2.

SPACE, TIME, AND MATTER

As children in blank darkness tremble and start at everything, so we in broad daylight are oppressed at times by fears as baseless as those horrors which children imagine coming to them in the dark. The dread and darkness of the mind cannot be dispelled by the sunbeams, the shining shafts of day, but only by an understanding of the outward form and inner workings of nature.

—Lucretius, *The Nature of Things*

Materialism and naturalism

Materialism is the doctrine that the universe is composed of a single substance called *matter* and nothing else. The answer materialism gives to the question "Is anything out there?" is: nothing is out there except matter.

Materialism is usually equated with *naturalism*, which is probably best described as the doctrine that denies the existence of gods or other "spirits." These entities are then, by definition, *supernatural.*

One might imagine a universe with no gods or spirits but still including stuff other than matter that we can still reasonably label as natural. By "stuff" here I refer to concrete, objective substances and exclude various abstractions like human thoughts and emotions, words, or mathematical equations. Think of the stuff as still being there even if humanity did not exist. For example, we might find substances that did not behave like matter but yet obeyed some identifiable "laws of nature" separate from the laws of nature we associate with matter. Since we have never seen any sign of such stuff, let's not bring up that possibility until the data require it. For our purposes we will equate any immaterial stuff with supernatural stuff. The *materialist/naturalist* view is that there is only matter. The *spiritualist/supernaturalist* view is that there is matter and spirit. I will not take seriously the *idealist* view that there is only spirit.

Often you will hear that science only deals with the natural. This is a position that is held by many scientists and is in fact the official doctrine of the National Academy of Sciences, the most prestigious scientific institution in the United States.[1] This has led to the charge from theists that science is dogmatically opposed to the supernatural or immaterial. This charge is understandable given the Academy's position, but nevertheless is unfair. We can rest assured that if any evidence were found for a world beyond matter scientists worldwide will be only too delighted to accept private or governmental funding to investigate such evidence further. Furthermore the NAS is dead wrong factually since reputable scientists in prestigious institutions such as Harvard University, Duke University, and the Mayo Clinic have done research on the efficacy of intercessory prayer, which surely is of supernatural significance.[2] So far the evidence is negative.

In fact, the purely material universe is nothing more than a working assumption, a scientific model that scientists have proposed to describe the data. So far this is all that is needed. If and when this model proves to be insufficient, then science will have to consider other possibilities.

Origins of materialism

Most of human history is the story of people dominated by shamans and priests who demanded worship, sacrifice, and strict obedience to unseen gods and spirits—as the shamans and priests interpreted the desires of gods and spirits. Materialism has ancient origins. In the sixth century BCE, Thales of Miletus (ca. 546 BCE), a Greek colony on the coast of what is now Turkey, proposed that everything was made of water. In the following century, the Greeks Leucippus (ca. 440 BCE) and Democritus (ca. 400 BCE) imagined that matter was composed of elementary "atoms" that could not be broken down further. Similar ideas are said to have appeared in India around the same time.

Two centuries later, Epicurus (d. 270 BCE) introduced a philosophical school of thought in which no gods existed and the universe was composed of atoms moving in empty space. He emphasized living a happy, self-sufficient life with no expectation of an afterlife. Although self-indulgence is often associated with the epicurean life style, Epicurus emphasized personal responsibility and morality.

The philosophy of Epicurus inspired one the of the great ancient poems, *De Rerum Natura* or *The Nature of Things* by the Roman Lucretius (d. 55 BCE), which is dated in the first century BCE. This poem was the only major work on classical materialism to survive antiquity intact.

Any voices of materialism that may have remained inside Christendom in the Dark Ages were suppressed by the Church until reappearing in the seventeenth century in the writings of Francis Bacon and Pierre Gassendi. In 1770, Paul d'Holbach published a monumental work, *The System of Nature,* which emphasized a materialistic, atheistic worldview in obvious contradiction to prevailing beliefs. In 1884, another influential manuscript appeared, *Force and Matter: Principles of the Natural Order of the Universe*, by Ludwig Buechner. This laid the groundwork for the modern materialistic view of nature that forms the underlying bedrock of science and much of secular human thinking today.[3]

Augustine and time

The materialist model of the universe is one of particles of matter moving about in space and time. Let us begin by taking a look at time.

In the fourth century, the great theologian Augustine of Hippo (d. 430) asked what God was doing before he made heaven and Earth. If he did nothing, why didn't he continue to do nothing? If he did something, performed some act, then that could not be part of true eternity since whatever the result of the act, it did not previously exist. Augustine jokes that God was busy preparing hell for those who "pry into mysteries." But he concludes more seriously that God is timeless, that time itself is not part of ultimate reality. Rather, time is subjective, existing only in the human mind, created by God. God thus lives in a different world than humans—a timeless one. Accordign to Augustine, time as we humans know it was created by God "when" he created the universe.

As for the world of time in which humans live, Augustine gave no good explanation for why God put the idea of time in our heads in the first place. Living well before humans had accurate clocks, he was not sure how to measure time, what it is when you say one period of time is longer than another.

However, Augustine's insight that time exists only in the human mind was right on the mark.

Time: a human invention

No human observation would seem to be so ubiquitous as the passage of time. Physicists and philosophers long after Augustine have never come up with a satisfactory explanation of time. Usually they try to describe time in terms of the concept of change, but how do you define change without having a notion of time to begin with?

Einstein, in his younger days before he became more metaphysical, gave a definition of time that remains to this day the best we can do: *Time is what you read on a clock.* This is an example of what we call an *operational* definition. All measurable quantities in physics are defined by how they are measured. Time is what you measure on a clock. Temperature is what you measure on a thermometer. Electric current is what you measure on an ammeter.

Like all the quantities of physics, time is a human invention. Of course, it is an invention used to describe phenomena in the external world, but it is a mistake to assume that what physics defines as time is identical to some metaphysical river that flows through the universe. Keep that in mind and you will have less difficulty accepting those modern physics notions of time that defy common sense.

In physical models time is usually represented by a real number. However, in cosmology you may read about "imaginary time," which is simply a mathematical construct whereby the measured time is multiplied by $\sqrt{-1}$ in order to provide for more convenient calculations.

Recall that Augustine had the deep insight that God, assuming he exists, operates outside of time.

Throughout most of history, the passage of time was registered by familiar regularities such as day and night and the phases of the moon, or more accurately by the apparent motions of certain stars. The second was defined by the ancient Babylonians to be 1/84,600 of a day. Our calendars are still based on *astronomical time* using the Gregorian calendar, introduced in 1582, in which the year is defined as 365.2425 days. More accurately, 1 year = 365.242199 days, from modern estimates.

Until the scientific revolution and the ages of exploration and industrialization that followed, most people had no need for accurate clocks. Farmers and fishermen measured time in relation to familiar processes in the cycle of work and domestic chores. Labor took place in the natural period from dawn to dusk. The sundial was widely used to tell time during the day. The great advance in the accuracy of household clocks came about in the mid-seventeenth century with the application of the pendulum, which had been introduced into scientific experiments by Galileo Galilei (d. 1642) in 1602. English clock- and watch-making became dominant in 1680 and remained so until competition from the French and Swiss caught up about a century later.

In 1759 John Harrison (d. 1776), seeking to win an English Parliamentary prize, produced a clock, or *chronometer*, that could keep exact Greenwich Mean Time at sea, enabling mariners to determine their longitude on the globe and making accurate marine navigation far from land possible for the first time.[4]

Today the primary time standard is provided by averaging the outputs of a bevy of Cesium Fountain atomic clocks at the National Institute for Standards and Technology laboratory in Boulder, Colorado near where I live, which will not gain or lose a second in more than 60 million years.

With the rise of science, the standard unit of time, the second, has undergone several redefinitions to make it more useful in the laboratory. The most recent change occurred in 1967 when the second was redefined by international agreement as the duration of 9,192,631,770 periods of the radiation corresponding to the transition between the two hyperfine energy levels of the ground state of the Cesium^{133} atom at rest at absolute zero. If you think of an oscillating electromagnetic wave being emitted by the atom and using each peak in the wave to move the clock one tick, then 9,192,631,770 ticks would correspond to one second. In other words, the time between ticks is 1/9,192,631,770 of a second or about 0.11 nanosecond, where a nanosecond is a billionth of a second.

In short, time, as we use it in both science and everyday life, is simply the number of ticks on a clock.

The minute remains 60 seconds, the hour remains 60 minutes, and the day remains 24 hours, following ancient traditions. The day is still taken to be 84,600 seconds, as in Babylonia. Our calendars need to be corrected occasionally to keep them in harmony with the seasons because of the lack of complete synchronization between atomic time and the motions of astronomical bodies.

The smallest time interval

Time intervals have been measured as small as 10^{-16} second, as of his writing. However, we cannot continue to divide time into smaller and smaller units. Because of both relativity and quantum mechanics, which we will describe later, the smallest operationally definable time interval is the *Planck time,* $6.4\text{x}10^{-44}$ second. This means that, fundamentally, time is an integer number of Planck units. It is (by definition) *discrete*, occurring in jumps, rather than continuous.

The discreteness of time is so small that it plays no role in even the most precise measurements of contemporary physics. As a result, physicists usually represent time in their equations with the real number t, which is assumed to be continuous. However it is important to recognize that assuming time is continuous is an approximation. In fact, it is discrete.

Time: limitless but not infinite

In Figure 2.1 a discrete time axis is shown in which each marker represents one step in Planck units. Suppose we define "now" as $t = 0$. Then we can count steps in the direction that we call the future: +1, +2, +3 and so on. Nothing that we know about the universe from cosmology and physics requires that we must stop counting, terminating the sequence at some point in the future. Of course we will all be dead and Earth extinct some time in the future, the universe may eventually be void of life in any form, but any clock that is still out there, such as a spinning neutrino, will keep ticking. From this we infer that time is limitless.

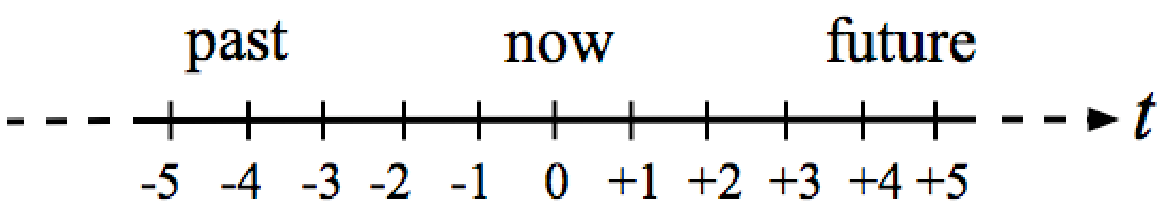

Fig. 2.1. The time axis is composed of discrete steps in Planck units. Times in between steps are undefined.

Similarly, we can start now and count back –1, –2, –3, and so on into the past. Despite the claims of theologians from Augustine to the contemporary Christian apologist William Lane Craig[5] that that the universe had a beginning in time, nothing we know about the universe from cosmology and physics requires that we stop counting, terminating the sequence sometime in the past. The universe does not appear to have any time limit in the past as well as in the future. Most likely it always was and always will be—just as it appeared to science before the discovery of the big bang.

Now to say that something is limitless is not the same as saying it is infinite. The term “infinity” is often used loosely, even by physicists, to refer to a very large number. However, from the work of the nineteenth century mathematician Georg Cantor, the set of real numbers we use to count the ticks on a clock form an infinite set, but none of the members of the set are themselves infinite.

The origin of time

Any point in time can be taken to represent the origin of our time axis, the point we call $t = 0$. In Fig. 2.1 I chose that origin to be “now.” In the West we count years starting four years after the supposed birth of Christ. We count forward in years we label as CE, the Common Era (previously AD) and backward is BCE, Before the Common Era (previously BC). Obviously that is an arbitrary choice not followed on other calendars such as those of Chinese, Jews, and Muslims. Some confusion arises since the first year of the Common Era is not year zero but 1 CE, while the preceding year is 1 BCE. Astronomers correct this in their own calendars by calling 1 CE year 1, 1 BCE year zero, 2 BCE is year –1, and so on.

When we time a race with a stopwatch, we reset the time to zero so we can read the race times directly off the watch. When we do so we are implicitly assuming a basic principle about time: *time intervals do not depend on when those intervals are measured*.

Now, we can imagine a world in which this was not the case. Suppose clocks ran differently at different times of day. That could happen if the standard clock we used to define time was, say, my heartbeats. Each morning I try to get some exercise such as playing tennis or taking a vigorous walk. After lunch I usually nap in my chair. So if you were timing a race by my heartbeats, a morning race would generally lead to larger race times than races after lunch.

Obviously we have avoided such complications by using objective means of measuring time, with the current definition in terms of atomic vibrations being an improvement over heartbeats or even over previous astronomical measures where, for example, using Earth's rotation would lead to small but similar discrepancies.

So, with time defined as objectively as possible we find that we can describe phenomena such as the motion of a runner or elementary particle in a way that does not depend on the origin of time. Putting it another way, the universe does not seem to single out any special moment in time.

But what about the beginning of the universe? Wasn't that a special moment in time?

What about the big bang?

Until the twentieth century, science had no evidence that our universe was of finite age. The stars and planets year by year repeated their motions through the skies to great precision. Rare cosmic events such as eclipses and comets were shown to also repeat in a predictable way. In the short period that humans have been making scientific observations of Earth and sky, these predictable cycles did not seem to change. For all anyone knew, the universe always was.

The discovery that our universe began some 13.7 billion years ago in an explosion called the *big bang* has been viewed by many theologians and even one pope as confirming the existence of a creator. Of course, the Genesis story of creation bears no resemblance to that described in big bang cosmology. Furthermore, many religions have creation myths of one kind or another, none more than superficially resembling the big bang, so none can claim that their particular beliefs have been scientifically confirmed by the big bang.

Nevertheless, the assertion is made that religion was ahead of science in conceiving of a universe of finite age, one that had a beginning. What is more, the physics of the big bang seemed to confirm Augustine's intuition that time itself began when the universe was created.

In 1970 cosmologists Stephen Hawking and Roger Penrose used Einstein's general theory of relativity to "prove" that our universe began with a *singularity*—an infinitesimal region in space in which the mass and energy densities are infinite.[6] Craig has used this result to argue that time must have begun with this singularity and thus the universe must have had a beginning. With no further basis, Craig has concluded that the universe must have been created by a personal God.[7]

However, both Hawking and Penrose now agree that no such singularity marked the beginning of our universe. Indeed, Hawking explicitly says so in his phenomenal 1988 bestseller, *The Brief History of Time*.[8] The original proof of Hawking and Penrose was not in error as far as it went. General relativity does imply the singularity. However, the authors now admit that general relativity, as it stands, does not apply below some minimum distance and before some minimum time. Furthermore, quantum mechanics strongly implies no such singularity occurred. In short, time need not have begun with the big bang. A prior universe may have existed and modern cosmological scenarios call for a prior universe and, very likely, many more as well.

Space: another human invention

We have seen that, at least as used in physics, time is defined operationally as what is measured on a clock. While any clock, such as my heartbeats, could be used, this would make time intervals depend on my personal activity. Even a clock based on Earth's rotation would require periodic adjustments because of changing tidal interactions between Earth and the other objects in the solar system. So we have defined time in terms of what is read on a cesium atomic clock. Now let us operationally define *space*.

Recall that our clocks only measure time intervals. No "absolute time" can be identified, measure from some special moment. Similarly, we can only specify a spatial interval between two points, which we call *distance* or *length.*

The familiar units of length still used in America and one or two other countries are defined in the *English system*. An inch is about the thickness of the thumb of a grown male; a foot is about the length of his foot; the yard about the length of his stride. This is not very objective, but these units are more accurately defined today in terms of the *meter* of the *metric system*, now the standard in most countries as well as in science.

In 1793 the meter was introduced as 1/10,000,000 of the distance from the pole to the equator. Since then it has gone through a series of increasingly precise definitions, from the length of a platinum-iridium bar stored under carefully controlled conditions in Paris to a certain number of wavelengths of the electromagnetic radiation from the krypton atom.

In 1905, Einstein introduced his *special theory of relativity*, profoundly revising our notions of space and time. The primary postulate of relativity is that the speed of light in a vacuum, a quantity conventionally referred to as *c*, is a constant that does not depend on the motion of the source of light or its observer. Thousands of scientific observations in the century since have confirmed the validity of Einstein's postulate.

In 1983, by international agreement, Einstein's postulate was incorporated into the definition of the meter, which was then defined to be the distance traveled by light in vacuum during 1/299,792,458 of a second. As discussed earlier, the second is defined as a certain number of vibrations of the cesium atom.

This latest definition of the meter has a profound consequence that is not widely recognized even among physicists. Since 1983, distance is no longer treated as a quantity that is independent of time. In fact, as we see from the definition of the meter above, distance is now officially defined in terms of time. Distance is the time it takes light to travel between two points in a vacuum. Of course, in practice we still use meter sticks and other means to measure distance, but in principle these must be calibrated against an atomic clock.

A further implication of the definition of the second and meter is that the quantity *c* is simply an arbitrary conversion factor. If you measure time in seconds and distance in meters, then *c* is *by definition* 299,792,458 meters per second. If you measure time in years and distance in light-years, $c = 1$ light-year per year, since the light-year is defined as the distance traveled by light in one year. When light travels through a medium, however, its speed is given by *c* divided by the index of refraction of the medium. Since no perfect vacuum exists in the universe, light can generally be found moving at a speed other than *c*, although the difference is very small in a near vacuum such as that of outer space.

The smallest space interval

We have seen that the smallest operationally defined time interval is the Planck time, $6.4\text{x}10^{-44}$ second. As long as we stick to the operational definition of time as what you read on a clock, then this becomes the smallest measurable time interval.

From the previous section, the operational definition of a space interval, what we call distance or length, is also what you measure on a clock as light moves in a vacuum from one end of the space interval to another. If the smallest measurable time interval is the Planck time, it follows that the smallest interval in space is the speed of light in a vacuum c = 299,792,458 meters per second times the Planck time. This distance, $1.9\text{x}10^{-35}$ meter, is called the *Planck* length.

And, just as time intervals can fundamentally be viewed as in integer number of Planck times, so space intervals can fundamentally be viewed as in integer number of Planck lengths. As with time, space is discrete. And, as with time, the fact that distance is usually thought of as a continuous variable is an approximation that is fine for most purposes but breaks down at the Planck scale. In other words, there exists no "space-time continuum" in any proper model describing physical events. We can get away with assuming a continuum for most applications but we cannot be expected to draw any universal or metaphysical conclusions from such models.

Limitless but not infinite space

In Fig. 2.1 a discrete time axis is shown in which each marker represents one step in Planck units. We can do the same for space, where we define "here" as $x = 0$. Then we can count steps in the positive direction on the x-axis: +1, +2, +3 and so on. Nothing that we know about the universe from cosmology and physics requires that we must stop counting, terminating the sequence at some distant place. Obviously we can do the same along the negative x-axis: –1, –2, –3, and so on. The universe has no known boundary in either space or time.

As was the case for time, it is technically incorrect to say the universe is "infinite" in size. It simply is without end in any direction. And, just as there is no special moment in time, there is no special position in space—no center of the universe. This was a recognition long time coming to the human race.

Matter and energy

Next, let us discuss matter and energy. A very simple definition of a matter is *anything that kicks back when you kick it*. That is, matter has the property that physicists call *inertia*. The inertia of a body is measured by its *mass*. The greater a body's mass, the harder it is to get moving. It is also harder to stop once it is moving. Or, more generally, the more massive a body the harder it is to change its motion. This is all common experience.

Two other physical quantities are closely related to mass. One is *momentum*, which Newton identified as the "quantity of motion." For speeds low compared to the speed of light, the magnitude of the momentum of a body is the product of it mass and speed. A more complicated formula is needed at speeds near the speed of light.

In 1905 Einstein showed that a body contains a *rest energy* E_o equal to its mass m multiplied by the speed of light c squared—what all writers call "Einstein's famous equation," $E_o = mc^2$. A body in motion has an additional energy called *kinetic energy* and can also have a *potential energy* that is stored energy. For example, a rock held above your head has potential energy that converts into kinetic energy when you release it and it falls to Earth. As in this example, energy can change its type and, because of $E_o = mc^2$, mass can be converted to energy and, inversely, energy can be converted to mass. The total energy E of a body is thus the sum of its rest, kinetic, and potential energies.

Material bodies are also affected by gravity, being pulled toward other bodies in proportion to the product of the masses of the bodies and in inverse proportion to the square of the distance between their centers. This is called *Newton's law of gravity*.

Atoms and particles

In common experience matter appears in three forms: solid, liquid, and gas. It looks continuous, but is in fact composed of large number of small objects called *molecules*. These molecules are composed of even smaller objects we call atoms. This is a bit of a misnomer, but in the nineteenth century it was thought that these were the elementary objects conjectured by Leucippus and Democritus, which were called atoms because they were assumed to be "uncuttable," not composed of even simpler parts. Today's atoms are identified with the *chemical elements* of the Periodic Table. Elements cannot be broken down further by chemical reactions, since these have insufficient energy. They can, however, be "transmuted" by nuclear reactions.

As we will discuss in future chapters, atoms have a substructure of electrons and nuclei, where the nuclei are composed of protons and neutrons. The protons and neutrons, in turn, are composed of two kinds of objects called *quarks:* the *up* (*u*) and *down* (*d*). We will also see that a large variety of very short-lived material particles exist that is produced in high-energy collisions. Two additional "generations" of quarks and heavier versions of the electron are known to constitute these particles. While these two generations do not currently play an important role in the universe, they were very important in the early stages of the big bang.

I will provide evidence that light is also a form of matter, composed of particles we call *photons.* Photons have inertia and are also affected by gravity. Very low energy photons left over from the big bang form a highly uniform gas, cooled by the expansion of the universe to 2.7 degrees above absolute zero (Kelvin scale) that fills the universe. This is called the *cosmic microwave background*. While not a major contributor to the total energy of the universe, the number of photons is a billion times greater than the number of atoms in all the galaxies.

Matter in the universe

Just three particles—the *u* and *d* quarks and the electron—are needed to describe atomic matter, which constitutes most of familiar matter, including all the matter in planets and stars including living organisms. By far most of the matter of the universe is invisible to both the naked eye and to conventional telescopes. Visible matter—all the stars and galaxies that give off light—constitutes a mere 0.5 percent of the mass of the universe.

Only 3.5 percent of the remainder is composed of non-luminous atomic matter—dust, rocks, planets, and burned out stars. We now know from its gravitational effects on the visible universe that 26 percent of the mass/energy of the universe resides in a yet unidentified form of invisible matter dubbed *dark matter*.[9] Cosmologists have ample evidence that dark matter cannot be the same kind of stuff as atomic matter, that is, it is not composed of quarks and electrons.

In 1998 it was discovered that the expansion of the universe was accelerating. This can only be explained by the action of some invisible stuff permeating the universe that actually has negative or repulsive gravity that is pushing all the stars and galaxies in the universe away from one another and an ever-increasing rate. This stuff is called *dark energy* and carries by far the most mass/energy of the universe, 70 percent. It is separate from dark matter, which exhibits familiar attractive gravity.

In his *general theory of relativity* published in 1916, Einstein showed that repulsive gravity was possible when a medium has a pressure that is sufficiently negative. He also introduced what is called the *cosmological constant*, which is the curvature of empty space that is equivalent to a field with negative pressure and repulsive gravity. Observations made since 1998 tend to favor the cosmological constant as the source of dark energy, but other possibilities remain.

Whatever the nature of dark matter and dark energy, they are clearly material and natural, having the properties of inertia and gravity that we associate with matter. Those seeking something supernatural out there need to look elsewhere for the dark matter and dark energy.

The arrow of time

Common experience tells us that time "flows" in one direction, from past to future. Would that it didn't and once in a while we could grow younger. However, none of the basic equations of physics specifies a direction of time. Those equations work either way. They can be used to predict the past as well as the future. The one exception is the *second law of thermodynamics* in which heat always flows from a higher temperature body to a lower temperature one, which is why we have to pay for air conditioning.

In the nineteenth century, Ludwig Boltzmann showed that the direction or "arrow" of time of common experience is purely a statistical effect that results from the large number of particles in more-or-less random motion that constitutes material systems on the macro scale.

For example, when you puncture a tire air will flow out flattening the tire. But no law of basic physics forbids that a moment later air from the outside flows in and re-inflates the tire. All that has to happen is that a sufficient number of outside air molecules move in the direction of the puncture. Since they are moving around randomly, there is some non-zero probability for this to happen. The problem is, that probability is very small.

So Boltzmann defined the arrow of time as the direction in which more probable occurrences take place. He also was able to explain the second law of thermodynamics by showing that the probability for heat to go from higher temperature to lower is much greater than the opposite direction.

It is important to keep in mind, then, that the universe has no fundamental direction of time. Effects can precede causes and the whole idea of creation, which has a built-in assumption on the direction of time, needs to be rethought.

Notes

[1] National Academy of Sciences. *Teaching About Evolution and the Nature of Science*. Washington, DC: National Academy of Sciences, 1998, http://www.nap.edu/catalog/5787.html (accessed March 5, 2006).

[2] M. W. Krucoff, S. W. Crater, et al. “Music, Imagery, Touch, and Prayer as Adjuncts to Interventional Cardiac Care: The Monitoring and Actualization of Noetic Trainings (MANTRA) II Randomized Study.” *Lancet* 366 (July 16, 2005): 211–17.

[3] Richard C. Vitzthum, *Materialism: An Affirmative History and Definition* (Prometheus Books: 1995).

[4] Dava Sobel, *Longitude: The True Story of a Lone Genius Who Solved the Greatest Scientific Problem of his Time* (Walker Publishing Company, 1995).

[5] William Lane Craig, *The Kaläm Cosmological Argument*. Library of Philosophy and Religion (Macmillan, 1979).

[6] Steven W. Hawking and Roger Penrose "The Singularities of Gravitational Collapse and Cosmology," *Proceedings of the Royal Society of London*, series A, 314, (1970): 529-48.

[7] Craig, 1979.

[8] Stephen W. Hawking, *A Brief History of Time: From the Big Bang to Black Holes* (Bantam, 1988): p. 50.

[9] These numbers can be expected to change slightly as measurements improve, but they define the ball park.