book of Nothing: Vacuums, Voids, and the latest Ideas about the Origins of the Universe* (New York: Pantheon Books, 2000) and Robert Kaplan, *The Nothing That Is: The Natural History of Zero* (Oxford: Oxford University Press, 1999).

15 In *Timeless Reality*, I argued that all fields are simply mathematical ways we describe a more fundamental reality of particles, which exist in the theory as the "quanta" associated with the fields. This does not affect the current discussion, in which it can be specified that I am simply using the field description and not implying any deep, metaphysical reality to these fields.