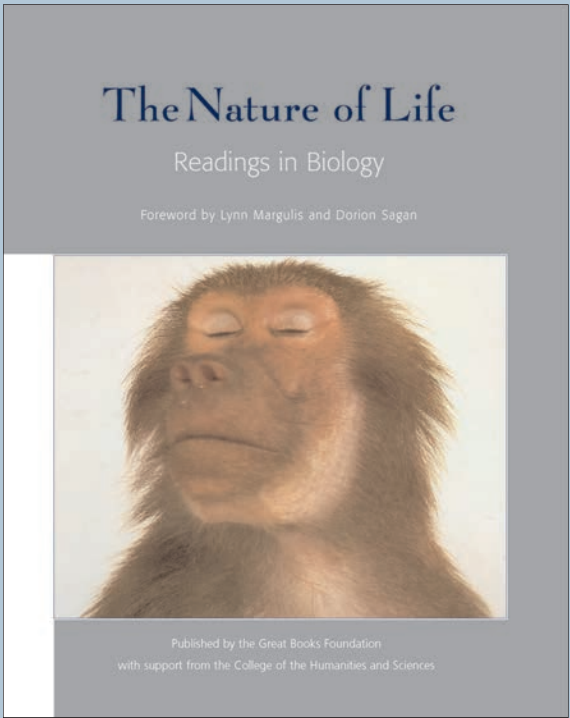
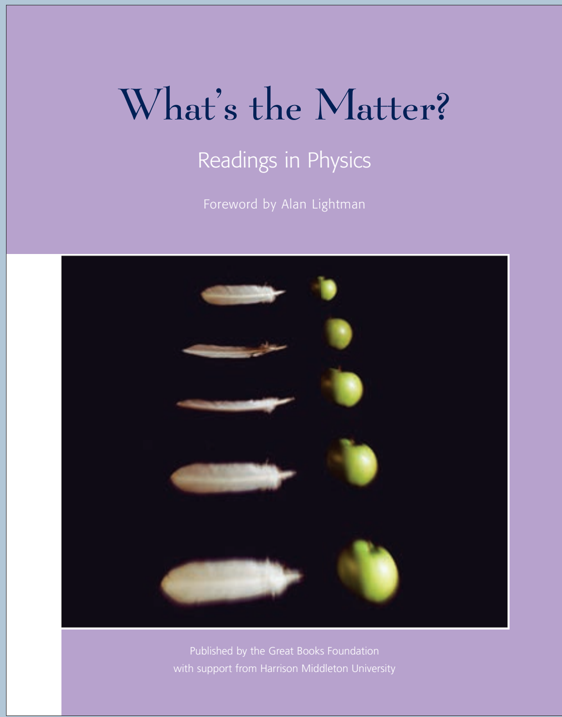
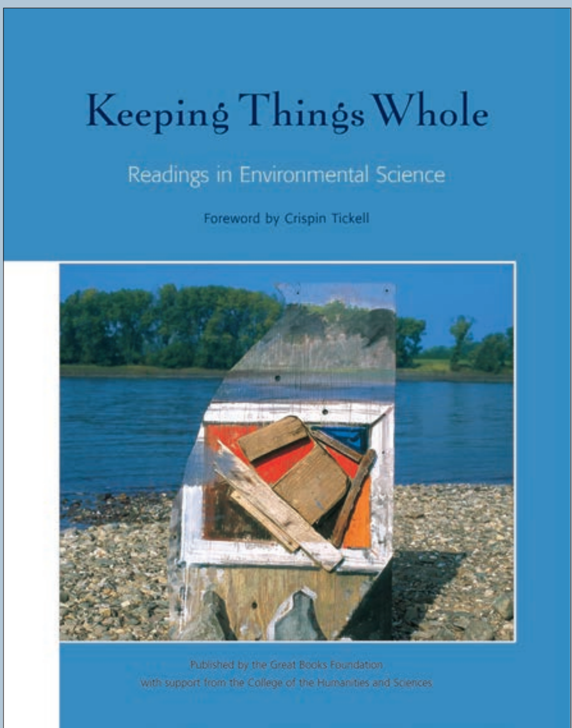
Great Books Science Series







Sample Units

The Great Books Foundation
A nonprofit educational organization

Series published with support
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Introduction to the Great Books Science Series

Using the Science Series in Your Classroom

Increasingly, middle school, high school, and college teachers are being held accountable for providing reading instruction in the content areas. The Great Books Science Series provides selections that address reading comprehension, critical thinking, and writing while providing interesting topics for discussion. The Great Books Foundation's Shared Inquiry™ method of learning is perfect for investigating works in biology, environmental science, and physics. In addition, many of the selections will complement laboratory experiments and practical demonstrations in the thematic areas of the sciences.

The science series is not intended to replace the classroom textbook, but rather to provide extended knowledge. You can use the series throughout the school year, or during the last 6 to 8 weeks, when students can apply knowledge learned in the textbook to readings in the science content areas.

About Shared Inquiry Discussion

Shared Inquiry is the effort to achieve a more thorough understanding of a text by discussing questions, responses, and insights with others. For both the leader and the participants, careful listening is essential. The leader guides the discussion by asking questions about specific ideas and problems of meaning in the text, but does not seek to impose his or her own interpretation on the group.

During a Shared Inquiry discussion, group members consider a number of possible ideas and weigh the evidence for each. Ideas that are entertained and then refined or abandoned are not thought of as mistakes, but as valuable parts of the thinking process. Group members gain experience in communicating complex ideas and in supporting, testing, and expanding their thoughts. Everyone in the group contributes to the discussion, and while participants may disagree with one another, they treat one another's ideas respectfully.

Shared Inquiry discussion is a vital way to develop an understanding of the ideas in texts that have fundamentally shaped how people think about the world. By reading and thinking together about these important works, participants in Shared Inquiry discussion groups are joining a great conversation extending across the centuries.

What Shared Inquiry Contributes to the Study of Science

Shared Inquiry focuses on the interpretation of texts, in the belief that many readers working together can achieve a more complete understanding than any one reader can alone. We hope that reading and discussing the selections in these anthologies will not only increase your students' knowledge of biology, environmental science, and physics, but also enhance their appreciation of the scientific process. By reading scientists' own explanations of their work, students can see the evolution of their ideas and the way in which they build on the work of colleagues both present and past. And because science advances by asking questions, posing hypotheses, and testing them, the parallels between the scientific method and Shared Inquiry discussion are strong.

Guidelines for Leading and Participating in Discussion

Over the past fifty years, the Great Books Foundation has developed guidelines that distill the experience of many discussion groups, with participants of all ages. We have found that when groups adhere to the following procedures, discussions are most focused and fruitful:

1. **Read the selection before participating in the discussion.** This ensures that all participants are equally prepared to talk about the ideas in the work, and helps prevent talk that would distract the group from its purpose.
2. **Support your ideas with evidence from the text.** This keeps the discussion focused on understanding the selection and enables the group to weigh textual support for different answers and to choose intelligently among them.
3. **Discuss the ideas in the selection, and try to understand them fully before exploring issues that go beyond the selection.** Reflecting on a range of ideas and the evidence to support them makes the exploration of related issues more productive.

4. **Listen to others and respond to them directly.** Shared Inquiry is about the give-and-take of ideas, a willingness to listen to others and to talk to them respectfully. Directing your comments and questions to other group members, not always to the leader, will make the discussion livelier and more dynamic.
5. **Expect the leader to ask questions, rather than answer them.** The leader is a kind of chief learner, whose role is to keep discussion effective and interesting by listening and asking questions. The leader's goal is to help the participants develop their own ideas, with everyone (the leader included) gaining a new understanding in the process. When participants hang back and wait for the leader to suggest answers, discussion falters.

Using the Questions for Each Reading

Content Questions

These questions will help students grasp more fully the scientific information in each selection. Students will be able to answer content questions on the basis of the selections themselves; no additional sources are needed.

Application Questions*

Going beyond the material covered in the reading is the distinguishing factor of these questions. They require students to bring in and apply information from other sources, and they may entail some research. Application questions will enable students to work more concretely with the ideas expressed in the readings.

Discussion Questions

These questions may be reasonably answered in many different ways because they ask students to express their own ideas about the issues raised in the selections. Discussion questions offer students the opportunity to weigh evidence, consider their own convictions, connect their study of

*Not included in *What's the Matter? Readings in Physics*.

science to other subjects, and respond to scientific thinkers with their own reasoned judgment.

Great Books Professional Development

Great Books programs involve teachers and students as partners in reading, discussing, and writing about the important questions and ideas raised by outstanding works of literature. We call this collaboration the Shared Inquiry method of learning.

Whether you are new to using the Shared Inquiry method in the classroom or you are a seasoned Great Books leader, we have a selection of courses to make sure you can start off strong, increase your proficiency as a leader, and master higher-level questioning skills. Our course format offers:

- Greater flexibility in scheduling, including many half-day options
- More research-based connections to effective classroom practices
- New professional development materials with hands-on components

For more information about Great Books materials or workshops, call the Great Books Foundation at 800-222-5870 or visit our website at www.greatbooks.org.

About the Great Books Foundation

The Great Books Foundation is an independent, nonprofit educational organization whose mission is to help people learn how to think and share ideas. Established in 1947 to promote liberal education for the general public, the Foundation extended its mission to children in 1962 with the introduction of Junior Great Books®. Since its inception, the Foundation has helped thousands of people in the United States and in other countries begin their own discussion groups in schools, libraries, and community centers. Today, staff instructors conduct hundreds of workshops each year, in which educators and parents learn to lead Shared Inquiry discussion.

The Nature of Life Sample Unit

Selections

Parts of Animals Aristotle

The Way Things Are Lucretius

Novum Organum Francis Bacon

Conclusion to *On the Origin of Species* Charles Darwin

Struggle for Existence Charles Darwin

The Descent of Man Charles Darwin

Natural Selection Charles Darwin

Experiments in Plant Hybridization Gregor Mendel

An Introduction to the Study of Experimental Medicine Claude Bernard

The Snout Loren Eiseley

Silent Spring Rachel Carson

Ecce Homo! Konrad Lorenz

Rats Konrad Lorenz

The Double Helix James D. Watson

The Selfish Gene Richard Dawkins

Why Big Fierce Animals Are Rare Paul Colinvaux

Just in the Middle Stephen Jay Gould

The Diversity of Life Edward O. Wilson

Life from Scum Lynn Margulis

Thematic Table

This table provides an overview of the major themes and subject areas addressed by each of the selections in *The Nature of Life*.

Theme	I. Molecules and Cells	II. Heredity and Evolution	III. Organisms and Populations
1. Science as a Process			
Aristotle			Aristotle
Bacon*			
Darwin		Darwin	Darwin
Mendel		Mendel	
Bernard			Bernard
Lorenz		Lorenz	Lorenz
Watson	Watson	Watson	
Colinvaux			Colinvaux
Gould	Gould		
Margulis	Margulis	Margulis	Margulis
2. Evolution			
Lucretius		Lucretius	
Darwin		Darwin	Darwin
Mendel		Mendel	
Eiseley		Eiseley	Eiseley
Lorenz		Lorenz	Lorenz
Watson	Watson	Watson	
Dawkins	Dawkins	Dawkins	Dawkins
Colinvaux		Colinvaux	Colinvaux
Wilson		Wilson	Wilson
Margulis	Margulis	Margulis	Margulis
3. Energy Transfer			
Carson	Carson	Carson	
Watson	Watson	Watson	
Colinvaux		Colinvaux	Colinvaux
Wilson			Wilson
Margulis	Margulis	Margulis	Margulis
4. Continuity and Change			
Aristotle			Aristotle
Lucretius		Lucretius	Lucretius
Darwin		Darwin	Darwin
Mendel		Mendel	
Eiseley		Eiseley	Eiseley
Lorenz		Lorenz	Lorenz
Watson	Watson	Watson	
Dawkins	Dawkins	Dawkins	Dawkins
Colinvaux		Colinvaux	Colinvaux
Gould	Gould	Gould	
Wilson			Wilson
Margulis	Margulis	Margulis	Margulis

Theme	I. Molecules and Cells	II. Heredity and Evolution	III. Organisms and Populations
5. Relationship of Structure to Function			
Aristotle			Aristotle
Darwin		Darwin	Darwin
Eiseley		Eiseley	Eiseley
Watson	Watson	Watson	
Dawkins	Dawkins	Dawkins	
Colinvaux		Colinvaux	Colinvaux
Gould	Gould	Gould	
Margulis	Margulis	Margulis	Margulis
6. Regulation			
Darwin		Darwin	Darwin
Mendel		Mendel	
Bernard			Bernard
Carson	Carson	Carson	Carson
Lorenz		Lorenz	Lorenz
Colinvaux			Colinvaux
Gould	Gould	Gould	
Wilson			Wilson
Margulis	Margulis	Margulis	Margulis
7. Interdependence in Nature			
Darwin		Darwin	Darwin
Eiseley		Eiseley	Eiseley
Carson	Carson	Carson	Carson
Lorenz		Lorenz	Lorenz
Dawkins	Dawkins	Dawkins	Dawkins
Colinvaux		Colinvaux	Colinvaux
Wilson		Wilson	Wilson
Margulis	Margulis	Margulis	Margulis
8. Science, Technology, and Society			
Bacon*			
Bernard			Bernard
Carson	Carson		Carson
Lorenz		Lorenz	Lorenz
Dawkins	Dawkins	Dawkins	
Gould	Gould	Gould	Gould
Margulis	Margulis		Margulis

* Although not specifically concerned with biology, the selection from Bacon's *Novum Organum* is included to raise general questions about the inductive scientific method.

Charles Darwin

When Charles Darwin (1809–1882) published *On the Origin of Species* in 1859, articulating and supporting the theory of evolution in a way that could be understood by the general public, a long and bitter controversy ensued. Until the mid-nineteenth century, most scientists believed that the earth was only several thousand years old and that species of plants and animals had been separately created and were unchanging. But by the beginning of the nineteenth century, new ideas were fermenting about the earth's age and changes in species over time. The idea that humanity was descended from apes shook the religious faith of many and fired others to resist Darwin's theories fiercely. This mid-Victorian gentleman began a debate about human origins that continues today.

As a child and a young man, Darwin seemed extremely unlikely to cause such cataclysmic change. A mediocre student, he pursued medical training chiefly because his father and grandfather had been prominent physicians. Medicine failed to keep his interest, however, and he found watching surgery in an era before anesthesia unendurable. When Darwin rejected medicine, his father advised him to study for the ministry and, in 1831, he took a divinity degree from Cambridge University.

Darwin's life changed decisively when his science tutor at Cambridge, John Stevens Henslow, recommended that he accompany Captain Robert Fitzroy on his voyage of scientific exploration aboard the HMS *Beagle*. On this five-year trip, Darwin honed his powers of observation, formed his first original scientific theories, and became fascinated by the question of how species develop, which he would explore for the next twenty years. Darwin was strongly influenced by Sir Charles Lyell, whose *Principles of Geology* suggested that the earth was eons older than previously thought; in 1856, Darwin began to write about his own theory of evolution. He was spurred to publish his work when he read an essay by Alfred Russel Wallace that presented the same ideas, though without much supporting evidence. Painfully aware of the controversy his work would create, Darwin nevertheless published both *On the Origin of Species* and, in 1871, *The Descent of Man*. At his death in 1882, Darwin was buried in Westminster Abbey.

Struggle for Existence

Before entering on the subject of this chapter, I must make a few preliminary remarks to show how the struggle for existence bears on natural selection. It has been seen in the last chapter that amongst organic beings in a state of nature there is some individual variability: indeed I am not aware that this has ever been disputed. It is immaterial for us whether a multitude of doubtful forms be called species or subspecies or varieties—what rank, for instance, the two or three hundred doubtful forms of British plants are entitled to hold, if the existence of any well-marked varieties be admitted. But the mere existence of individual variability and of some few well-marked varieties, though necessary as the foundation for the work, helps us but little in understanding how species arise in nature. How have all those exquisite adaptations of one part of the organization to another part, and to the conditions of life, and of one organic being to another being, been perfected? We see these beautiful coadaptations most plainly in the woodpecker and the mistletoe, and only a little less plainly in the humblest parasite which clings to the hairs of a quadruped or feathers of a bird, in the structure of the beetle which dives through the water, in the plumed seed which is wafted by the gentlest

This selection is taken from The Origin of Species by Means of Natural Selection, or The Preservation of Favored Races in the Struggle for Life, *Sixth Edition (1872), chapter 3, "Struggle for Existence."*

breeze; in short, we see beautiful adaptations everywhere and in every part of the organic world.

Again, it may be asked, how is it that varieties, which I have called incipient species, become ultimately converted into good and distinct species which in most cases obviously differ from each other far more than do the varieties of the same species? How do those groups of species, which constitute what are called distinct genera and which differ from each other more than do the species of the same genus, arise? All these results, as we shall more fully see in the next chapter, follow from the struggle for life. Owing to this struggle, variations, however slight and from whatever cause proceeding, if they are in any degree profitable to the individuals of a species in their infinitely complex relations to other organic beings and to their physical conditions of life, will tend to the preservation of such individuals and will generally be inherited by the offspring. The offspring, also, will thus have a better chance of surviving, for, of the many individuals of any species which are periodically born, but a small number can survive. I have called this principle, by which each slight variation, if useful, is preserved, by the term *natural selection* in order to mark its relation to man's power of selection. But the expression often used by Mr. Herbert Spencer of the *survival of the fittest* is more accurate and is sometimes equally convenient. We have seen that man by selection can certainly produce great results and can adapt organic beings to his own uses through the accumulation of slight but useful variations given to him by the hand of nature. But natural selection, as we shall hereafter see, is a power incessantly ready for action and is as immeasurably superior to man's feeble efforts as the works of nature are to those of art.

Content Questions

1. What are *coadaptations,* and why does Darwin consider them so important to the theory of natural selection? (10)

2. How does Darwin answer the question of how, over time, varieties of plants and animals become distinct species? (11)

3. Based on this selection, how would you define the terms *natural selection* and *survival of the fittest?*

Application Questions

Darwin writes that "owing to this struggle, variations, however slight and from whatever cause proceeding, if they are in any degree profitable to the individuals of a species . . . will tend to the preservation of such individuals and will generally be inherited by the offspring." (11)

1. Darwin was unaware of the sources of the variations to which he refers. What are the sources of genetic variation known to us today?

2. In general, from what we know today, what kinds of variations can be inherited as Darwin suggests? What kinds of variations cannot be inherited? Give examples of each.

Discussion Question

What does Darwin mean when he says that "natural selection . . . is a power incessantly ready for action and is as immeasurably superior to man's feeble efforts as the works of nature are to those of art"? (11)

Keeping Things Whole Sample Unit

Selections

Rules for the Direction of the Mind René Descartes

Katahdin Henry David Thoreau

Death of a Pine Henry David Thoreau

Man and Nature George Perkins Marsh

The Biosphere Vladimir I. Vernadsky

The Climax Concept Frederic E. Clements

The Ecosystem A. G. Tansley

The Land Ethic Aldo Leopold

Odyssey Aldo Leopold

The Economics of the Coming Spaceship Earth Kenneth E. Boulding

The Tragedy of the Commons Garrett Hardin

The Closing Circle Barry Commoner

The World's Biggest Membrane Lewis Thomas

Intricacy Annie Dillard

The Recognition of Gaia James E. Lovelock

The End of Nature Bill McKibben

The Words *Nature, Wild*, and *Wilderness* Gary Snyder

Water Songs Terry Tempest Williams

The Politics of Wilderness and the Practice of the Wild R. Edward Grumbine

Cutover Jan Zita Grover

Dimensions of Deformity Gordon L. Miller

Thematic Table

This table provides an overview of the major themes and subject areas addressed by each of the selections in *Keeping Things Whole*.

Theme	I. Natural Science	II. Social Science	III. Philosophy and Literature
1. SCIENCE AS A PROCESS			
Descartes			Descartes
Clements	Clements		
Tansley	Tansley		
Leopold	Leopold		Leopold
Lovelock	Lovelock		
Miller	Miller		Miller
2. ENERGY CONVERSION			
Vernadsky	Vernadsky		
Leopold	Leopold		Leopold
Boulding		Boulding	
Commoner	Commoner	Commoner	
Thomas	Thomas		Thomas
Dillard	Dillard		Dillard
Lovelock	Lovelock		
3. EARTH'S INTERCONNECTEDNESS			
Vernadsky	Vernadsky		
Clements	Clements		
Tansley	Tansley		
Leopold	Leopold		Leopold
Boulding		Boulding	
Commoner		Commoner	
Thomas	Thomas		Thomas
Dillard	Dillard		Dillard
Lovelock	Lovelock		
4. HUMAN ALTERATIONS			
Thoreau			Thoreau
Marsh	Marsh	Marsh	
Leopold	Leopold	Leopold	Leopold
Boulding		Boulding	

Theme	I. Natural Science	II. Social Science	III. Philosophy and Literature
4. HUMAN ALTERATIONS (continued)			
Hardin		Hardin	Hardin
Commoner	Commoner	Commoner	
McKibben			McKibben
Snyder			Snyder
Williams	Williams		Williams
Grumbine	Grumbine	Grumbine	Grumbine
Grover			Grover
Miller	Miller		Miller
5. ENVIRONMENTAL PROBLEMS: SOCIAL AND CULTURAL CONTEXT			
Thoreau			Thoreau
Leopold	Leopold	Leopold	Leopold
Boulding		Boulding	
Hardin		Hardin	Hardin
Commoner	Commoner	Commoner	
McKibben			McKibben
Snyder			Snyder
Williams	Williams		Williams
Grumbine	Grumbine	Grumbine	Grumbine
Grover	Grover	Grover	Grover
Miller	Miller		Miller
6. SURVIVAL AND SUSTAINABILITY			
Marsh	Marsh	Marsh	
Leopold	Leopold	Leopold	Leopold
Boulding		Boulding	
Hardin		Hardin	Hardin
Commoner	Commoner	Commoner	
McKibben			McKibben
Grumbine	Grumbine	Grumbine	Grumbine

Henry David Thoreau

Henry David Thoreau (1817–1862) met Ralph Waldo Emerson in 1837 and with him formed the transcendentalist group, an association of writers and philosophers that included the social reformer and feminist Margaret Fuller and the educator Bronson Alcott. As set forth in Emerson's essay "Nature" (1836), the transcendental mindset was one of idealism and optimism; transcendentalists argued that it is necessary to transcend the empirical and scientific through intuition to arrive at an ideal spiritual reality where truth is revealed. But Thoreau's distrust of like-minded communities and his propensity for detailed observation—that is, empirical methods—eventually led him away from the group and forced him to reject some of Emerson's tenets.

In 1845, Thoreau built a cabin on Emerson's property at Walden Pond, near Concord, Massachusetts, the town where he was born. There Thoreau set out to test his transcendental convictions, going to the woods to "live deliberately, to front only the essential facts of life," and to exercise self-reliance. His observations and meditations at Walden from 1845 to 1847 convinced him that nature is less benevolent than Emerson believed, but still sublime—even awesome—in its profound indifference. *Walden,* finally published in 1854, with its surveys of the pond and the surrounding terrain, brought Thoreau recognition as one of America's early naturalists.

As a protest against slavery and war with Mexico, Thoreau refused to pay his poll tax and spent a night in jail in 1846. He explained his actions in "Resistance to Civil Government" (1849), later published as "Civil Disobedience." Throughout the 1850s, Thoreau worked as a surveyor and became deeply involved in the abolitionist movement, sheltering escaped slaves on their way to Canada. His political activism, his support of abolition, and the popularity of *Walden* make Thoreau a forerunner of the civil rights and ecology movements.

"Katahdin" was first published in 1848.

Katahdin

(selection)

Setting out on our return to the river, still at an early hour in the day, we decided to follow the course of the torrent, which we supposed to be Murch Brook, as long as it would not lead us too far out of our way. We thus traveled about four miles in the very torrent itself, continually crossing and recrossing it, leaping from rock to rock, and jumping with the stream down falls of seven or eight feet, or sometimes sliding down on our backs in a thin sheet of water. This ravine had been the scene of an extraordinary freshet in the spring, apparently accompanied by a slide from the mountain. It must have been filled with a stream of stones and water, at least twenty feet above the present level of the torrent. For a rod or two on either side of its channel, the trees were barked and splintered up to their tops, the birches bent over, twisted, and sometimes finely split like a stable broom; some a foot in diameter snapped off, and whole clumps of trees bent over with the weight of rocks piled on them. In one place we noticed a rock two or three feet in diameter, lodged nearly twenty feet high in the crotch of a tree. For the whole four miles, we saw but one rill emptying in, and the volume of water did not seem to be increased from the first. We traveled thus very rapidly with a downward impetus, and grew remarkably expert at leaping from rock to rock, for leap we must, and leap we did, whether there was any rock at the right distance or not. It was a pleasant picture when the foremost turned about and looked up the winding ravine, walled in with rocks and the green forest, to see at intervals of a rod or two, a red-shirted or green-jacketed mountaineer against the white torrent, leaping down the channel with his pack on his back, or pausing upon a convenient rock in the midst of the torrent to mend a rent in his clothes, or unstrap the dipper at his belt to take a draft of the water. At one place we were startled by seeing, on a little sandy shelf by the side of the stream, the fresh print of a man's foot, and for a moment realized how Robinson Crusoe felt in a similar case; but at last we remembered that we had struck this stream on our way up, though we could not have told where, and one had descended into the ravine for a drink. The cool air above, and the continual bathing of our bodies in mountain water, alternate foot, sitz, douche, and plunge baths, made this walk exceedingly refreshing, and we had traveled only a mile or two after leaving the torrent before every thread of our clothes was as dry as usual, owing perhaps to a peculiar quality in the atmosphere.

After leaving the torrent, being in doubt about our course, Tom threw down his pack at the foot of the loftiest spruce tree at hand and shinned up the bare trunk some twenty feet, and then climbed through the green tower, lost to our sight, until he held the topmost spray in his hand. . . . To Tom we cried, where away does the summit bear? Where the burnt lands? The last he could only conjecture; he descried, however, a little meadow and pond, lying probably in our course, which we concluded to steer for. On reaching this secluded meadow, we found fresh tracks of moose on the shore of the pond, and the water was still unsettled as if they had fled before us. A little further, in a dense thicket, we seemed to be still on their trail. It was a small meadow, of a few acres, on the mountainside, concealed by the forest, and perhaps never seen by a white man before, where one would think that the moose might browse and bathe, and rest in peace. Pursuing this course, we soon reached the open land, which went sloping down some miles toward the Penobscot.

Perhaps I most fully realized that this was primeval, untamed, and forever untamable *Nature,* or whatever else men call it, while coming down this part of the mountain. We were passing over "Burnt Lands," burnt by lightning, perchance, though they showed no recent marks of fire, hardly so much as a charred stump, but looked rather like a natural pasture for the moose and deer, exceedingly wild and desolate, with occasional strips of timber crossing them, and low poplars springing up, and patches of blueberries here and there. I found myself traversing them familiarly, like some pasture run to waste, or partially reclaimed by man; but when I reflected what man, what brother or sister or kinsman of our race made it and claimed it, I expected the proprietor to rise up and dispute my passage. It is difficult to conceive of a region uninhabited by man. We habitually presume his presence and influence everywhere. And yet we have not seen pure Nature, unless we have seen her thus vast, and drear, and inhuman, though in the midst of cities. Nature was here something savage and awful, though beautiful. I looked with awe at the ground I trod on, to see what the Powers had made there, the form and fashion and material of their work. This was that Earth of which we have heard, made out of Chaos and Old Night. Here was no man's garden, but the unhandseled globe. It was not lawn, nor pasture, nor mead, nor woodland, nor lea, nor arable, nor wasteland. It was the fresh and natural surface of the planet Earth, as it was made forever and ever—to be the dwelling of man, we say—so Nature made it, and many may use it if he can. Man was not to be associated with it. It was Matter, vast, terrific—not his Mother Earth that we have heard of, not for him to tread on, or be buried in—no, it were being too familiar even to let his bones lie there—the home this of Necessity and Fate. There was there felt the presence of a force not bound to be kind to man. It was a place for heathenism and superstitious rites—to be inhabited by men nearer of kin to the rocks and to wild animals than we. We walked over it with a certain awe, stopping from time to time to pick the blueberries which grew there and had a smart and spicy taste. Perchance where *our* wild pines stand, and leaves lie on their forest floor in Concord, there were once reapers, and husbandmen planted grain; but here not even the surface had been scarred by man, but it was a specimen of what God saw fit to make this world. What is it to be admitted to a museum, to see a myriad of particular things, compared with being shown some star's surface, some hard matter in its home! I stand in awe of my body, this matter to which I am bound has become so strange to me. I fear not spirits, ghosts, of which I am one—*that* my body might—but I fear bodies, I tremble to meet them. What is this Titan that has possession of me? Talk of mysteries! Think of our life in nature—daily to be shown matter, to come in contact with it—rocks, trees, wind on our cheeks! The *solid* earth! The *actual* world! The *common sense! Contact! Contact! Who* are we? *Where* are we?

Content Questions

1. What do Thoreau's observations while hiking down Murch Brook reveal about the terrain? (17–18)

2. What does Thoreau mean when he speaks of "passing over 'Burnt Lands,' . . . though they showed no recent marks of fire"? (18)

3. According to Thoreau, why is it "difficult to conceive of a region uninhabited by man"? What must we see or experience to see "pure Nature"? (19)

Application Question

Choose a familiar place—your backyard, a city or state park—and, following Thoreau's example, pay careful attention to what surrounds you. What new information does this familiar place reveal through careful observation?

Discussion Questions

1. What does Thoreau mean by the word *nature?* Why does he assert that the terrain of Katahdin is "primeval, untamed, and forever untamable"? (18)

2. What is it that Thoreau sees on Katahdin that makes him look upon it "with awe"? (19)

3. If, as Thoreau says, we believe the earth "was made forever . . . to be the dwelling of man," then why does Thoreau observe of Katahdin, "Man was not to be associated with it"? (19)

4. How does Thoreau's experience on Katahdin contradict the common image of "Mother Earth"? (19)

5. Why is Thoreau suddenly at odds with his own body, saying that "this matter to which I am bound has become so strange to me"? Why does he "fear bodies" and "tremble to meet them"? (19)

6. Why does coming in contact with other matter create so many mysteries and questions in Thoreau's mind?

What's the Matter? Sample Unit

Selections

The Uncertainty of Science
Richard Feynman

The Science of Nature Aristotle

Moving Things Aristotle

Falling Bodies and Projectiles
Galileo

Forces Isaac Newton

Laws of Motion Isaac Newton

Time, Space, and Motion
Isaac Newton

Rules of Doing Philosophy
Isaac Newton

On Light Isaac Newton / Thomas Young

Heat and Friction Count Rumford (Benjamin Thompson)

The Mechanical Equivalent of Heat
James Prescott Joule

Entropy: The Running-Down of the Universe Arthur Eddington

Induction of Electric Currents
Michael Faraday

On the Physical Lines of Magnetic Force Michael Faraday

The Science of Electromagnetism
James Clerk Maxwell

Electricity and Electromotive Force
James Clerk Maxwell

A Dynamical Theory of the Electromagnetic Field James Clerk Maxwell

Extending the Theories of Physics
Max Planck

The Special Theory of Relativity
Albert Einstein

The General Theory of Relativity
Albert Einstein

$E = mc^2$ Albert Einstein

Quantum Uncertainty
George Gamow

Quantum Behavior Richard Feynman

The Copenhagen Interpretation of Quantum Theory Werner Heisenberg

Quantum Perplexity and Debate
John Polkinghorne

The Origin of the Universe
Steven Weinberg

Beautiful Theories: Symmetry and Mathematics Steven Weinberg

Why Physics Is the Easiest Science: Effective Theories Gordon Kane

Metaphor in Science Alan Lightman

Black Holes and Predictable Worlds
Stephen Hawking

The Scientist's Responsibilities
Albert Einstein

Thematic Guide

The selections in *What's the Matter?* are arranged in roughly chronological order; reading them from start to finish can provide an understanding of the ways that many of the major concepts of physics have developed over time. However, some readers may want to approach the contents more selectively, depending on their individual interests. The following guide gives suggestions for how the selections can be read and discussed in order to focus on specific topics and themes, offering numerous ways to explore the complex interplay of ideas represented in *What's the Matter?*

Part I: Topics

Many of the selections in *What's the Matter?* are concerned with the topics ordinarily included in physics courses and can supplement corresponding textbook chapters and course materials. The selections listed under each of the following headings are closely related to one another and can be read and discussed as a sequence, although each can also be read and discussed independently of the others.

Mechanics

Aristotle	Moving Things
Galileo	Falling Bodies and Projectiles
Newton	Forces
Newton	Laws of Motion
Newton	Time, Space, and Motion
Einstein	The Special Theory of Relativity
Einstein	The General Theory of Relativity
Gamow	Quantum Uncertainty

Thermodynamics/Energy

Rumford	Heat and Friction
Joule	The Mechanical Equivalent of Heat
Eddington	Entropy: The Running-Down of the Universe
Einstein	$E = mc^2$

Electromagnetism

Faraday	Induction of Electric Currents
Faraday	On the Physical Lines of Magnetic Force
Maxwell	The Science of Electromagnetism
Maxwell	Electricity and Electromotive Force
Maxwell	A Dynamical Theory of the Electromagnetic Field

Light

Newton and Young	On Light
Gamow	Quantum Uncertainty
Feynman	Quantum Behavior

The Theory of Relativity

Einstein	The Special Theory of Relativity
Einstein	The General Theory of Relativity
Einstein	$E = mc^2$
Hawking	Black Holes and Predictable Worlds

Quantum Theory

Planck	Extending the Theories of Physics
Gamow	Quantum Uncertainty
Feynman	Quantum Behavior
Heisenberg	The Copenhagen Interpretation of Quantum Theory
Polkinghorne	Quantum Perplexity and Debate
Hawking	Black Holes and Predictable Worlds

Cosmology

Eddington	Entropy: The Running-Down of the Universe
Weinberg	The Origin of the Universe
Hawking	Black Holes and Predictable Worlds

Part II: Themes

Readers of *What's the Matter?* will find many thematic connections among the selections, particularly where physicists refer to the work of their predecessors and contemporaries as they proceed with their own investigations. Each sequence of selections that follows has been arranged to facilitate the exploration of a general theme in the development of physics.

The Nature of Science and Scientific Investigation

Feynman	The Uncertainty of Science
Aristotle	The Science of Nature
Newton	Rules of Doing Philosophy
Planck	Extending the Theories of Physics
Kane	Why Physics Is the Easiest Science: Effective Theories
Weinberg	Beautiful Theories: Symmetry and Mathematics
Lightman	Metaphor in Science

Investigating the Physical World: Experiment and Observation

Feynman	The Uncertainty of Science
Newton	Rules of Doing Philosophy
Galileo	Falling Bodies and Projectiles
Rumford	Heat and Friction
Joule	The Mechanical Equivalent of Heat
Faraday	Induction of Electric Currents
Maxwell	The Science of Electromagnetism
Maxwell	Electricity and Electromotive Force
Newton and Young	On Light
Feynman	Quantum Behavior
Heisenberg	The Copenhagen Interpretation of Quantum Theory

Explaining the Physical World: Theories and Laws of Nature

Weinberg	Beautiful Theories: Symmetry and Mathematics
Aristotle	The Science of Nature
Newton	Rules of Doing Philosophy
Planck	Extending the Theories of Physics
Kane	Why Physics Is the Easiest Science: Effective Theories

Lightman	Metaphor in Science
Einstein	The Special Theory of Relativity
Feynman	Quantum Behavior
Feynman	The Uncertainty of Science

From Classical Physics to the Theory of Relativity

Galileo	Falling Bodies and Projectiles
Newton	Time, Space, and Motion
Planck	Extending the Theories of Physics
Einstein	The Special Theory of Relativity
Newton	Forces
Newton	Laws of Motion
Einstein	The General Theory of Relativity
Einstein	$E = mc^2$
Weinberg	Beautiful Theories: Symmetry and Mathematics
Hawking	Black Holes and Predictable Worlds

From Classical Physics to Quantum Theory

Newton	Rules of Doing Philosophy
Newton and Young	On Light
Feynman	Quantum Behavior
Planck	Extending the Theories of Physics
Gamow	Quantum Uncertainty
Heisenberg	The Copenhagen Interpretation of Quantum Theory
Polkinghorne	Quantum Perplexity and Debate
Hawking	Black Holes and Predictable Worlds

Albert Einstein

The equation $E = mc^2$ has come to symbolize everything from a brilliant scientist's extraordinary ability to uncover the secrets of the universe to the horrors unleashed by the development of nuclear weapons. However, this wide array of associations obscures the equation's significance as the precise formulation of one of modern physics' most important principles: the equivalence of energy and mass.

Albert Einstein (1879–1955) was primarily a theoretical rather than an experimental physicist. His discoveries resulted from his profound analysis and redefinition, often in mathematical terms, of the basic concepts that scientists use to explain physical events: space, time, energy, mass, motion, and force. Einstein recognized that a scientific theory's value lies in its ability to adequately represent observable and measurable physical phenomena. At the same time, he believed that the principles underlying scientific theories are "free inventions of the human intellect," having their source in the physicist's intuition and creative imagination. The brevity of the equation $E = mc^2$ reflects Einstein's conviction that it should be possible to express fundamental insights about the physical world in simple terms.

In 1905, when he was twenty-six, Einstein published a paper laying the foundations of the theory of relativity by postulating that the speed of light is constant in empty space and that the laws of physics are the same for all observers moving relatively to one another at constant velocities. Although each of these principles was already widely known from experiments, Einstein's creative insight was that they could serve together as the axioms of his new theory. He then logically deduced that measurements of space and time depend on the relative motion of observers, leading to new laws of motion radically different from those of Newtonian physics. Several months later, Einstein published a brief paper entitled, "Does the Inertia of a Body Depend on Its Energy Content?" In a few pages, he demonstrated mathematically that the equivalence of mass and energy is a direct consequence of the postulate of light's constant velocity. Since physicists had previously considered mass and energy to be fundamentally different from each other, the startling theoretical discovery of their equivalence led Einstein to write to a friend, "The argument is amusing and seductive; but for all I know, the Lord might be laughing over it and leading me around by the nose."

To see how the equivalence of mass and energy follows from Einstein's theory of relativity, it is necessary to consider what happens to an object's mass as it is accelerated. Before the theory of relativity, scientists thought that when a force acts continuously on an object, the object will keep accelerating without limit, while the mass of the object will remain constant. Einstein theoretically demonstrated that from the postulate of light's constant velocity, it follows that a moving object's velocity can never be measured as equaling or exceeding that of light. Therefore, the kinetic energy that an object acquires as it is acted on by force becomes less and less effective in making the object accelerate. To account for this increase in the object's inertial resistance to acceleration, Einstein concluded that the object's kinetic energy is converted into increased mass. When an object approaches the velocity of light as a limit, its rate of acceleration becomes infinitely slow and its mass becomes infinitely large. The equation $E = mc^2$ states the conversion relationship between energy and mass, emphasizing that even a small portion of the inertial mass of an object is equivalent to vast amounts of energy, since the speed of light, c, is an immense number.

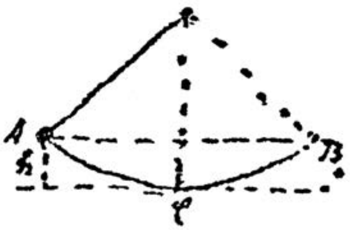
Einstein's affirmative answer to the question in his paper's title led physicists to a greatly extended statement of the law of the conservation of energy. Mass was now understood to be one aspect of the energy that must be taken into consideration in calculating any physical system's total energy. Although in most physical changes the amount of converted energy or mass is too small to detect, in the decades following Einstein's discovery, scientists experimentally confirmed his theory in reactions involving radioactive substances where the amount of energy converted from mass is very large and can be measured. Both peaceful and military applications of the principle quickly followed.

Einstein's discovery of the equivalence of mass and energy was one of the most important developments since the time of Galileo and Newton in scientists' ongoing search for theories that unify physical concepts previously thought to be separate. Einstein spent the last decades of his career in an unrelenting but unsuccessful attempt to bring together the two most significant streams of thought in twentieth-century physics—the theory of relativity and quantum theory—into one unified theory.

The following selection was published in the magazine *Science Illustrated* in 1946, the year after the only nuclear bombs ever used in warfare were dropped by the United States on the Japanese cities of Hiroshima and Nagasaki. In his explanation of the origin of $E = mc^2$, Einstein asks us to consider how physicists acquire greater theoretical power to explain the physical world by discovering fundamental relationships among mass, energy, and the forces of nature. He also raises urgent questions about the practical consequences of this increased power and our responsibilities in using it wisely.

$E = mc^2$

In order to understand the law of the equivalence of mass and energy, we must go back to two conservation or "balance" principles which, independent of each other, held a high place in pre-relativity physics. These were the principle of the conservation of energy and the principle of the conservation of mass. The first of these, advanced by Leibnitz as long ago as the seventeenth century, was developed in the nineteenth century essentially as a corollary of a principle of mechanics.



Drawing from Dr. Einstein's manuscript

Consider, for example, a pendulum whose mass swings back and forth between the points *A* and *B*. At these points the mass *m* is higher by the amount *h* than it is at *C*, the lowest point of the path (see drawing). At *C*, on the other hand, the lifting height has disappeared and instead of it the mass has a velocity v. It is as though the lifting height could be converted entirely into velocity, and vice versa. The exact relation would be expressed as $mgh = (1/2)mv^2$, with g representing the acceleration of gravity.[1] What is interesting here is that this relation is independent of both the length of the pendulum and the form of the path through which the mass moves.

The significance is that something remains constant throughout the process, and that something is energy. At *A* and at *B* it is an energy of position, or "potential" energy; at *C* it is an energy of motion, or "kinetic" energy. If this conception is correct, then the sum $mgh + (1/2)mv^2$ must have the same value for any position of the pendulum, if h is understood to represent the height above *C*, and v the velocity at that point in the pendulum's path. And such is found to be actually the case. The generalization of this principle gives us the law of the conservation of mechanical energy. But what happens when friction stops the pendulum?

The answer to that was found in the study of heat phenomena. This study, based on the assumption that heat is an indestructible substance that flows from a warmer to a cooler object, seemed to give us a principle of the "conservation of heat." On the other hand, from time immemorial it has been known that heat could be produced by friction, as in the fire-making drills of the Indians. The physicists were for long unable to account for this kind of heat "production." Their difficulties were overcome only when it was successfully established that, for any given amount of heat produced by friction, an exactly proportional amount of energy had to be expended. Thus did we arrive at a principle of the "equivalence of work and heat." With our pendulum, for example, mechanical energy is gradually converted by friction into heat.

In such fashion the principles of the conservation of mechanical and thermal energies were merged into one. The physicists were thereupon persuaded that the conservation principle could be further extended to take in chemical and electromagnetic processes—in short, could be applied to all fields. It appeared that in our physical system there was a sum total of energies that remained constant through all changes that might occur.

1. [*mgh*: the conventional expression for potential energy—sometimes called the energy of position—in a gravitational field; $(1/2)mv^2$: the conventional expression for kinetic energy, the energy of motion.]

Now for the principle of the conservation of mass. Mass is defined by the resistance that a body opposes to its acceleration (inert mass). It is also measured by the weight of the body (heavy mass). That these two radically different definitions lead to the same value for the mass of a body is, in itself, an astonishing fact. According to the principle—namely, that masses remain unchanged under any physical or chemical changes—the mass appeared to be the essential (because unvarying) quality of matter. Heating, melting, vaporization, or combining into chemical compounds would not change the total mass.

Physicists accepted this principle up to a few decades ago. But it proved inadequate in the face of the special theory of relativity. It was therefore merged with the energy principle—just as, about sixty years before, the principle of the conservation of mechanical energy had been combined with the principle of the conservation of heat. We might say that the principle of the conservation of energy, having previously swallowed up that of the conservation of heat, now proceeded to swallow that of the conservation of mass—and holds the field alone.

It is customary to express the equivalence of mass and energy (though somewhat inexactly) by the formula $E = mc^2$, in which c represents the velocity of light, about 186,000 miles per second. E is the energy that is contained in a stationary body; m is its mass. The energy that belongs to the mass m is equal to this mass, multiplied by the square of the enormous speed of light—which is to say, a vast amount of energy for every unit of mass.

But if every gram of material contains this tremendous energy, why did it go so long unnoticed? The answer is simple enough: so long as none of the energy is given off externally, it cannot be observed. It is as though a man who is fabulously rich should never spend or give away a cent; no one could tell how rich he was.

Now we can reverse the relation and say that an increase of E in the amount of energy must be accompanied by an increase of E/c^2 in the mass. I can easily supply energy to the mass—for instance, if I heat it by 10 degrees. So why not measure the mass increase, or weight increase, connected with this change? The trouble here is that in the mass increase the enormous factor c^2 occurs in the denominator of the fraction. In such a case the increase is too small to be measured directly, even with the most sensitive balance.

For a mass increase to be measurable, the change of energy per mass unit must be enormously large. We know of only one sphere in which such amounts of energy per mass unit are released: namely, radioactive disintegration. Schematically, the process goes like this: An atom of the mass M splits into two atoms of the mass M' and M'', which separate with tremendous kinetic energy. If we imagine these two masses as brought to rest—that is, if we take this energy of motion from them—then, considered together, they are essentially poorer in energy than was the original atom. According to the equivalence principle, the mass sum $M' + M''$ of the disintegration products must also be somewhat smaller than the original mass M of the disintegrating atom—in contradiction to the old principle of the conservation of mass. The relative difference of the two is on the order of one-tenth of one percent.

Now, we cannot actually weigh the atoms individually. However, there are indirect methods for measuring their weights exactly. We can likewise determine the kinetic energies that are transferred to the disintegration products M' and M''. Thus it has become possible to test and confirm the equivalence formula. Also, the law permits us to calculate in advance, from precisely determined atom weights, just how much energy will be released with any atom disintegration we have in mind. The law says nothing, of course, as to whether—or how—the disintegration reaction can be brought about.

What takes place can be illustrated with the help of our rich man. The atom M is a rich miser who, during his life, gives away no money (energy). But in his will he bequeaths his fortune to his sons M' and M'', on condition that they give to the community a small amount, less than one thousandth of the whole estate (energy or mass). The sons together have somewhat less than the father had (the mass sum $M' + M''$ is somewhat smaller than the mass M of the radioactive atom). But the part given to the community, though relatively small, is still so enormously large (considered as kinetic energy) that it brings with it a great threat of evil. Averting that threat has become the most urgent problem of our time.

Selected Content Questions*

1. How does Einstein's example of the pendulum demonstrate the law of the conservation of mechanical energy? What does it mean to say that mechanical energy is conserved? (28–29)

2. How could the stopping of a pendulum by friction demonstrate the "equivalence of work and heat"? When scientists recognized this equivalence, how were conservation principles affected? (29)

3. What does Einstein mean when he says, "It appeared that in our physical system there was a sum total of energies that remained constant through all changes that might occur"? (29)

4. How would the formula $E = mc^2$ be written if it were reversed to show an increase in mass resulting from an increase in energy? How does this reversed formula show that the increase in mass that occurs when energy is increased is usually "too small to be measured directly"? (30)

5. How does $E = mc^2$ show that "the mass sum $M' + M''$ of the disintegration products must also be somewhat smaller than the original mass M of the disintegrating atom"? How is this result "in contradiction to the old principle of the conservation of mass"? (31)

6. In Einstein's story about the miser's bequest, what does the rich man's fortune represent? Why does Einstein emphasize that the portion to be given to the community is "relatively small" compared to the entire fortune? (31)

Selected Discussion Questions*

1. Why would physicists look for conservation principles, such as those for mechanical energy, thermal energy, and mass? (28–30)

2. In physics, what does it mean to say that heat and work, or mass and energy, are equivalent to each other? Is this relation of equivalence the same as saying that they are identical? (29–30)

*For a complete list of questions for $E = mc^2$, visit www.greatbooks.org/physicsbook and download the excerpt from *What's the Matter?*

3. After the principle of the conservation of energy "swallowed up" the principles of the conservation of heat and the conservation of mass, were the conservation principles of heat and mass still valid? (30)

4. Why does Einstein point out that the law of the equivalence of mass and energy "says nothing, of course, as to whether—or how—the [radioactive] disintegration reaction can be brought about"? (31)

5. Why does Einstein add the story of the miser's bequest to his explanation of the meaning of the equation that he discovered? Why does he say that the bequest brings "a great threat of evil," and that "averting that threat has become the most urgent problem of our time"? (31)

Suggestions for Further Reading

By the author

Einstein, Albert. *Ideas and Opinions*. Reprint. New translations and revisions by Sonja Bargmann. New York: Modern Library, 1994. This anthology of Einstein's shorter writings, from which the selection in *What's the Matter?* is taken, includes several brief explanations of the basic ideas of his theory of relativity.

About the author

Hoffmann, Banesh. *Albert Einstein, Creator and Rebel*. In collaboration with Helen Dukas. New York: Viking Press, 1972; reprint, New York: Plume Books, 1988. The author of this biography was a colleague of Einstein's and conveys a deep understanding of Einstein's independent-minded approach to scientific investigation.

About the topic

Bodanis, David. $E = mc^2$*: A Biography of the World's Most Famous Equation*. New York: Walker, 2000; New York: Berkley Publishing, 2001. After explaining the meaning of each of the equation's symbols, this book traces the history of its immense significance for scientific research and its consequences in the development of atomic weapons.

Lightman, Alan. *Great Ideas in Physics: The Conservation of Energy, the Second Law of Thermodynamics, the Theory of Relativity, and Quantum Mechanics*. 3rd ed. New York: McGraw-Hill, 2000. The chapter on the theory of relativity provides a clear derivation of the equation $E = mc^2$ as well as an interesting discussion of Einstein's approach to creating scientific theories.

Rigden, John S. *Einstein 1905: The Standard of Greatness*. Cambridge, MA: Harvard University Press, 2005. In this history of Einstein's most productive year, the significance of each of his five groundbreaking papers is discussed, including the one in which he first formulated $E = mc^2$ almost as an afterthought to the theory of relativity.

Schwinger, Julian. *Einstein's Legacy: The Unity of Space and Time*. New York: Scientific American Library, 1986; Mineola, NY: Dover Publications, 2002. This outstanding survey of Einstein's work by an eminent physicist includes a detailed explanation of $E = mc^2$, showing its connection to the conservation of energy law.

Notes on Key Terms and Concepts

This section is intended to clarify some of the terms and concepts used by the authors of the selections, in order to make their ideas more accessible. For this reason, the entries are referenced to one another and to the selections themselves, emphasizing that many concepts in physics are best understood in the context in which they have been developed and used.

Selected Entries

acceleration The rate of change of a moving object's velocity with respect to time (for example, miles per hour per second). Since velocity represents an object's speed and direction, acceleration can be the rate of change of speed, direction, or both. See also: *velocity.*

RELATED READINGS: Newton, "Forces"; Einstein, "The General Theory of Relativity"

action at a distance The idea that objects interact without any mechanical connection between them. Classical physics, although it is largely founded on mechanistic principles, attributes the operation of gravity to action at a distance. One of the central problems faced by early researchers in electromagnetism was to explain how electromagnetic effects, thought of as propagating waves, were transmitted through apparently empty space. The medium of the ether and the idea of fields were offered as hypothetical solutions to this problem. See also: *classical physics; ether; field; gravity.*

RELATED READINGS: Faraday, "On the Physical Lines of Magnetic Force"; Maxwell, "A Dynamical Theory of the Electromagnetic Field"; Lightman, "Metaphor in Science"

big bang The generally accepted cosmological theory that the universe originated from an explosive event approximately 14 billion years ago that created space, time, and matter, and was the beginning of the universe's continuing expansion. See also: *standard model; symmetry.*

RELATED READING: Weinberg, "The Origin of the Universe"

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